COMPUTER MANUAL SERIES No. 16

Wien Automatic System Planning (WASP) Package

A Computer Code for Power Generating System Expansion Planning

Version WASP-IV

User's Manual

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2001

The originating Section of this document in the IAEA was:

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WIEN AUTOMATIC SYSTEM PLANNING (WASP) PACKAGE
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Printed by the IAEA in Austria
November 2001

FOREWORD

As a continuation of its efforts to provide methodologies and tools to Member States to carry out comparative assessment and analyse priority environmental issues related to the development of the electric power sector, the IAEA has completed a new version of the Wien Automatic System Planning (WASP) Package — WASP-IV — for carrying out power generation expansion planning taking into consideration fuel availability and environmental constraints. This manual constitutes a part of this work and aims to provide users with a guide to use effectively the new version of the model — WASP-IV.

WASP was originally developed in 1972 by the Tennessee Valley Authority and the Oak Ridge National Laboratory in the USA to meet the IAEA's needs to analyse the economic competitiveness of nuclear power in comparison to other generation expansion alternatives for supplying the future electricity requirements of a country or region. Previous versions of the model were used by Member States in many national and regional studies to analyse the electric power system expansion planning and the role of nuclear energy in particular.

Experience gained from its application allowed development of WASP into a very comprehensive planning tool for electric power system expansion analysis. New, improved versions were developed, which took into consideration the needs expressed by the users of the programme in order to address important emerging issues being faced by the electric system planners. In 1979, WASP-III was released and soon after became an indispensable tool in many Member States for generation expansion planning. The WASP-III version was continually upgraded and the development of version WASP-III Plus commenced in 1992. By 1995, WASP-III Plus was completed, which followed closely the methodology of the WASP-III but incorporated new features.

In order to meet the needs of electricity planners and following the recommendations of the Helsinki symposium, development of a new version of WASP was initiated in 1992 with the co-operation of some Member States (Hungary and Greece). Advisory group and consultancy meetings on the subject convened during 1992–1996 focused on identifying necessary enhancements to the model and appropriate methodological approaches to address the new issues. Like its predecessors, the current WASP-IV version is designed to find the economically optimal expansion policy for an electric utility system within user specified constraints. It utilises probabilistic estimation of system production costs, unserved energy costs, and reliability, linear programming technique for determining optimal dispatched policy satisfying exogenous constraints on environmental emissions, fuel availability and electricity generation by some plants, and the dynamic programming method for optimising the costs of alternative system expansion policies.

The new features and enhancements incorporated in WASP-IV are:

Option for introducing constraints on environmental emissions, fuel usage and energy generation. Each type of constraints can be introduced to a group of power plants, existing or candidates. Liner programming technique is employed to determine an optimal dispatching of plants satisfying these constraints. This option is very useful in view of increasing environmental concerns and awareness of issues such as health impacts of air pollution, regional acidification etc. As well in some cases, availability of a certain fuel for power generation may be limited.

Representation of pump storage plants to accommodate the increasing importance of pump storage plants and other energy storage technologies under development.

Fixed maintenance schedule. This option allows the user to specify a certain schedule for annual maintenance of some of the plants in the system.

Environmental emission calculation. WASP-IV version calculates environmental emissions from electricity generation for each year and for each period within a year, based on estimates of electricity generated by each plant and the user specified characteristics of fuels used.

Expanded dimensions for handling up to 90 types of plants and a larger number of configurations (up to 500 per year and 5000 for the study period).

The WASP-IV version can be released under the arrangements to Member States which have the necessary analytical and computer capabilities. The present manual allows us to support the use of the WASP-IV version and to illustrate the capabilities of the model.

This manual contains 13 chapters. Chapter 1 gives a summary description of WASP-IV Computer Code and its Modules and file system. Chapter 2 explains the hardware requirement and the installation of the package. The sequence of the execution of WASP-IV is also briefly introduced in this chapter. Chapters 3 to 9 explains, in detail, how to execute each of the module of WASP-IV package, the organisation of input files and output from the run of the model. Special attention was paid to the description of the linkage of modules. Chapter 10 specially guides the users on how to effectively search for an optimal solution. Chapter 11 describes the execution of sensitivity analyses that can be (recommend to be) performed with WASP-IV. To ease the debugging during the running of the software, Chapter 12 provides technical details of the new features incorporated in this version. Chapter 13 provides a list of error and warning messages produced for each module of WASP.

The reader of this manual is assumed to have experience in the field of power generation expansion planning and to be familiar with all concepts related to such type of analysis, therefore these aspects are not treated in this manual. Additional information on power generation expansion planning can be found in the IAEA publication " Expansion Planning for Electrical Generating Systems, A Guidebook", Technical Reports Series No. 241 (1984) or User's Manual of WASP-III Plus, Computer Manual Series No. 8, (1995).

All suggestions for improving this manual based on user experience are welcome and should be addressed to:

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P.E. Molina, assisted by P. Heinrich, of the Division of Nuclear Energy were responsible for the development of the WASP-IV computer code. B. Hamilton and D.T. Bui, of the same Division, were responsible for the compilation of this manual.

Special recognition is due to: G. Korres of the National Technical University of Athens, who made a valuable contribution in developing enhancements related to the user-specified maintenance schedule and pumped storage representation; J. Fulop and J. Hoffer of the Hungarian Academy of Sciences, who developed the new feature for representing group limitations; as well as, Ahmed Irej Jalal and Muhammad Latif of the Pakistan Atomic Energy Commission, who drafted the WASP-IV manual, performed final testing of the WASP-IV computer software, and developed a graphical user interface for operating the model under MS Windows. Finally, acknowledgements are given to the many WASP experts who provided suggestions for improvements introduced into the final version of the WASP-IV program.

CONTENTS

Chapter 1
INTRODUCTION

1.1. BACKGROUND INFORMATION

The Wien Automatic System Planning Package (WASP) was originally developed by the Tennessee Valley Authority (TVA) and Oak Ridge National Laboratory (ORNL) of the United States of America to meet the needs of the IAEA's Market Survey for Nuclear Power in Developing Countries conducted by the IAEA in 1972–1973 [1, 2].

Based on the experience gained in using the program, many improvements were made to the computer code by IAEA Staff, which led to the WASP-II version in 1976. Later, the needs of the United Nations Economic Commission for Latin America (ECLA) to study the interconnection of the electrical grids of the six Central American countries, where a large potential of hydroelectric resources is available, led to a joint ECLA/IAEA effort from 1978 to 1980 to develop the WASP-III version [3].

The WASP-III version has been distributed to several Member States for use in electric expansion analysis. In addition, other computer models have been added to the IAEA's catalogue of planning methodologies to complement the WASP analysis. Firstly, in 1981, the Model for Analysis of Energy Demand (MAED) was developed in order to allow the determination of electricity demand, consistently with the overall requirements for final energy, and thus, to provide a more adequate forecast of electricity needs to be considered in the WASP study [4]. Later in 1992, the VALORAGUA model for determination of the optimal operating strategy for mixed hydro-thermal power systems was completed as a means of improving the determination of the characteristics of hydroelectric power stations to be fed into WASP [5]. Microcomputers (PC) versions of WASP-III and MAED have also been developed as stand alone programs [6, 7] and as part of an integrated package for energy and electricity planning called ENPEP (Energy and Power Evaluation Program) [8]. A PC version of the VALORAGUA model has also been completed in 1992 [9]. More recently, following the recommendations of an IAEA Advisory Group on WASP Experience in Member States convened in 1990 and 1991, additional enhancements were incorporated in the WASP model, further increasing its capabilities for modelling additional aspects of electricity generation system, handling larger number of fuel types, adding flexibility to capital cost distribution during construction period and for generating additional information. This version has been called WASP-III Plus, and has been released to interested Member States.

With all these improvements, the WASP model has been enhanced to facilitate the work by electricity planners and is currently accepted as a powerful tool for electric system expansion planning. Nevertheless, experienced users of the program have indicated the need to introduce more enhancements within the WASP model in order to cope with the problems constantly faced by the planners owing to the increasing complexity of the system particularly with emerging environmental and other issues.

The Inter-Agency International Symposium on Electricity and the Environment, Helsinki, 1991 [10], also recommended incorporation of environmental and health impacts of electricity sector into comparative assessment of various electricity generation options for making realistic evaluation of different strategies for future development of the sector.

In order to meet the needs of electricity planners and following the recommendations of Helsinki symposium, development of a new version of WASP was initiated in 1992 with cooperation of some Member States (Hungary and Greece). Advisory Group and Consultancy meetings on the subject convened during 1992–1996 focused on identifying necessary enhancements to the model and suggesting appropriate methodological approaches to address new issues. The new version of the model with a number of new features has been completed and named WASP-IV.

Like its predecessor, WASP-IV is designed to find the economically optimal generation expansion policy for an electric utility system within user-specified constraints. It utilizes *probabilistic estimation* of system — production costs, — unserved energy cost, and — reliability, *linear programming technique* for determining optimal dispatch policy satisfying exogenous constraints on environmental emissions, fuel availability and electricity generation by some plants, and the *dynamic method of optimization* for comparing the costs of alternative system expansion policies.

The modular structure of WASP-IV permits the user to monitor intermediate results, avoiding waste of large amounts of computer time due to input data errors. It operates under DOS environment and uses magnetic disc files to save information from iteration to iteration, thus avoiding repetition of calculations which have been previously done.

The new features and enhancements incorporated in WASP-IV are:

- *Option for introducing constraints on environmental emissions, fuel usage and energy generation*: WASP-IV allows user to introduce limits on environmental emissions (up to 2 types of pollutants) by a set of plants; on fuel usage by a set of plants; and/or on energy generation by a set of plants. These constraints are handled by multiple group-limitation technique wherein a group of plants may take role in a constraint and some plants can be involved in more than one type of constraints. Linear programming method is employed to determine an optimal policy for dispatch of plants satisfying these constraints. This option can be extremely useful for real life planning in view of increasing importance of environmental concerns as well as due to the fact that in many cases availability of some fuels for power generation may be limited or energy generation from some plants may be limited.

- *Representation of pumped storage plants*: Such an option was available in WASP-II but was taken out in WASP-III to accommodate more flexibility for hydro plants representation. However, in view of increasing importance of pumped storage plants and other energy storage technologies under development (e.g. large batteries or compressed air storage systems) this option has been included in WASP-IV.

- *Fixed maintenance schedule*: Due to some practical considerations the user may like to specify a certain schedule for annual maintenance of some of the plants in the system. WASP-IV allows for this option.

- *Environmental emission calculations*: WASP-IV calculates environmental emissions from electricity generation, for each year and for each period within a year, based on estimates of electricity generated by each plant and the user specified characteristics of fuels used.

- *Expanded dimensions* for handling up to 90 types of plants and larger number of configurations (up to 500 per year and up to 5000 for the study period).

The purpose of this manual is to show the WASP-IV user how to undertake the following tasks:

- preparation of input data needed to run the WASP modules,
- execution of the modules,
- review of the WASP outputs, and
- repetition of this process until an expansion plan is identified which is optimal within the constraints imposed by the user.

These aspects will be illustrated using an example (DEMOCASE). In general, the information presented throughout the manual illustrates how this study was conducted on the IAEA's computer facilities. In some cases, particularly for some of the input data and computer printouts, the information presented in this manual has been compressed to facilitate their description and to reduce the size of the manual. It must be emphasised that the sample problem has been selected to demonstrate the input and output capabilities of the code and it is not meant to represent a typical system or a typical power planning study.

1.2. SUMMARY DESCRIPTION OF THE WASP-IV COMPUTER CODE

The WASP-IV code permits finding the optimal expansion plan for a power generating system over a period of up to thirty years, within constraints given by the planner. The optimum is evaluated in terms of minimum discounted total costs. A simplified description of the model follows. For matters of convenience, the symbols used in this description are not the same as in the various WASP modules and the different expressions presented have been simplified.

Each possible sequence of power units added to the system (expansion plan or expansion policy) meeting the constraints is evaluated by means of a cost function (the objective function) which is composed of:

- Capital investment costs (I)
- Salvage value of investment costs (S)
- Fuel costs (F)
- Fuel inventory costs (L)
- Non-fuel operation and maintenance costs (M)
- Cost of the energy not served (O)

The cost function to be evaluated by WASP can be represented by the following expression:

$$B_j = \sum_{t=1}^{T} [\, \overline{I_{j,t}} - \overline{S_{j,t}} + \overline{F_{j,t}} + \overline{L_{j,t}} + \overline{M_{j,t}} + \overline{O_{j,t}} \,] \qquad (1.1)$$

where:

Bj is the **objective function** attached to the expansion plan j,
t is the time in years (1, 2, ... , T),
T is the length of the study period (total number of years), and
the bar over the symbols has the meaning of discounted values to a reference date at a given discount rate i.

The optimal expansion plan is defined by:

$$\text{Minimum } B_j \qquad \text{among all } j \tag{1.2}$$

The WASP analysis requires as a starting point the determination of alternative expansion policies for the power system. If $[K_t]$ is a vector containing the number of all generating units which are in operation in year t for a given expansion plan, then $[K_t]$ must satisfy the following relationship:

$$[K_t] = [K_{t-1}] + [A_t] - [R_t] + [U_t] \tag{1.3}$$

where:

$[A_t]$ = vector of committed additions of units in year t,
$[R_t]$ = vector of committed retirements of units in year t,
$[U_t]$ = vector of candidate generating units added to the system in year t,

$[A_t]$ and $[R_t]$ are given data, and $[U_t]$ is the unknown variable to be determined; the latter is called the system configuration vector or, simply, the system configuration.

Defining the critical period (p) as the period of the year for which the difference between the corresponding available generating capacity and the peak demand has the smallest value, and if $P(K_{t,p})$ is the installed capacity of the system in the critical period of year t, the following constraints should be met by every acceptable configuration:

$$(1 + a_t)D_{tp} \geq P(K_{tp}) \geq (1 + b_{t)}D_{tp} \tag{1.4}$$

which simply states that the installed capacity in the critical period must lie between the given maximum and minimum reserve margins, a_t and b_t respectively, above the peak demand $D_{t,p}$ in the critical period of the year.

The reliability of the system configuration is evaluated by WASP in terms of the Loss-of-Load Probability index (LOLP). This index is calculated in WASP for each period of the year and each hydro-condition defined. The LOLP of each period is determined as the sum of LOLP's for each hydro-condition (in the same period) weighted by the hydro-condition probabilities, and the average annual LOLP as the sum of the period LOLPs divided by the number of periods.

If $LOLP(K_{t,a})$ and $LOLP(K_{t,i})$ are the annual and the period's LOLP's, respectively, every acceptable configuration must respect the following constraints:

$$LOLP(K_{t,a}) \leq C_{t,a} \tag{1.5}$$

$$LOLP(K_{t,i}) \leq C_{t,p} \qquad \text{(for all periods)} \tag{1.6}$$

where $C_{t,a}$ and $C_{t,p}$ are limiting values given as input data by the user.

If an expansion plan contains system configurations for which the annual energy demand E_t is greater than the expected annual generation G_t of all units existing in the configuration for the corresponding year t, the total costs of the plan should be penalized by the resulting cost of the energy not served. Obviously, this cost is a function of the amount of energy not served Nt, which can be calculated as:

$$N_t = E_t - G_t \qquad (1.7)$$

The user may also impose tunnel constraints on the configuration vector $[U_t]$ so that every acceptable configuration must respect:

$$[U_t^O] \leq [U_t] \leq [U_t^O] + [\Delta U_t] \qquad (1.8)$$

where $[U_t^O]$ is the smallest value permitted to the configuration vector $[U_t]$ and $[\Delta U_t]$ is the tunnel constraint or tunnel width.

The generation by each plant for each period of the year is estimated based on an optimal dispatch policy which, in turn, is dependent on availability of the plants/units, maintenance requirements, spinning reserves requirements and any exogenous constraints imposed by the user on environmental emissions, fuel availability and/or generation by some plants. The user may impose constraints on environmental emissions, fuel usage and energy generation for a set of power plants through the new feature introduced in this version, i.e. through multiple group limitations. Such constraints take the form:

$$\sum_{i \in I_j} COEF_{ij} \cdot G_i \leq LIMIT_j \qquad \text{for } j = 1,...,M \qquad (1.9)$$

where G_i is generation by plant i, $COEF_{ij}$ is per unit emission (for emission constraints) or per unit fuel usage (for fuel availability constraint), etc by plant i in group limitation j, $LIMIT_j$ is the user specified value for the limit and *I*j is the set of plants taking role in group limitation j. These special constraints are handled by a new algorithm incorporated in WASP-IV, which determines dispatch of plants in such a way that these constraints are respected with minimum production cost. The details of this feature are explained in Chapter 12.

The problem as stated here corresponds to finding the values of the vector $[U_t]$ over the period of study which satisfy expressions (1.1) to (1.9). This will be the "best" system expansion plan within the constraints given by the user. The WASP code finds this best expansion plan using the dynamic programming technique. In doing so, the program also detects if the solution has hit the tunnel boundaries of expression (1.8) and gives a message in its output. Consequently, the user should proceed to new iterations, relaxing the constraints as indicated in the WASP output, until a solution free of messages is found. This will be the "optimum expansion plan" for the system.

1.2.1. Calculation of costs

The calculation of the various cost components in expression (1.1) is done in WASP with certain models in order to account for:

(a) Characteristics of the load forecast;
(b) Characteristics of thermal and nuclear plants;

(c) Characteristics of hydroelectric plants;
(d) Stochastic nature of hydrology (hydrological conditions); and
(e) Cost of the energy not served.

In the above list and throughout this manual, the word plant is used when referring to a combination of one or more units (for thermal) or to one or more projects (for hydro or pumped storage).

The load is modelled by the peak load and the energy demand for each period (up to 12) for all years (up to 30), and their corresponding inverted load duration curves. The latter represents the probability that the load will equal or exceed a value taken at random in the period (for computational convenience, the inverted load duration curves are expanded in Fourier Series by the computer program).

The models for thermal and nuclear plants are described, each of them, by:

– Maximum and minimum capacities;

– Heat rate at minimum capacity and incremental heat rate between minimum and maximum capacity;

– Maintenance requirements (scheduled outages);

– Failure probability (forced outage rate);

– Emission rates and specific energy use;

– Capital investment cost (for expansion candidates);

– Variable fuel cost;

– Fuel inventory cost (for expansion candidates);

– Fixed component and variable component of (non-fuel) operating and maintenance costs; and

– Plant life (for expansion candidates).

The models for hydroelectric projects are for run-of-river, daily peaking, weekly peaking and seasonal storage regulating cycle. They are defined by identifying for each project:

– Minimum and maximum capacities;

– Energy storage capacity of the reservoirs;

– Energy available per period;

– Capital investment cost (for projects considered as expansion candidates);

– Fixed operating and maintenance (O & M) costs; and

– Plant life (for projects considered as expansion candidates).

The hydroelectric plants are assumed to be 100% reliable and have no associated cost for the water. The stochastic nature of the hydrology is treated by means of hydrological conditions (up to 5), each one defined by its probability of occurrence and the corresponding available capacity and energy of each hydro project in the given hydro-condition.

The pumped storage plants are modelled by specifying:

- Installed capacity;
- Cycle efficiency;
- Pumping capacity (for each period);
- Generation capacity (for each period);
- Maximum feasible energy generation (for each period).

The cost of energy not served reflects the expected damages to the economy of the country or region under study when a certain amount of electric energy is not supplied. This cost is modelled in WASP through a quadratic function relating the incremental cost of the energy not served to the amount of energy not served. In theory at least, the cost of the energy not served would permit automatic definition of the adequate amount of reserve capacity in the power system.

In order to calculate the present-worth values of the cost components of Eq. (1.1), the present-worth factors used are evaluated assuming that the full capital investment for a plant added by the expansion plan are made at the beginning of the year in which it goes into service and that its salvage value is the credit at the horizon for the remaining economic life of the plant. Fuel inventory costs are treated as investment costs, but full credit is taken at the horizon (i.e. these costs are not depreciated). All the other costs (fuel, O&M, and energy not served) are assumed to occur in the middle of the corresponding year. These assumptions are illustrated in Figure 1.1.

According to the above, the cost components of Bj in expression (1.1) are calculated as follows:

(a) Capital investment cost and salvage values:

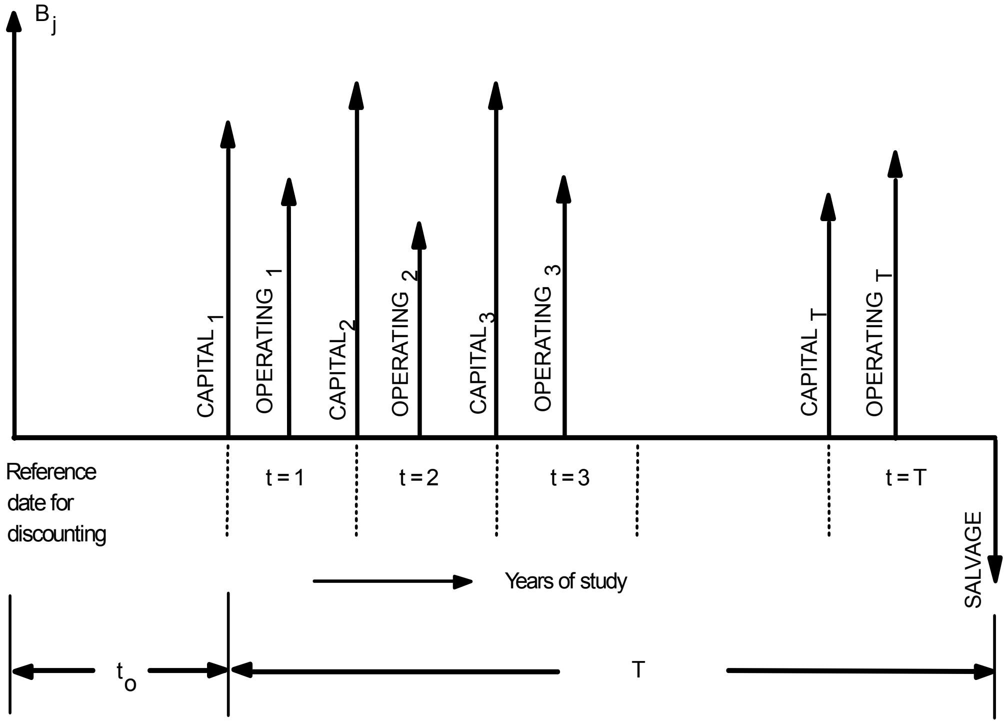
$$\overline{I_{j,t}} = (1+i)^{-t'} \times \sum \left[UI_k \times MW_k \right] \tag{1.10}$$

$$\overline{S_{j,t}} = (1+i)^{-T'} \times \sum \left[\delta_{k,t} \times UI_k \times MW_k \right] \tag{1.11}$$

where:

Σ = sum calculated considering all (thermal, hydro or pumped storage) units k added in year t by expansion plan j,

UI_k = capital investment cost of unit k, expressed in monetary units per MW,



Notes:

B_j	=	objective function (total cost) of the expansion plan
$CAPITAL_1$	=	sum of the investment costs of all units added in the first year of study
$OPERATING_1$	=	sum of all system operating costs (fuel, O&M, and energy not served) in the first year of study
SALVAGE	=	sum of the salvage values at horizon of all plants added during the study period
t_o	=	number of years between the reference date for discounting and the first year of study
T	=	length (in number of years) of the study period

Figure 1.1 Schematic diagram of cash flows for an expansion programme.

MW_k	=	capacity of unit k in MW,
$\delta_{k,t}$	=	salvage value factor at the horizon for unit k,
i	=	discount rate,
t'	=	$t + t_0 - 1$
T'	=	$T + t_0$

and t, t_0, and T follow the same definitions given in Figure 1.1.

(b) Fuel costs:

$$\overline{F_{j,t}} = (1+i)^{-t'-0.5} \times \sum_{h=1}^{NHYD} \left[\alpha_h \times \Psi_{j,t,h} \right] \tag{1.12}$$

where α_h is the probability of hydro-condition h, $\Psi_{j,t,h}$ the total fuel costs (sum of fuel costs for thermal and nuclear units) for each hydro-condition, and NHYD represents the total number of hydro-conditions defined.

The energy generated by each unit in the system is calculated by probabilistic simulation. In this approach the forced outages of thermal units are convolved with the inverted load duration curve and, consequently, the effect of unexpected outages of thermal units upon other units is accounted for in a probabilistic way. The net effect is an increase of peaking units generation in order to make up the reduction of base units generation due to scheduled outages for maintenance and unit failures. Thus, increasing the expected generating costs of the system. Obviously the fuel cost of a particular block of energy generated by a unit is calculated as the amount of generation times the unit fuel cost times its heat rate.

If special constraints on a set(s) of plants are imposed for maximum amount of emissions, fuel usage and/or energy generation, linear programming technique is used for determining an optimal dispatch strategy for the plants satisfying these constraints.

(c) Fuel inventory cost:

$$\overline{L_{j,t}} = \left[(1+i)^{-t'} - (1+i)^{-T'}\right] \times \sum\left[UFIC_{kt} \times MW_{kt}\right] \qquad (1.13)$$

where the indicated sum(☝) is calculated over all thermal units kt added to the system in year t, and $UFIC_{kt}$ is the unitary full inventory cost of unit kt (in monetary units per MW).

(d) Operation and maintenance costs:

$$\overline{M_{j,t}} = (1+i)^{-t'-0.5} \times \sum\left[UFO\&M_l \times MW_l + UVO\&M_l \times G_{l,t}\right] \qquad (1.14)$$

where:

Σ	=	sum over all units (*l*) existing in the system in year t,
$OFO\&M_l$	=	unitary fixed O&M cost of unit *l* , expressed in monetary units per MW-year,
$OVO\&M_l$	=	unitary variable O&M cost of unit *l* , expressed in monetary units per kWh,
$G_{l,t}$	=	expected generation of unit *l* in year t, in kWh, which is calculated as the sum of the energy generated by the unit in each hydro-condition weighted by the probabilities of the hydro-conditions.

(e) Energy not served costs:

$$\overline{O_{j,t}} = (1+i)^{-t'-0.5} \times \sum_{h=1}^{NHYD}\left[a + \frac{b}{2} \times \left(\frac{N_{t,h}}{EA_t}\right) + \frac{c}{3} \times \left(\frac{N_{t,h}}{EA_t}\right)^2\right] \times N_{t,h} \times \alpha_h \qquad (1.15)$$

where: a, b, and c are constants ($/kWh) given as input data, and:

$N_{t,h}$ = amount of energy not served (kWh) for the hydro-condition h in year t,

EA_t = energy demand (kWh) of the system in year t.

As stated in the introduction of Section 1.2, the cost components of the objective function (B_j) are presented in expressions (1.10) to (1.15) in a simplified form. In fact, the above expressions have been derived considering each expansion candidate as one single unit (P-S, hydro, thermal or nuclear) whereas in WASP-IV the expansion candidates are defined as plants and the number of units (or projects) from each plant to be added in each year is to be determined by the WASP study. Besides, WASP-IV:

- combines capital investment cost and associated salvage value with the fuel inventory cost and its salvage value;

- aggregates operating costs by types of (fuel) plant;

- separates all expenditures (capital or operating) into local and foreign components;

- permits escalating all costs over the study period;

- has provisions to apply different discount rates and escalation ratios for each year, for the local and foreign cost components, and to change the constants (a, b, and c) for evaluating the energy not served cost from year to year.

Finally, the units of the different variables in Eqs (1.10) to (1.15) and the variable names used in the above discussion do not correspond to the units and terminology used in the WASP modules. Table 1.1 summarises the capabilities of the WASP-IV computer code.

1.2.2. Dimensions of the WASP-IV computer program

Table 1.1 provides a listing of the more important capabilities of the WASP-IV code. Other characteristics and limitations of second order of importance are explained in the description of the various modules of the program along the chapters of this manual. Section 8.7 (for DYNPRO) and Section 9.5 (for REPROBAT) describe special restrictions applicable to these modules.

1.3. DESCRIPTION OF WASP-IV MODULES

Figure 1.2 shows a simplified flow chart of WASP-IV illustrating the flow of information from the various WASP modules and associated data files. The numbering of the first three modules is symbolic, since they can be executed independently of each other in any order. For convenience, however, these three modules have been given numbers in this manual. Modules 4, 5, and 6, however, must be executed in order, after execution of Modules 1, 2, and 3. There is also a seventh module, REPROBAT, which produces a summary report of the first six modules, in addition to its own results.

Module 1, LOADSY (**Load Sy**stem Description), processes information describing period peak loads and load duration curves for the power system over the study period.

Module 2, FIXSYS (**Fix**ed **Sys**tem Description), processes information describing the existing generation system and any pre-determined additions or retirements, as well as information on any constraints imposed by the user on environmental emissions, fuel availability or electricity generation by some plants.

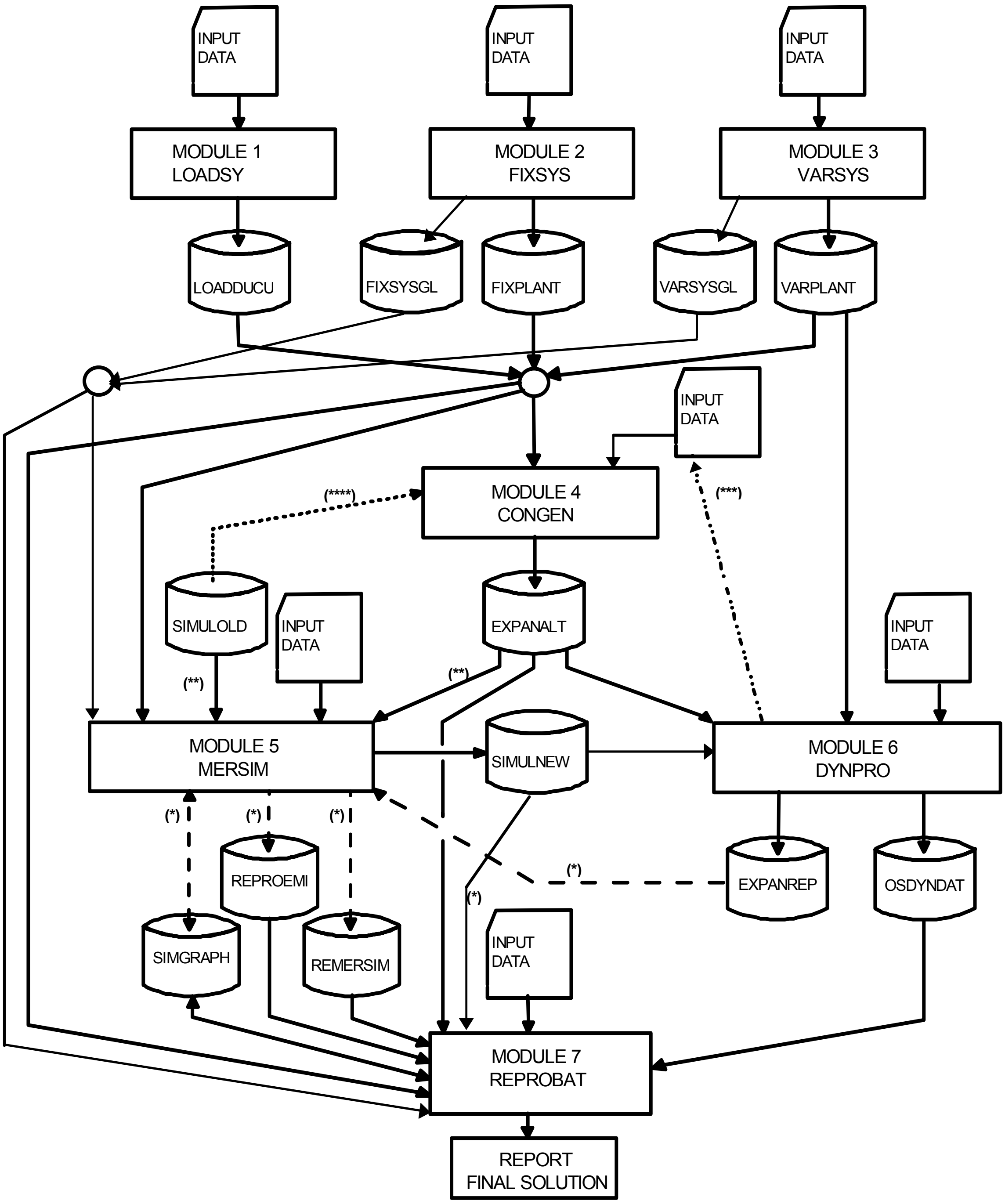
Module 3, VARSYS (**Var**iable **Sys**tem Description), processes information describing the various generating plants which are to be considered as candidates for expanding the generation system.

Table 1.1 Principal Capabilities of WASP-IV

Parameters	Maximum allowable
Years of study period	30
Periods per year.	12
Load duration curves (one for each period and for each year).	360
Cosine terms in the Fourier representation of the inverted load duration curve of each period.	100
Types of plants grouped by "fuel" types of which: 10 types of thermal plants; and 2 composite hydroelectric plants and one pumped storage plants.	12
Thermal plants of multiple units. This limit corresponds to the total number of plants in the Fixed System plus those thermal plants considered for system expansion which are described in the Variable System (87 if P-S is used).	88
Types of plants candidates for system expansion, of which: 12 types of thermal plants (11 if P-S is used); 2 hydroelectric plant types, each one composed of up to 30 projects; and1 pumped storage plant type with up to 30 composed projects.	15
Environmental pollutants (materials)	2
Group limitations	5
Hydrological conditions (hydrological years).	5
System configurations in all the study period (in one single iteration involving sequential runs of modules 4 to 6).	5000

Module 4, CONGEN (**Con**figuration **Gen**erator), calculates all possible year-to-year combinations of expansion candidate additions which satisfy certain input constraints and which in combination with the fixed system can satisfy the loads. CONGEN also calculates the basic economic loading order of the combined list of FIXSYS and VARSYS plants.

Module 5, MERSIM (**Mer**ge and **Sim**ulate), considers all configurations put forward by CONGEN and uses probabilistic simulation of system operation to calculate the associated production costs, energy not served and system reliability for each configuration. In the process, any limitations imposed on some groups of plants for their environmental emissions, fuel availability or electricity generation are also taken into account. The dispatching of plants is determined in such a way that plant availability, maintenance requirement, spinning reserve



(*)	*FOR RESIMULATION OF BEST SOLUTION ONLY*
(**)	*OMMIT FOR RESIMULATION OF BEST SOLUTION*
(***)	*ITERATION PATTERN IF BEST SOLUTION STILL CONSTRAINED*
(****)	*FOR CHECK OF CONFIGURATIONS ALREADY SIMULATED*

Figure 1.2. Simplified flow chart of the WASP-IV computer code.

requirements and all the group limitations are satisfied with minimum cost. The module makes use of all previously simulated configurations. MERSIM can also be used to simulate the system operation for the best solution provided by the current DYNPRO run and in this mode of operation is called REMERSIM. In this mode of operation detailed results of the simulation are also stored on a file that can be used for graphical representation of the results.

Module 6, DYNPRO (**Dyn**amic **Pr**ogramming **O**ptimization), determines the optimum expansion plan based on previously derived operating costs along with input information on capital costs, energy not served cost and economic parameters and reliability criteria.

Module 7, REPROBAT (**Rep**ort W**r**iter **o**f WASP in a **Bat**ched Environment), writes a report summarizing the total or partial results for the optimum or near optimum power system expansion plan and for fixed expansion schedules. Some results of the calculations performed by REPROBAT are also stored on the file that can be used for graphical representation of the WASP results (see REMERSIM above).

1.4. FILE SYSTEM

Various modules of WASP-IV use a number of files (magnetic disc files) for providing input information, storing results/outputs and for passing information from one module to another. The input information is provided in input data files referred with extension .DAT, results/output in report files with extension .REP and intermediate information/results in files with extension .BIN and .WRK. Besides passing information from one module to another, the intermediate files also help to save information from one simulation to another, thus avoiding waste of computer time on repetition of calculations previously done. Some of the modules also produce debug files with extension .DBG for debugging purposes. The details of different files used/produced by each module are given in the subsequent chapters describing individual modules.

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Chapter 2

EXECUTION OF WASP-IV

This chapter describes the steps required to setup WASP-IV on a PC and to execute the program for conducting case studies for electric system expansion planning for a country. The computer code of WASP-IV operates under MS DOS environment. The system requirements for execution of WASP-IV are an IBM compatible PC with MS DOS. Execution of WASP model is very time consuming (computationally), use of the fastest available PC is recommended.

2.1. SYSTEM SET-UP

The first step to prepare your computer for execution of WASP-IV is to make following changes in the "AUTOEXEC.BAT" and "CONFIG.SYS" files present in the root directory of your computer.

Edit the "AUTOEXEC.BAT" file and locate the PATH statement.
Add to this line C:\WASP;
For example, the following might be present in your "AUTOEXEC.BAT" file:
PATH=C:\;C:\DOS;C:\WINDOWS;
Change this statement to:
PATH=C:\;C:\DOS;C:\WINDOWS;C:\WASP;
Save the "AUTOEXEC.BAT" file.

Edit the "CONFIG.SYS" file and make sure the following lines are present:
Buffers = 20
Files = 50
If these lines are not already present, add them and save the file.

Restart (re-boot) the computer to make these changes effective.

2.2. CREATING DIRECTORIES

A main directory with appropriate name (e.g. WASP) should be created on the hard disk drive (e.g. C drive). Within this directory, sub-directories for different case studies to be analysed should be created having appropriate names (e.g. DEMOCASE, CASE01, CASE02, ...). Each sub-directory will contain a different case study. These separate sub-directories are required to distinguish different case studies because the names of various input and output files will be the same for each case study. For the purpose of following discussion, "WASP" as the name for main directory, and "DEMOCASE" for the sub-directory will be used.

For creating main directory and sub-directory following instructions (under DOS environment) can be followed, unless substituted by a higher level software, e.g. Windows MS-Explorer:

First go to root directory on the "C" drive.
Type MD WASP (this DOS command will create WASP directory on C drive).
Then, type CD WASP (this will bring you in the WASP directory).

Type MD DEMOCASE (this will create a sub-directory named DEMOCASE within WASP directory). For additional case studies, create additional sub-directories, with appropriate names, in the WASP directory.

2.3. INSTALLATION OF WASP-IV

WASP-IV program and a demonstration case are provided on a diskette. All the files in this diskette should be copied to appropriate directories created as per instructions above. The following steps should be followed for this purpose:

First, insert the WASP-IV diskette in drive A.
Then go to WASP directory on your C drive.
Type COPY A:*.EXE
Then type COPY A:*.BAT
These commands will copy all files on diskette in A drive with extensions EXE and BAT to your WASP directory on C drive. (Make sure that all files with extension EXE and BAT are copied).

Then go to DEMOCASE sub-directory within WASP directory on your C drive.
Type COPY A:*.DAT
This will copy all files with extension DAT to your sub-directory DEMOCASE within the WASP directory on your C drive.

The WASP-IV computer program is now ready for use. Its various modules can be executed from the sub-directory according to instructions described in the next section.

2.4. EXECUTION OF WASP-IV MODULES

All the modules of WASP-IV can be executed from the case sub-directory (e.g., DEMOCASE sub-directory) created within the WASP directory using the appropriate batch files. Before execution of each module, its input file has to be prepared as described in respective chapters for each module. (For DEMOCASE, the input files are already provided with the WASP-IV software).

For execution of various modules suitable batch files have been provided. These files were also copied to the main WASP directory at the start of installation process and contain appropriate file assignments and some restructuring of output report files. The batch file for various modules are:

LOAD.BAT	for LOADSY
FIX.BAT	for FIXSYS
VAR.BAT	for VARSYS
FCON.BAT	for CONGEN for a Fixed (predetermined) Expansion case
VCON.BAT	for CONGEN for a Variable (dynamic) Expansion case
MER.BAT	for MERSIM
DYN.BAT	for DYNPRO
REMER.BAT	for REMERSIM mode of MERSIM module
REPRO.BAT	for REPROBAT.
RESFILES.BAT	restore files for further optimization

The two batch files for execution of CONGEN are for two different modes of WASP use, i.e. Fixed (predetermined) Expansion case and Variable (dynamic) Expansion case (see chapters 6 and 10 for details). In addition to the above batch files, two more batch files are provided with WASP-IV software; these are: RESFILES.BAT for restoring the large SIMUL.NEW file in special cases (as mentioned later), and SPOOL.BAT for converting a Fortran print file (with carriage controls) into a normal printable file.

For running a module, just type the name of its batch file at DOS prompt in the case directory. The batch file present in the main WASP directory will be executed; it will make necessary file assignments (if applicable), will run the executable program file of the corresponding module and will restructure the output report file(s). The output files will be created in the case sub-directory.

For a successful execution in each case, the computer will respond "FILES ARE CLOSED". In case of an error, some message will appear, which in most of the cases would be due to some format mismatch in the input file or due to some inconsistency in the inputs to preceding modules. Rectify the error, or consult computer analyst, and re-run the program.

Since some of the modules use information generated by other modules, a certain sequence has to be observed in the execution of various modules. The first three modules (LOADSY, FIXSYS and VARSYS) can be executed in any order, but the fourth module (CONGEN) can only be executed after successful execution of first three modules. After a CONGEN run, next modules MERSIM and then DYNPRO can be executed. Finding an optimal solution will involve a number of iterations of CONGEN-MERSIM-DYNPRO runs. At this stage, no change can be made in any of the first three modules. If any change is deemed necessary in the input of any of these modules, a fresh start has to be made.

Execution of REMERSIM will be required in the "Variable (dynamic) Expansion case" (as explained in chapters 6 and 7) after finding an optimal solution through iterations of CONGEN-MERSIM-DYNPRO, as well as in the case of "Fixed (predetermined) Expansion case" for obtaining detailed output. Finally, after REMERSIM run, the REPROBAT module can be executed to generate a report of the case study (in fact, REPROBAT can be executed after successful execution of any one or more modules, however in such a case the reports requested from REPROBAT have to be only related to the respective modules).

For correct execution of various modules, some important points are to be noted (these are also explained in other chapters). At the end of execution of each module and before moving to the next, the output report file must be checked for confirmation of successful execution of the module.

Secondly, during iterative process in search of optimal solution, when CONGEN-MERSIM-DYNPRO modules are executed, no change should be made in the input of MERSIM, because in this case MERSIM will copy the configurations simulated in the previous runs and will only simulate the new configurations for this iteration. If any change in the loading order, maintenance schedule, spinning reserves or group limitations is made at this stage, the simulation results will be completely wrong.

Thirdly, as explained in chapter 10, before moving to Variable (dynamic) Expansion case, a number of runs of different Fixed (predetermined) Expansion cases should be made. One of these Fixed (predetermined) Expansion cases will be used as the starting point for optimization process of the Variable (dynamic) Expansion case. All of the Fixed (predetermined) Expansion cases should be developed in separate sub-directories within the main WASP directory, and the case selected for starting the optimization process should be copied to a new sub-directory for the Variable (dynamic) Expansion case.

Finally, at the end of Variable (dynamic) Expansion case, when optimal solution has been found, the sensitivity studies should also be made in a separate sub-directory, after copying all files of the optimal case to a new sub-directory. In this case, a number of DYNPRO runs may be required to study the impact of any change in the economic parameters on the optimal solution. Before starting sensitivity studies, some files which have been renamed by the last REMERSIM run have to be restored. This can be done by executing RESFILES.BAT file. This batch file will re-set appropriate file assignments for DYNPRO for starting the sensitivity studies.

Execution of RESFILES.BAT will also be necessary if for a REMERSIM run some error messages are found in its output report file as well as in the case if after completing the REPROBAT it is felt necessary to go back to optimization process for further improvements.

2.5. DATA RECORDS OF INPUT FILES

The input file of each module of WASP-IV will contain a number of data records which will be described in the respective chapters for the module. When discussing the data records used in each module, reference will be made to “record type” and “record number”. Since some types of records, such as index records, may occur more than once in the input data file of a module, it is necessary to identify not only the type of record used in each case but also its position in the file. Index records are used to control the flow of certain input data and to identify what type of record(s) follow. They are given as an integer number starting from 1 with the maximum number varying from module to module.

The format of the data on each record is very important, as the computer will reject or misinterpret input data which are not presented in the form specified. The format specifies both, the input information and the column number (i.e. field) in which it must appear. The following formats have been used in WASP-IV input files for presenting various input items:

The "I" format specifies an integer number (e.g. “4” or “1998”); no decimal point is allowed. It is necessary that the integer appears at the right-hand side of its field, i.e., it is "*right-adjusted*." Any blanks to the right of a number in the field will be interpreted by the computer as zeroes, e.g. a "5" typed in the third column (from left to right) of a four-column field will be interpreted as "50".

The "F" format specifies a floating point decimal number. Generally speaking, the decimal point should always be included in the field, even if there are no numbers to the right of the decimal point. This decimal point can appear anywhere in the field and it is not necessary to adjust a decimal number to the right of the field. A number which is actually an integer can be entered in an "F" field but the decimal point must be placed at its end (e.g. “4.” or “1998.”) and it will be handled by the computer as a decimal number.

The "A" format (Alphanumeric) specifies any combination of letters and digits; special symbols, such as asterisk [*], hyphen [-], dollar [$], etc., can also be included in this type of format with the only restriction (for the WASP code) that the first character *cannot* be a number.

```
****  LOAD.BAT  ****
LOADSY
CALL spool loadsy.rep
============================================
****  FIX.BAT  ****
FIXSYS
CALL spool fixsys.rep
=============================================
****  VAR.BAT  ****
VARSYS
CALL spool varsys.rep
=============================================
****  FCON.BAT  ****
CONGEN
CALL spool congen.rep
=============================================
****  CON.BAT  ****
CONGEN
CALL spool congen.rep
=============================================
****  MER.BAT  ****
@echo off
echo **** A large MERSIM RUN will produce very large OUTPUT files,
echo **** if the detailed OUTPUT OPTION (IOPT=2) is selected.
echo.
choice /c:yn Did you check the OUTPUT OPTION for this RUN ?
if errorlevel 2 goto NO
@echo ON
MERSIM
CALL spool mersim1.rep
CALL spool mersim2.rep
CALL spool mersim3.rep
goto END
:NO
echo.
echo **** Please check the OUTPUT OPTION and RE-RUN.
:END
=================================================
****  DYN.BAT  ****
DYNPRO
CALL spool dynpro1.rep
=============================================
****  REMER.BAT  ****
copy expanalt.bin expanalt.sav
copy expanrep.bin expanalt.bin
copy simulnew.bin simulnew.sav
if exist simulold.bin del simulold.bin
MERSIM
if errorlevel 1 goto AA
CALL spool mersim1.rep
CALL spool mersim2.rep
CALL spool mersim3.rep
goto BB
:AA
if exist simulnew.bin del simulnew.bin
rename simulnew.sav simulnew.bin
:BB
if exist expanalt.bin del expanalt.bin
rename expanalt.sav expanalt.bin
=============================================
****  REPRO.BAT  ****
REPROBAT
CALL spool reprob1.rep
=============================================
****  RESFILES.BAT ****
if exist simulnew.bin del simulnew.bin
rename simulnew.sav simulnew.bin
=============================================
****  SPOOL.BAT  ****
copy %1 spool.dat
spl
copy spool.dat %1
===================================================
```

Figure 2.1. Listing of BATCH files for execution of WASP-IV modules.

Chapter 3

EXECUTION OF LOADSY

3.1. INPUT/OUTPUT FILES

The LOADSY module of WASP-IV uses an input file called "LOADSY.DAT" provided by the user and produces two output files namely "LOADDUCU.BIN" and "LOADSY.REP". Before execution of this module, the user has to prepare "LOADSY.DAT" file *exactly in accordance with the details given in the next section*. The "LOADDUCU.BIN" file generated by the module contains information on system load to be used by other modules of WASP-IV. "LOADSY.REP" is the output file of this module which reports the results of present execution. This file *must* be reviewed by the user to confirm successful execution before moving to the next module.

3.2. INPUT DATA PREPARATION

Table 3.1 describes the data record types used in "LOADSY.DAT", and shows the fields, formats, Fortran names and descriptions of each piece of information given as input.

The type-X and type-A data records are used only once, as the first two data records, and apply to all years of the study period. For each year, the first data record is a type-B record and the last one is a type-1 record with INDEX=1 indicating end of input data for the given year.

A type-1 with INDEX=2 (3 or 4) record tells the computer that the next group of record(s) to be read is of type equal to the INDEX number. Thus, it is necessary that the proper sequence of data records be used; otherwise, it will lead to wrong calculations or interruption of program execution and the printing of an error message (see Chapter 13). Each type-1 record with INDEX=2 (3 or 4) and the corresponding type-2 (3 or 4) record(s) will constitute a group. Some of these groups *must* be supplied for the first year of study and are used for subsequent years only if there is a change in information for the respective year.

The group of input lines involving one type-1 INDEX=2 and one (or two) type-2 records give the peak loads of the periods expressed as the ratio of the period peak loads to the annual peak load given in the type-B record for the same year. Each time this group of records is used in the LOADSY input data, the corresponding type-2 record (or records) must contain the ratios for all periods, even if the values of the ratios for one or more periods do not change from the values applicable for the preceding year.

As indicated in Table 3.1, input data on load duration curves (LDC's) must be specified for each period into which the year has been sub-divided, at least for the first year of study and may be changed every year if necessary.

Input data on LDC's are prepared using the normalized load duration curve of the period, for which load magnitudes are expressed as fractions of the peak load of the period and the respective load duration values as fractions of the total hours of the period. Input data on normalized LDC for the periods may be expressed, *either* in the form of a *Fifth order polynomial* describing the shape of the curve for each period (type-3 records), *or* in a *discrete form by points* (load magnitude and load duration) of the curve (type-4 records). For a given case study these *two options are mutually exclusive in the same year*, i.e. if records type-3 are used for a particular year, then type-4 records should not be used and vice-versa. It is, nevertheless, permitted to change the LDC Input Option from year to year with the only restriction that each time a change of the option is made, the complete set of LDC's input information for all periods must be included for that year. Section 11.2 advises on LDC Input Option use for a given case study.

If the *Fifth-order polynomial option* for LDC input data is chosen, then type-3 records (preceded by one type-1 INDEX=3 record) are used to give the coefficients, a_n, of the polynomial approximating the normalized LDC for each period of the year. It may happen that these coefficients are identical for two or more periods; however, it is still necessary to have a separate record for each period.

If the period LDC's are to be input by *points of the curve*, then groups of type-1 INDEX=4, type-4 (-4a and -4b) records are used to give the required information. The *type-4 record* indicates the number of periods (NP) and the index (IPER) of the periods for which LDC data are specified in the *type-4a* and *type-4b* records that follow. For the first year in which the LDC point-by-point option is used, the value of NP on record type-4 *must* be equal to the value of NPER specified in record type-A and in this case the indices (IPER(I)) are not required since one record type-4a for each period must be included as input data and their ordering (1, 2, 3, ...) is automatically handled by LOADSY. For the next and subsequent years, NP will indicate the number of periods with new LDC information and IPER the index of the respective periods. A data record type-4a is needed for each period with new LDC data.

Each *type-4a record* will tell the computer the number of points (NPTS) of the LDC used as input data and either that these points are to be read (IO=0) from records type-4b which follow, or that the LDC of this period is identical to the LDC of a preceding period IO (IO > 0). For this option to be valid, the value of IO must be less than the index of the current period (e.g. if current period = 3 then IO = 1 or 2) and the value of NPTS given in record type-4a for current period must be equal to NPTS of period IO (and no record type-4b follow). Finally, *records type-4b* are used to specify the points of the normalized LDC of the period using one record per point, each one containing the load magnitude (LD) and load duration (DUR) as fractions of the period peak load and the total hours of the period. It is necessary that the first point on the curve be adjusted to the period peak load [LD(1)= 1.0, DUR(1)= 0.0] and the last point to the minimum load of the period [LD(NPTS)= minimum load and DUR(NPTS)= 1.0]. Points must be arranged in a descending order in such a way that the LDC does not have a point with positive slope.

Regardless of the LDC input data option used, the order in which the curves for the different periods are given *must be consistent* with the ordering of the period peak load ratios on data record(s) type-2. Furthermore, the order must be *consistent* with the ordering of hydro data for each period described in Modules 2 and 3 or the inconsistency will be manifested as wrong answers in Module 5.

Certain input data are checked up by the program to make sure that the requested calculations for the run are within the capabilities of the program and that there are no inconsistencies between input information. These checks and the corresponding error messages are described in Section 2 of Chapter 13.

Table 3.1. (page 1) Types of data records used in LOADSY

Record type	Columns	Format[1]	Fortran name	Information
X	1-60	A	IDENT	Title of the study which has to be centered in the given space (columns 30-31 are the center columns).
A	1-4	I	NPER	Number of periods per year (maximum 12).
	5-8	I	NOCOF	Number of cosine terms to be used in the Fourier approximation to the inverted load duration curve (100 maximum, 50 recommended).
	9-12	I	IOPT	Printout option. "0" (zero), default value, calls for normal output. "1" calls for extended output (equal to normal output but including, in addition, the Fourier coefficients calculated by the program each time a new set of LDC shapes is read in (from records type-3 or type-4 depending on the LDC input option selected).
B	1-8	F	PKMW	Annual peak load (MW).
	9-14	I	JAHR	Year of PKMW.
1	1-4	I	INDEX	Index number; "1" indicates end of input data for the current year; "2" indicates that one or two type-2 records follow defining the period peak load; "3" indicates that the periods load duration curve data are expressed in polynomial form and that one type-3 record follows for each period; "4" indicates that periods LDC data are expressed by points of the curve and that groups of records type-4 (-4a and -4b) follow.
2	1-8 9-16 17-24 . . 73-80	F F F . . F	PUPPK	Ratio of the peak load in each period expressed as a fraction of the annual peak; up to 10 numbers per record; for 4 periods, for example, only the first four fields of one record type-2 would be used; for 11 or 12 periods per year use the first one or two fields of a second type-2 record. One of the ratios must be 1.0.

Table 3.1. (page 2) Types of data records used in LOADSY

Record type	Columns	Format[1]	Fortran name	Information
3[2]	1-12	F	COEF	a_0 constant coefficient of the fifth-order polynomial representing the original load duration curve for the period (normally 1.0).
	13-24	F		a_1 coefficient of first order.
	25-36	F		a_2 coefficient of second order.
	37-48	F		a_3 coefficient of third order.
	49-60	F		a_4 coefficient of fourth order.
	61-72	F		a_5 coefficient of fifth order.
4	1-4	I	NP	Number of periods for which load duration curve data are changed from the preceding year. For the first year in which this record is used, NP must be equal to NPER on data record type-A.
	5-8	I	IPER(I)	Index of periods for which LDC data are to be changed from the applicable to preceding years. Leave blank for the first year in which this type of record is specified.
	9-12	I		
	.			
	.			
	49-52	I		
4a[3]	1-4	I	NPTS	Number of points representing the LDC of the period IPER (Maximum = 100).
	5-8	I	IO	Index option; if = 0 it indicates that data points for the LDC of period IPER follow on type-4b records; if > 0, it indicates that the LDC of period IPER is identical to the LDC of a preceding period IO (where IO < IPER).
4b[4]	1-10	F	LD	Load magnitude (as a fraction of the period peak load) of each point on the LDC for period IPER.
	11-20	F	DUR	Load duration (as a fraction of total hours of the period) of LD. Note: Load points are to be given in descending order of load magnitudes (LDC should not have a positive slope anywhere). The first and last points must be adjusted, respectively, to the peak and minimum loads of the period, i.e.: LD (1) = peak load = 1.0; DUR(1) = 0.0 LD (NPTS)=min. load; DUR(NPTS) = 1.0

(1) See Section 2.5 for format description
(2) One record for each period (up to NPER) of the year
(3) One record for each period (IPER) indicated in record type-4
(4) One record for each point (up to NPTS) of LDC for period IPER

The input data to LOADSY are arranged in the following sequence:

(a) For the first year:

First line: One type-X record with the title of the study.

Second line: One type-A record with the general information for the study.

Third line: One type-B record with annual peak load and the first year of study.

Next lines: One type-1 INDEX=2 record followed by one (or two) type-2 record(s) with the ratios of periods' peak load to the annual peak.

Following lines: Depend on the option chosen for the LDC input data:

If the *polynomial option* is chosen: one type-1 INDEX=3 record followed by *one type-3 record per period* with the coefficients of the polynomial describing the period's LDC.
If the *point by point* option is chosen: one type-1 INDEX=4 record followed by one type-4 record with the number of periods (NP) of the year (NP must be = NPER on data record type-A); the rest of the record is left blank. Next, for each period, a group of one record type-4a and the necessary type-4b records as follows: One record type-4a with the number of points (NPTS) of the LDC and a value of IO indicating what to do next. If IO=0, the record type-4a is followed by NPTS data records type-4b with the points (load magnitude and load duration) of the LDC for the period. If IO>0, the LDC of current period is identical to the LDC of the preceding period IO.

Last line: One type-1 INDEX=1 record (end of the year).

(b) Second and subsequent years:

First line: One type-B record with the annual peak load and corresponding year.

Group of one type-1 INDEX=2 and one (or two) type-2 records if a change is to be introduced to the ratios of period peak load to the annual peak.

For change in the LDC shape of one or more periods: The group of records depend on the LDC input option chosen for the first year. If the *polynomial option* was selected: Group of one type-1 INDEX=3 and NPER type-3 records (one type-3 record per period). If the *point by point* option was chosen: A group composed of one type-1 INDEX=4, followed by one type-4 record to specify how many periods (NP) are to be changed and the index (IPER(I)) of these periods. Next, for each of the above periods, one record type-4a with the values of NPTS and IO. If IO=0, the record type-4a is followed by NPTS records type-4b with the points of the LDC for the period IPER. If IO > 0, the LDC for current period is identical to the one for a preceding period IO (i.e. no records type-4b follow for period IPER considered)[1].

Last line: One type-1 INDEX=1 record (end of the year).

---

[1] Note: the above explanation assumes that only one of the two options for definition of LDC input data is used in the run. Section 3.3 describes how the input data should be arranged when both options are used in the input data.

3.3. SAMPLE PROBLEM

3.3.1. Input data

Figure 3.1 shows a partial listing of the input data used to run LOADSY for the sample problem, DEMOCASE. Some lines in Fig. 3.1 have been identified with a number or extra information (not read by the program and appearing to the right of the data fields in the respective record) in order to facilitate the discussion which follows.

The first line is the type-X record with the title of the study. This information is simply used by LOADSY for printing purposes, i.e. to produce the cover page identifying the output (see Section 3.3.2). The headings on the cover page have been centered to columns 30-31 of the field for the title. This "title" will not be compared to similar information given to any other module, so that in principle the title could be changed for any subsequent LOADSY run. However, it is advisable to maintain the same title along all runs of the study for reference purposes. For this reason, the title of the study of the sample problem is kept the same along all modules. Different titles could be used to identify additional studies for the same sample problem, e.g. assuming different growth rates for the electricity demand.

The second line of input data is the type-A record specifying the number of periods per year (4); the number of cosine terms to be considered in the Fourier series (50); and the printout option chosen (1). The third line is a type-B record specifying the annual peak load (6000. MW) and the year number for the first year of the study (1998). The fourth line is a type-1 INDEX-2 record indicating that a type-2 record follows giving the peak load of each period as a fraction of the annual peak.

In the sample problem, the Fifth Order Polynomial option has been chosen for input data on load duration curves for the periods. Thus, the 6th input line is a type-1 INDEX=3 record indicating that it is followed by a type-3 record for each period (four in this case) with the coefficients of the polynomial representing the load duration curve of the period. Next line is a type-1 INDEX-1 record indicating that the input information for the year have been completed. It should be noticed that the information appearing to the right of this record is not read by the program and has been added here only for identification purposes.

The data for next year follow, including one type-B record with the annual peak load (6333. MW) and the year (1999), followed by a type-1 INDEX=1 record indicating end of input information for the year. Similar groups are presented for the subsequent years (2000 and 2001). In this case, the data specified on type-2 and type-3 records for the first year of study will apply to all these years. Again, the information appearing to the right of each type-1 INDEX=1 has been added only for identification purposes.

The next Input line is a type-1 INDEX=3 record indicating that type-3 records will follow to specify new coefficients of the polynomial describing the load duration curves from this year on. In this case, the *new* polynomial coefficients on the type-3 records are equal to the ones specified for the first year of study, so that there is no change of the load duration curves shape. In fact, these records may have been omitted altogether, but they have been included to demonstrate the use of LOADSY data record type-3. The last type-3 record in this group is followed by a type-1 INDEX=1 record indicating the end of input information for the current year, 2002 in this case.

The subsequent lines are groups of one type-B record and one type-1 INDEX=1 record for the next years of study (2003, 2004 and 2005). Again, since no other records are given for these years, all information on LDCs and period's peak load fractions will remain the same as in the preceding years. The next group of input data lines correspond to the information for year 2006, starting with one type-B record, followed by one type-1 INDEX=4 record to specify information on period's LDC using the point by point option[2].

The next line is the type-4 record with the number of periods for which new data for the period's LDC are to be specified in subsequent type-4a and type-4b records. In this example, this record shows a 4 (note that this is equal to the total number of periods, since no previous information about period's LDC on a point-by-point basis has been specified). The rest of this line is left blank since LDC information must be given for each period.

The next input line is a type-4a record which shows in columns 3-4 that 61 points will be used to specify the LDC of the first period while the value of IO in column 8 (a blank in this case is read as a 0) indicates that these points are given next. Thus, this record is followed by 61 records type-4b, each one with the load magnitude and load duration for each of the LDC points selected. Note that the first type-4b record *must specify* the peak load of the period (LD= 1.000 and DUR= 0.0) and the last one the minimum load of the period (LD= 0.4000 and DUR= 1.000). After the last LDC point, an additional type-4a record is used to specify the number of LDC points for the second period (60) and is followed by the 60 type-4b records required for this period.

The type-4a record which follows corresponds to period 3. This gives a 2 in column 8, indicating that the LDC for this period is identical to the one specified for period 2. Therefore, the number of points describing the LDC which is given in this record (60) *must be* equal to the respective number of LDC points already specified for period 2. Similarly, the next line of input is a type-4a record indicating (in column 8) that the LDC for period 4 is identical to the LDC already specified for period 1. Thus, the same number of points (61) used for the LDC in period 1 is shown in this record. It should be noticed that the information appearing to the right of this record is not read by the program and has been added here only for identification purposes.

For years 2007 to 2010, only one type-B and one type-1 INDEX=1 records, are specified, indicating no change in the data for LDC shapes and period peak load ratios from the previous year. For the year 2011, after a type-B record, a type-1 INDEX=4 record is given followed by a group of type-4 records. In this case, the first record containing NP (=2) means that for 2 of the 4 periods LDC shapes will change. These two periods are specified on the same record by IPER (=1 and 3). The next inputs are type-4a and type-4b records for these two periods of this year. Finally, a type-1 INDEX=1 record indicates end of the input for this year.

In this example, the rest of the input data shown in Figure 3.1 consist of groups of one type-B record and one type-1 INDEX=1 record for the remaining years of the study, with no further changes of LDC shapes or period peak load ratios.

---

[2] Note: This option is used here only for demonstration of the capabilities of LOADSY. In fact, the shape of the LDCs used to define the given points are identical to the respective ones used for the definition of the LDC as a fifth order polynomial used for 1998 and 2002. For a real case study, it is *strongly recommended* to use only one of the two options for LDC input in all years of study.

```
    DEMOCASE: CASE STUDY FOR THE WASP-IV USERS MANUAL
  4  50   1
  6000.  1998
  2
   0.90    0.87    0.93    1.00
  3
     1.0000     -3.6000     16.6000     -36.800     36.0000     -12.800
     1.0000     -3.0000     13.8500     -31.200     31.0000     -11.200
     1.0000     -3.0000     13.8500     -31.200     31.0000     -11.200
     1.0000     -3.6000     16.6000     -36.800     36.0000     -12.800
  1            (END OF 1998)
 6333.0  1999
  1            (END OF 1999)
6725.65  2000
  1            (END OF 2000)
7109.01  2001
  1            (END OF 2001)
7496.45  2002
  3
     1.0000     -3.6000     16.6000     -36.800     36.0000     -12.800
     1.0000     -3.0000     13.8500     -31.200     31.0000     -11.200
     1.0000     -3.0000     13.8500     -31.200     31.0000     -11.200
     1.0000     -3.6000     16.6000     -36.800     36.0000     -12.800
  1            (END OF 2002)
7897.51  2003
  1            (END OF 2003)
8304.23  2004
  1            (END OF 2004)
8702.83  2005
  1            (END OF 2005)
9120.57  2006
  4
  4
 61
   1.0000    0.0000     1
   0.9964    0.0010     2
   0.9929    0.0020     3
   0.9893    0.0030     4
   0.9824    0.0050     5
   0.9656    0.0100     6
   0.9496    0.0150     7
   0.9344    0.0200     8
   0.9060    0.0300     9

      .         .        .
      .         .        .
      .         .        .

   0.4453    0.8600     54
   0.4429    0.8800     55
   0.4401    0.9000     56
   0.4364    0.9200     57
   0.4313    0.9400     58
   0.4240    0.9600     59
   0.4138    0.9800     60
   0.4000    1.0000     61
```

Figure. 3.1. (page 1) WASP-IV - LOADSY input data for the sample problem.

```
  60
    1.0000    0.0000      1
    0.9970    0.0010      2
    0.9941    0.0020      3
    0.9853    0.0050      4
    0.9714    0.0100      5
    0.9580    0.0150      6
    0.9453    0.0200      7
    0.9216    0.0300      8
    0.9002    0.0400      9

       .         .        .
       .         .        .
       .         .        .

    0.4993    0.9000      55
    0.4940    0.9200      56
    0.4871    0.9400      57
    0.4780    0.9600      58
    0.4658    0.9800      59
    0.4500    1.0000      60
  60   2
  61   1
   1          (END OF 2006)
 9558.36  2007
   1          (END OF 2007)
 10017.2  2008
   1          (END OF 2008)
 10488.   2009
   1          (END OF 2009)
 10980.9  2010
   1          (END OF 2010)
 11497.   2011
   4
   2   1   3
  61
    1.0000    0.0000      1
    0.9964    0.0010      2
    0.9929    0.0020      3
    0.9893    0.0030      4
    0.9824    0.0050      5
    0.9656    0.0100      6
    0.9496    0.0150      7
    0.9344    0.0200      8
    0.9060    0.0300      9

       .         .        .
       .         .        .

    0.4429    0.8800      55
    0.4401    0.9000      56
    0.4364    0.9200      57
    0.4313    0.9400      58
    0.4240    0.9600      59
    0.4138    0.9800      60
    0.4000    1.0000      61
```

Figure 3.1. (page 2) WASP-IV - LOADSY input data for the sample problem.

```
 60
     1.0000    0.0000     1
     0.9970    0.0010     2
     0.9941    0.0020     3
     0.9853    0.0050     4
     0.9714    0.0100     5
     0.9580    0.0150     6
     0.9453    0.0200     7
     0.9216    0.0300     8
     0.9002    0.0400     9

       .         .        .
       .         .        .
       .         .        .

     0.5035    0.8800     54
     0.4993    0.9000     55
     0.4940    0.9200     56
     0.4871    0.9400     57
     0.4780    0.9600     58
     0.4658    0.9800     59
     0.4500    1.0000     60
   1           (END OF 2011)
  12025.9  2012
   1           (END OF 2012)
  12579.1  2013
   1           (END OF 2013)
  13157.7  2014
   1           (END OF 2014)
  13749.8  2015
   1           (END OF 2015)
  14368.5  2016
   1           (END OF 2016)
  15015.1  2017
   1           (END OF 2017)
```

Figure 3.1. (page 3) WASP-IV - LOADSY input data for the sample problem.

3.3.2. Printout

Figure 3.2 illustrates the LOADSY output results for the sample problem, DEMOCASE, for several years of the study period (1998, 1999, 2006 and 2011), as reported in the output file “LOADSY.REP”. Page 1 of Fig. 3.2 corresponds to the cover page printed by LOADSY which is used to identify the run. It contains the title of the study, the number of periods defined for each year, hours in each period (in this case 2190 since the year has been sub-divided in four periods) and the number of coefficients of cosine terms used in the Fourier approximation of the inverted load duration curve (50).

Page 2 of Fig. 3.2 shows the Load System description for the first year of the study (1998). This starts with the yearly input data on annual peak load and the period peak loads as fractions of the annual peak. Next comes the load description for each period of the year, beginning with the input data for the polynomial coefficients representing the load duration curve of the period, followed by the calculated values for the period: 1) *peak and minimum load*, both in MW; 2) *energy demand* (in GWh); 3) *load factor* (in %). (Energy demand and load factor values are both given for each of the two approximations to the load duration curve); and 4) the *coefficients of the cosine terms of the Fourier approximation* to the inverted load curve (since in this case the printout option was set to 1). The constant coefficient, a_O, is given separately, and the other terms are given in groups of 10 per line. After the last period has been considered, the program prints an annual summary showing the values of the energy demand and the load factor as calculated for the polynomial (input) and Fourier (output) approximations to the load duration curve.

A similar output is given for each year of the study, but if no new LDC input data are given (on records type-3 or type-4, depending on the option chosen), the Fourier coefficients for the periods are not printed again. Page 3 of Fig. 3.2 shows the Load System description for year 1999. An output similar to the one in page 3 will be printed for all years of the study if the printout option is set to zero ("0"), regardless of how many changes are introduced to the load duration curve shapes throughout the study period. For this reason, the use of printout option 0 is particularly advisable for WASP studies considering more than 4 periods per year and different load duration curve shapes throughout the study period, as a means to reduce the LOADSY printout.

Pages 4 and 5 of Fig. 3.2 show the (partial) results of the LOADSY run of DEMOCASE for year 2006, for which the point-by-point input option for LDC information has been used. At the beginning the year annual peak load and year are listed, followed by the data on period's LDC given as input. Only the first and last portions of the listing of these input data are shown on page 4 of the figure. Since the shape of the period's LDC has not been altered, the results on Page 5 for the Fourier Series coefficients and load factors are quite similar to the respective ones for the first year of study (Page 2), except for some minor differences, which are considered negligible. These differences, however, could have been avoided by defining a greater number of points for the period LDC's.

Pages 6 and 7 of Fig. 3.2 show the (partial) results of the present run for year 2011, for which the LDC information has been changed from the previous year for 2 of the 4 periods, viz. period 1 and 3. The point-by-point LDC information given in the input for these two periods and the corresponding results of the Fourier approximation are reported, along with usual period and annual results.

As mentioned in Section 3.2, certain input data are internally checked up by the program and in case of "error," they will cause interruption of the program execution, and printing of an "error message." If the message does not correspond to any of the LOADSY "error messages" described in Chapter 13 the user should ask the WASP analyst to interpret it. In some cases there is no error message but something is obviously wrong, such as a load factor greater than 100%. In such cases, correct the errors and consult the WASP analyst as necessary.

```
                 WASP  COMPUTER  PROGRAM  PACKAGE

                          LOADSY  MODULE

                           CASE  STUDY

          DEMOCASE: CASE STUDY FOR THE WASP-IV USERS MANUAL

       **********************************************************
       *                                                        *
       *           NUMBER OF PERIODS PER YEAR =  4              *
       *                                                        *
       *           HOURS IN EACH PERIOD =  2190.00              *
       *                                                        *
       *     NUMBER OF COEFFICIENTS OF COSINE TERMS             *
       *     IN FOURIER APPROXIMATION OF THE L.D.C. =  50       *
       *                                                        *
       **********************************************************
```

Figure 3.2. (page 1) LOADSY printout for the sample problem. Cover page.

```
          PEAK LOAD FOR YEAR **** 1998 **** IS :    6000.0 MW

          PERIOD PEAK LOADS AS FRACTION OF ANNUAL PEAK LOAD :
            0.9000  0.8700  0.9300  1.0000

          * * * * * * * * * * *  PERIOD  1  * * * * * * * * * * *
          INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
    1.00000   -3.60000   16.60000  -36.80000   36.00000  -12.80000

          PEAK LOAD :  5400.0 MW    MINIMUM LOAD :  2160.0 MW

                            ENERGY DEMAND       LOAD FACTOR
                               (GWH)               (%)
          INTEGRATION    :     7095.6             60.00
          FOURIER SERIES :     7095.9             60.00

      FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
          CONSTANT TERM -AOO- IS : 0.8571429
          COEFFICIENTS OF COSINE TERMS ARE :
  0.5914358   0.1190372  -0.1001728  -0.0637807   0.0009492   0.0119581   0.0060982   0.0110108   0.0129758  -0.0059543
 -0.0213913  -0.0075546   0.0125758   0.0121567  -0.0000323  -0.0059782  -0.0036225  -0.0015444  -0.0012656   0.0026733
  0.0060277   0.0014792  -0.0051021  -0.0047674   0.0007260   0.0037691   0.0018198  -0.0005167  -0.0006604  -0.0011445
 -0.0017181   0.0000382   0.0023317   0.0018547  -0.0009078  -0.0022762  -0.0006563   0.0010610   0.0008485   0.0002470
  0.0000868  -0.0003751  -0.0009006  -0.0004871   0.0007919   0.0012151  -0.0000165  -0.0010468  -0.0005940   0.0002522

          * * * * * * * * * * *  PERIOD  2  * * * * * * * * * * *
          INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
    1.00000   -3.00000   13.85000  -31.20000   31.00000  -11.20000

          PEAK LOAD :  5220.0 MW    MINIMUM LOAD :  2349.0 MW

                            ENERGY DEMAND       LOAD FACTOR
                               (GWH)               (%)
          INTEGRATION    :     7430.7             65.00
          FOURIER SERIES :     7430.6             65.00

      FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
          CONSTANT TERM -AOO- IS : 0.8965517
          COEFFICIENTS OF COSINE TERMS ARE :
  0.6048022   0.0903804  -0.1289211  -0.0577438   0.0220275   0.0210460   0.0058457   0.0047452  -0.0004984  -0.0133372
 -0.0116268   0.0087155   0.0162260  -0.0001980  -0.0116095  -0.0045610   0.0037899   0.0035679   0.0009932   0.0003636
 -0.0009393  -0.0033337  -0.0016296   0.0035034   0.0035242  -0.0016724  -0.0033617  -0.0002237   0.0018436   0.0008765
 -0.0003714  -0.0002772  -0.0002463  -0.0007512   0.0000587   0.0013826   0.0004761  -0.0012929  -0.0009248   0.0006832
  0.0010209  -0.0000234  -0.0006919  -0.0002653   0.0001136   0.0000525   0.0003344   0.0004346  -0.0003295  -0.0007820

          * * * * * * * * * * *  PERIOD  3  * * * * * * * * * * *
          INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
    1.00000   -3.00000   13.85000  -31.20000   31.00000  -11.20000

          PEAK LOAD :  5580.0 MW    MINIMUM LOAD :  2511.0 MW

                            ENERGY DEMAND        LOAD FACTOR
                               (GWH)               (%)
          INTEGRATION    :     7943.1             65.00
          FOURIER SERIES :     7943.1             65.00

      FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
          CONSTANT TERM -AOO- IS : 0.8965517
          COEFFICIENTS OF COSINE TERMS ARE :
  0.6048022   0.0903804  -0.1289211  -0.0577438   0.0220275   0.0210460   0.0058457   0.0047452  -0.0004984  -0.0133372
 -0.0116268   0.0087155   0.0162260  -0.0001980  -0.0116095  -0.0045610   0.0037899   0.0035679   0.0009932   0.0003636
 -0.0009393  -0.0033337  -0.0016296   0.0035034   0.0035242  -0.0016724  -0.0033617  -0.0002237   0.0018436   0.0008765
 -0.0003714  -0.0002772  -0.0002463  -0.0007512   0.0000587   0.0013826   0.0004761  -0.0012929  -0.0009248   0.0006832
  0.0010209  -0.0000234  -0.0006919  -0.0002653   0.0001136   0.0000525   0.0003344   0.0004346  -0.0003295  -0.0007820

          * * * * * * * * * * *  PERIOD  4  * * * * * * * * * * *
          INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
    1.00000   -3.60000   16.60000  -36.80000   36.00000  -12.80000

          PEAK LOAD :  6000.0 MW    MINIMUM LOAD :  2400.0 MW

                            ENERGY DEMAND       LOAD FACTOR
                               (GWH)               (%)
          INTEGRATION    :     7884.0             60.00
          FOURIER SERIES :     7884.3             60.00

      FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
          CONSTANT TERM -AOO- IS : 0.8571429
          COEFFICIENTS OF COSINE TERMS ARE :
  0.5914358   0.1190372  -0.1001728  -0.0637807   0.0009492   0.0119581   0.0060982   0.0110108   0.0129758  -0.0059543
 -0.0213913  -0.0075546   0.0125758   0.0121567  -0.0000323  -0.0059782  -0.0036225  -0.0015444  -0.0012656   0.0026733
  0.0060277   0.0014792  -0.0051021  -0.0047674   0.0007260   0.0037691   0.0018198  -0.0005167  -0.0006604  -0.0011445
 -0.0017181   0.0000382   0.0023317   0.0018547  -0.0009078  -0.0022762  -0.0006563   0.0010610   0.0008485   0.0002470
  0.0000868  -0.0003751  -0.0009006  -0.0004871   0.0007919   0.0012151  -0.0000165  -0.0010468  -0.0005940   0.0002522

          ***************** ANNUAL  SUMMARY *****************

                            ENERGY DEMAND       LOAD FACTOR
                               (GWH)               (%)
          INTEGRATION    :    30353.4             57.75
          FOURIER SERIES :    30354.0             57.75


     * * * * * * * * *  END OF DATA FOR YEAR  1998  * * * * * * * * *
```

Figure 3.2. (page 2) LOADSY printout for the sample problem. Load description — 1998.

```
      PEAK LOAD FOR YEAR **** 1999 **** IS :    6333.0 MW

      PERIOD PEAK LOADS AS FRACTION OF ANNUAL PEAK LOAD :
        0.9000  0.8700  0.9300  1.0000

      * * * * * * * * * *  PERIOD  1  * * * * * * * * * *
      INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
1.00000   -3.60000   16.60000  -36.80000   36.00000  -12.80000

      PEAK LOAD :  5699.7 MW    MINIMUM LOAD :  2279.9 MW

                        ENERGY DEMAND       LOAD FACTOR
                            (GWH)               (%)
      INTEGRATION    :      7489.4             60.00
      FOURIER SERIES :      7489.7             60.00


      * * * * * * * * * *  PERIOD  2  * * * * * * * * * *
      INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
1.00000   -3.00000   13.85000  -31.20000   31.00000  -11.20000

      PEAK LOAD :  5509.7 MW    MINIMUM LOAD :  2479.4 MW

                        ENERGY DEMAND       LOAD FACTOR
                            (GWH)               (%)
      INTEGRATION    :      7843.1             65.00
      FOURIER SERIES :      7843.0             65.00


      * * * * * * * * * *  PERIOD  3  * * * * * * * * * *
      INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
1.00000   -3.00000   13.85000  -31.20000   31.00000  -11.20000

      PEAK LOAD :  5889.7 MW    MINIMUM LOAD :  2650.4 MW

                        ENERGY DEMAND       LOAD FACTOR
                            (GWH)               (%)
      INTEGRATION    :      8384.0             65.00
      FOURIER SERIES :      8383.9             65.00


      * * * * * * * * * *  PERIOD  4  * * * * * * * * * *
      INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
1.00000   -3.60000   16.60000  -36.80000   36.00000  -12.80000

      PEAK LOAD :  6333.0 MW    MINIMUM LOAD :  2533.2 MW

                        ENERGY DEMAND       LOAD FACTOR
                            (GWH)               (%)
      INTEGRATION    :      8321.6             60.00
      FOURIER SERIES :      8321.9             60.00


      ***************** ANNUAL  SUMMARY ****************

                        ENERGY DEMAND       LOAD FACTOR
                            (GWH)               (%)
      INTEGRATION    :     32038.0             57.75
      FOURIER SERIES :     32038.6             57.75

* * * * * * * * * *  END OF DATA FOR YEAR  1999  * * * * * * * * * *
```

Figure 3.2. (page 3)LOADSY printout for the sample problem. Load description — 1999.

```
               PEAK LOAD FOR YEAR **** 2006 **** IS :    9120.6 MW

 NUMBER OF PERIODS FOR WHICH DATA FOLLOW :   4
 INDEX  OF PERIODS TO BE CHANGED :     1     2     3     4

 PERIOD  1 :   61 POINTS
      LD        DUR

    1.0000    0.0000
    0.9964    0.0010
    0.9929    0.0020
    0.9893    0.0030
    0.9824    0.0050
    0.9656    0.0100
    0.9496    0.0150
    0.9344    0.0200
    0.9060    0.0300
    0.8803    0.0400
    0.8571    0.0500
    0.8363    0.0600
       .         .
       .         .
       .         .
       .         .
       .         .
       .         .

    0.4537    0.8000
    0.4504    0.8200
    0.4477    0.8400
    0.4453    0.8600
    0.4429    0.8800
    0.4401    0.9000
    0.4364    0.9200
    0.4313    0.9400
    0.4240    0.9600
    0.4138    0.9800
    0.4000    1.0000

 PERIOD  2 :   60 POINTS
      LD        DUR

    1.0000    0.0000
    0.9970    0.0010
    0.9941    0.0020
    0.9853    0.0050
    0.9714    0.0100
    0.9580    0.0150
    0.9453    0.0200
    0.9216    0.0300
    0.9002    0.0400
    0.8809    0.0500
    0.8635    0.0600
    0.8479    0.0700
       .         .
       .         .
       .         .
.         .

    0.5172    0.8000
    0.5135    0.8200
    0.5102    0.8400
    0.5070    0.8600
    0.5035    0.8800
    0.4993    0.9000
    0.4940    0.9200
    0.4871    0.9400
    0.4780    0.9600
    0.4658    0.9800
    0.4500    1.0000
```

Figure 3.2. (page 4) LOADSY printout for the sample problem. Input information for 2006.

```
PERIOD PEAK LOADS AS FRACTION OF ANNUAL PEAK LOAD :
  0.9000  0.8700  0.9300  1.0000

* * * * * * * * * *  PERIOD  1  * * * * * * * * * *

PEAK LOAD :  8208.5 MW    MINIMUM LOAD :  3283.4 MW

                  ENERGY DEMAND       LOAD FACTOR
                      (GWH)               (%)
INTEGRATION    :     10786.6             60.00
FOURIER SERIES :     10787.0             60.01


        FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
                CONSTANT TERM -AOO- IS : 0.8571885
                COEFFICIENTS OF COSINE TERMS ARE :
 0.5914137  0.1189862 -0.1001288 -0.0637293  0.0009174  0.0119343  0.0061207  0.0109987  0.0129295 -0.0059423
-0.0213123 -0.0075242  0.0125015  0.0120916 -0.0000009 -0.0059314 -0.0036237 -0.0015402 -0.0012469  0.0026469
 0.0059729  0.0014753 -0.0050470 -0.0047250  0.0007132  0.0037323  0.0017968 -0.0005231 -0.0006472 -0.0011112
-0.0016963  0.0000239  0.0022995  0.0018330 -0.0009031 -0.0022460 -0.0006314  0.0010540  0.0008270  0.0002342
 0.0000808 -0.0003706 -0.0008781 -0.0004681  0.0007793  0.0011855 -0.0000226 -0.0010265 -0.0005828  0.0002464

* * * * * * * * * *  PERIOD  2  * * * * * * * * * *

PEAK LOAD :  7934.9 MW    MINIMUM LOAD :  3570.7 MW

                  ENERGY DEMAND        LOAD FACTOR
                      (GWH)               (%)
INTEGRATION    :     11295.6             65.00
FOURIER SERIES :     11295.5             65.00


        FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
                CONSTANT TERM -AOO- IS : 0.8965703
                COEFFICIENTS OF COSINE TERMS ARE :
 0.6047779  0.0903512 -0.1288676 -0.0576992  0.0219827  0.0210080  0.0058650  0.0047489 -0.0005119 -0.0133049
-0.0115872  0.0086774  0.0161539 -0.0001879 -0.0115338 -0.0045395  0.0037465  0.0035445  0.0009966  0.0003562
-0.0009289 -0.0032921 -0.0016218  0.0034553  0.0034920 -0.0016482 -0.0033272 -0.0002189  0.0018321  0.0008634
-0.0003862 -0.0002780 -0.0002240 -0.0007338  0.0000483  0.0013639  0.0004716 -0.0012876 -0.0009169  0.0006919
 0.0010199 -0.0000355 -0.0006973 -0.0002586  0.0001185  0.0000518  0.0003336  0.0004331 -0.0003306 -0.0007798

* * * * * * * * * *  PERIOD  3  * * * * * * * * * *

PEAK LOAD :  8482.1 MW    MINIMUM LOAD :  3817.0 MW

                  ENERGY DEMAND       LOAD FACTOR
                      (GWH)               (%)
INTEGRATION    :     12074.6             65.00
FOURIER SERIES :     12074.5             65.00

* * * * * * * * * *  PERIOD  4  * * * * * * * * * *

PEAK LOAD :  9120.6 MW    MINIMUM LOAD :  3648.2 MW

                  ENERGY DEMAND       LOAD FACTOR
                      (GWH)               (%)
INTEGRATION    :     11985.1             60.00
FOURIER SERIES :     11985.6             60.01

***************** ANNUAL  SUMMARY *****************

                  ENERGY DEMAND       LOAD FACTOR
                      (GWH)               (%)
INTEGRATION    :     46141.7             57.75
FOURIER SERIES :     46142.7             57.75

  * * * * * * * * *  END OF DATA FOR YEAR  2006  * * * * * * * * *
```

Figure 3.2. (page 5) LOADSY printout for the sample problem. Load description — 2006.

```
                PEAK LOAD FOR YEAR **** 2011 **** IS :    9370.0 MW
NUMBER OF PERIODS FOR WHICH DATA FOLLOW :   2
INDEX  OF PERIODS TO BE CHANGED :     1     3
PERIOD  1 :   61 POINTS
      LD        DUR

    1.0000    0.0000
    0.9964    0.0010
    0.9929    0.0020
    0.9893    0.0030
    0.9824    0.0050
    0.9656    0.0100
    0.9496    0.0150
    0.9344    0.0200
    0.9060    0.0300
       .         .
       .         .
       .         .
       .         .
       .         .
       .         .
    0.4429    0.8800
    0.4401    0.9000
    0.4364    0.9200
    0.4313    0.9400
    0.4240    0.9600
    0.4138    0.9800
    0.4000    1.0000

PERIOD  3 :   60 POINTS
      LD        DUR

    1.0000    0.0000
    0.9970    0.0010
    0.9941    0.0020
    0.9853    0.0050
    0.9714    0.0100
    0.9580    0.0150
    0.9453    0.0200
    0.9216    0.0300
    0.9002    0.0400
       .         .
       .         .
       .         .
       .         .
       .         .
       .         .
    0.5035    0.8800
    0.4993    0.9000
    0.4940    0.9200
    0.4871    0.9400
    0.4780    0.9600
    0.4658    0.9800
    0.4500    1.0000
```

Figure 3.2. (page 6) LOADSY printout for the sample problem. Input information for 2011.

```
              PERIOD PEAK LOADS AS FRACTION OF ANNUAL PEAK LOAD :
                0.9000  0.8700  0.9300  1.0000


              * * * * * * * * * *  PERIOD  1  * * * * * * * * * *
              PEAK LOAD :  8433.0 MW    MINIMUM LOAD :  3373.2 MW
                                ENERGY DEMAND        LOAD FACTOR
                                    (GWH)                (%)
              INTEGRATION    :      11081.6              60.00
              FOURIER SERIES :      11082.0              60.01

         FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
              CONSTANT TERM -AOO- IS : 0.8571885
              COEFFICIENTS OF COSINE TERMS ARE :
 0.5914137   0.1189862  -0.1001288  -0.0637293   0.0009174   0.0119343   0.0061207   0.0109987   0.0129295  -0.0059423
-0.0213123  -0.0075242   0.0125015   0.0120916  -0.0000009  -0.0059314  -0.0036237  -0.0015402  -0.0012469   0.0026469
 0.0059729   0.0014753  -0.0050470  -0.0047250   0.0007132   0.0037323   0.0017968  -0.0005231  -0.0006472  -0.0011112
-0.0016963   0.0000239   0.0022995   0.0018330  -0.0009031  -0.0022460  -0.0006314   0.0010540   0.0008270   0.0002342
 0.0000808  -0.0003706  -0.0008781  -0.0004681   0.0007793   0.0011855  -0.0000226  -0.0010265  -0.0005828   0.0002464


              * * * * * * * * * *  PERIOD  2  * * * * * * * * * *
              PEAK LOAD :  8151.9 MW    MINIMUM LOAD :  3668.4 MW
                                ENERGY DEMAND        LOAD FACTOR
                                    (GWH)                (%)
              INTEGRATION    :      11604.5              65.00
              FOURIER SERIES :      11604.5              65.00


              * * * * * * * * * *  PERIOD  3  * * * * * * * * * *
              PEAK LOAD :  8714.1 MW    MINIMUM LOAD :  3921.3 MW
                                ENERGY DEMAND        LOAD FACTOR
                                    (GWH)                (%)
              INTEGRATION    :      12404.8              65.00
              FOURIER SERIES :      12404.8              65.00

         FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
              CONSTANT TERM -AOO- IS : 0.8965703
              COEFFICIENTS OF COSINE TERMS ARE :
 0.6047779   0.0903512  -0.1288676  -0.0576992   0.0219827   0.0210080   0.0058650   0.0047489  -0.0005119  -0.0133049
-0.0115872   0.0086774   0.0161539  -0.0001879  -0.0115338  -0.0045395   0.0037465   0.0035445   0.0009966   0.0003562
-0.0009289  -0.0032921  -0.0016218   0.0034553   0.0034920  -0.0016482  -0.0033272  -0.0002189   0.0018321   0.0008634
-0.0003862  -0.0002780  -0.0002240  -0.0007338   0.0000483   0.0013639   0.0004716  -0.0012876  -0.0009169   0.0006919
 0.0010199  -0.0000355  -0.0006973  -0.0002586   0.0001185   0.0000518   0.0003336   0.0004331  -0.0003306  -0.0007798


              * * * * * * * * * *  PERIOD  4  * * * * * * * * * *
              PEAK LOAD :  9370.0 MW    MINIMUM LOAD :  3748.0 MW
                                ENERGY DEMAND        LOAD FACTOR
                                    (GWH)                (%)
              INTEGRATION    :      12312.8              60.00
              FOURIER SERIES :      12313.4              60.01


              ***************** ANNUAL  SUMMARY *****************
                                ENERGY DEMAND        LOAD FACTOR
                                    (GWH)                (%)
              INTEGRATION    :      47403.6              57.75
              FOURIER SERIES :      47404.6              57.75


        * * * * * * * * *  END OF DATA FOR YEAR  2011  * * * * * * * * *
```

Figure 3.2. (page 7) LOADSY printout for the sample problem. Load description — 2011.

Chapter 4

EXECUTION OF FIXSYS

4.1. INPUT/OUTPUT FILES

The input data file for FIXSYS, to be provided by the user, is "FIXSYS.DAT". It contains all the necessary information about the existing plants (thermal, hydro and pumped storage plants) and the ones which are already committed. This input file should be prepared exactly according to the format described in the next section. FIXSYS produces four files, namely "FIXPLANT.BIN", "FIXSYSGL.WRK", "FIXSYSGL.DBG" and "FIXSYS.REP". The "FIXPLANT.BIN" and "FIXSYSGL.WRK" will be used by other modules of the model while the "FIXSYSGL.DBG" is a debug file. The results of this module are reported in "FIXSYS.REP" file. This file should be reviewed by the user to check successful execution before proceeding to the next module.

4.2. INPUT DATA PREPARATION

FIXSYS uses up to 17 types of data records depending on the complexity of the system being described. Table 4.1 lists all of these types of records and describes what data they contain (in sequence for records containing more than one piece of information) along with the required format for each item of the input data..

The type-X, -Y, -Z, -A, -B, -Ba, -C, -Da, -Db, -Ea and -Eb records are used only once and apply to all years of the study period. (The type-Ea and -Eb records are used only if group limitations are imposed on the system.) The type-1 record with INDEX=1 (2, 3 or 4) tells the computer what to do next. A type-1 record with INDEX=1 means end of input for the year (this should be the last record for each year). A type-1 record with INDEX=2 is followed by a group of type-2a and type-2b records containing data for each hydro project in the system (if any). A type-1 record with INDEX=3 is followed by a type-3 record indicating addition(s) or retirement(s) of the thermal plants (if any). A type-1 record with INDEX=4 is followed by a group of type-4a and type-4b records containing information on pumped storage plants in the system (if any). The type-1 with INDEX=2 (or 4) followed by corresponding group of records are also used for specifying any change(s) (additions or retirements) in the description of hydro plants (or pumped storage plants).

The data records are arranged in the input file "FIXSYS.DAT" in the following sequence:

(a) For the first year:

First line: One type-X record with the title of the study and the number of type-Y records to be read next.

Second and following lines: As many type-Y records (equal to the value of NID on record type-X) as fuel types are to be used by the thermal plants of FIXSYS and VARSYS. (see Table 4.1 for explanation of information to be given in each record).

Following lines: Two type-Z records, one for each hydro plant type. (see Table 4.1 for information to be given in each record.)

Next line: One type-A record with the general information for the study (see Table 4.1).

Following lines: A group of type-B and type-Ba records describing each of the thermal plants (two records for each thermal plant).

Next line: A type-C record specifying the information on group limitations to be imposed (see Table 4.1 and Chapter 12 for details).

Following lines: A group of type-Da and type-Db records for each of the pollutants. (Two pollutants are considered in WASP-IV; the default are SO2 and NOx, the user may, however, change these to any other, e.g. CO2, as desired.). If all (or none) thermal plants are involved in emission of a pollutant, then type-Db record will not be required.

Next lines: A group of type-Ea and type-Eb records for each of the group limitation considered, specifying the number of plants taking role in that group limitation and the upper bound value for that limit, and the indices of the plants involved in that limitation.

Following lines: Groups of type-2a and type-2b records preceded by a type-1 record with INDEX=2 for each hydroelectric plant in operation (if any) for the first year of study. Each group is composed of one type-2a record and as many type-2b records as periods have been defined for the study (NPER on record type-A). Each type-2b record should contain the energy and capacity data (see Table 4.1 (page 5)) for each hydro-condition used (total equal to IHYDIS on record type-A).

Next lines: Groups of one type-1 INDEX=3 and one type-3 records for each change in the number of units (if any) of the thermal plant (additions or retirements).

Following lines: Groups of type-4a and type-4b records preceded by a type-1 record with INDEX=4 for each pumped storage project in operation (if any) for the first year of the study. Each group comprises one type-4a record and as many type-4b records as the number of periods defined for the study (NPER on record type-A).

Last line: One type-1 record with INDEX=1 (end of the year record).

(b) For the second and subsequent years:

Groups of one type-1 record INDEX=2, followed by one type-2a record and the corresponding type-2b records for each change to be made to the hydroelectric plant types (additions or retirements).

Groups of one type-1 with INDEX=3 and one type-3 records for changes (additions or retirements) to be made to the number of units in the thermal plants.

Groups of one type-1 record with INDEX=4 record followed by one type-4a and the corresponding type-4b records for each change to be made to the pumped storage plants (additions or retirements).

One type-1 record with INDEX=1 (end of the year record).

Table 4.1. (page 1) Types of data records used in FIXSYS

Record type	Columns	Format[1]	Fortran name	Information
X	1-60	A	IDENT	Title of study (centered to columns 30-31).
	61-64	I	NID	Number of type-Y records to be read next (maximum 10).
	65-68	I	IODBG	Print option for debug file FIXSYSGL.DBG.
Y[2]	1-4	I	IDNUM	Thermal plant fuel type number (0 to 9).
	6-9	A	IDNAM	Code name for this fuel type.
	11-30	A	IDTXT[3]	Short description of this fuel type (starting in Col. 11).
Z[4]	6-9	A	IDNAM	Code name of the hydroelectric plant type (must be equal to NAMH on record type-A of FIXSYS and VARSYS) i.e. name or blank.
	11-30	A	IDTXT[3]	Description of the hydroelectric plant type, or blank (if it is the case).
A	1-4	I	JAHR	First year of study.
	5-8	I	NPER	Number of periods per year (maximum 12).
	9-12	I	NTHPL	Number of thermal plants in FIXSYS; minimum=1, maximum=88 less the number of expansion candidates in VARSYS (NTHPL must be equal to the number of type-B records to be read).
	13-16	I	IHYDIS	Number of hydro-conditions (maximum 5). *This field and rest of the record must be blank if hydro is not used in FIXSYS.*
	19-22	A	NAMH(1)	Code name of hydroelectric plant type A (must be blank if not used in FIXSYS).
	23-28	F	HOM(1)	Fixed operating and maintenance costs of hydroelectric plant type A ($/kW-month).
	31-34	A	NAMH(2)	Code name of hydroelectric plant type B (must be blank if not used in FIXSYS).
	35-40	F	HOM(2)	Fixed operating and maintenance costs of hydroelectric plant type B ($/kW-month).
	41-46	F	PROBH	Probability of hydro-conditions 1 to 5
	47-52	F		(in the same order used in type-2b records).
	53-58	F		(The sum of these probabilities must be
	59-64	F		equal to 1.0.)
	65-70	F		

Table 4.1. (page 2) Types of data records used in FIXSYS

Record type	Columns	Format[1]	Fortran name	Information
B[5]	1-4	A	NAME	Code name for the thermal power station.
	5-7	I	NSETS	Number of identical units in the power station at start of study.
	8-12	F	MWB	Minimum operating level of each unit (MW).
	13-17	F	MWC	Maximum unit generating capacity (MW).
	18-24	F	BHRT	Heat rate at minimum operating level (kcal/kWh).
	25-31	F	CRMHRT	Average incremental heat rate between minimum and maximum operating levels (kcal/kWh).
	32-36	F	FCST	Domestic fuel costs (c/10^6 kcal).
	37-41	F	FCSTF	Foreign fuel costs (c/10^6 kcal).
	42-44	I	NTYPE	Plant type number (0,1,2, .. 9)
	45-46	I	ISPIN[6]	Unit spinning reserve as % of MWC.
	47-51	F	FOR	Unit forced outage rate (%).
	52-54	I	MAINT	Number of days per year required for scheduled maintenance of each unit.
	55-59	F	MAINCL	Maintenance class size (MW).
	66-70	F	OMA	Fixed component of non-fuel operation and maintenance cost ($/kW-month) of each unit; it is assumed to be a domestic cost.
	71-75	F	OMB	Variable component of non-fuel operation and maintenance cost ($/MWh) of each unit; it is assumed to be a domestic cost.
Ba[5]	1-10	F	HEATVALU	heat value of the fuel used by plant, measuring the heat equivalent of 1 kg fuel used (kcal/kg).
	11-20	F	POLLUT(1)	percentage of polluting emission, the ratio of emitted first material (default: SO_2) and fuel used in plant I (%).
	21-30	F	POLLUT(2)	percentage of polluting emission, the ratio of emitted second material (default: NOx) and fuel used in plant I (%).

Table 4.1. (page 3) Types of data records used in FIXSYS

Record type	Columns	Format[1]	Fortran name	Information
	1-2	I	NGROUPLM	number of group-limitations, this number equals to the number of type-E records to be read next (maximum 5) if=0 group limits not active in FIXSYS and VARSYS.
	3-4	I	IPNLT	index for change of both default penalty factors =1 content of next two fields replaces defaults =0 content of next two fields ignored
	5-14	F	PNLTLOLP	penalty factor for the loss-of-load probability when determining the optimal mix of strategies. default = 0.0 α in the model description.
	15-24	F		penalty factor for the unserved energy when determining the optimal mix of strategies. default =1.0 ß in the model description.
C	26-28	A	EMISNAME(1)	text of three characters, abbreviating the name of the first emitted material. If it is left blank, the default name is: SO2.
	30-32	A	EMISNAME(2)	text of three characters, abbreviating the name of the second emitted material. If it is left blank, the default name is: NOx.
	33-34 35-36 37-38 39-40 41-42	I	MEASIND(N)	index number; defining the type of limit used. "1" indicates that the corresponding limit concerns the **fuel** used for energy generation, the unit is kT; "2" indicates that the emitted **EMISNAME(1)** is limited, the unit is kT; "3" indicates that the emitted **EMISNAME(2)** is limited, the unit is kT; "4" indicates that the used **heat** is limited, the unit is Tcal; "5" indicates that the **generation** is directly limited, the unit is GWh.
Da[7]	1-4	I	NPLANTS(I)	for real emission I, if = 0 (not active), if = NTHPL (all thermal plants); in both cases no Db record follows
Db[7,8]	1-4 5-8 etc.	I	PLANTIND(I,K)	index of plant taking role in the real emission I, I = 1,2 and K = 1,... NPLANTS(I) (value of PLANTIND (I,K)=IP+2)

Table 4.1. (page 4) Types of data records used in FIXSYS

Record type	Columns	Format[1]	Fortran name	Information
	1-4	I	NPLANTS(N)	number of plants taking role in the corresponding limitation (if=0, this group limit is only active in VARSYS; if=NTHPL, all thermal plants; in both cases no type-Eb records required).
	5-8	I	INDIV(N)	index of individual period group limits =0 (default) GRLRAT ignored =1 distribute GRLIMIT with GRLRAT
Ea[9]	9-18	F	GRLIMIT(N)	upper bound value of constraint N measured in kT, kT, kT, Tcal or GWh depending on the above values of the variable MEASIND.
	19-23 24-28 etc.	F F	GRLRAT(N,J)	ratio of GRLIMIT(N) for J=1,NPER for INDIV=1, else leave blank
Eb[8,9]	1-4, 5-8 9-12, ...	I	PLANTIND(N,K)	index of plant taking role in the limitation N, for K=1,...,NPLANTS(N) and N=1,...,NGROUPLM (value of PLANIND(N,K)=IP+2)
1	1-4	I	INDEX	An "index number" telling the computer what to do next; "1" means process current year data and proceed to read data for next year; "2" means hydro project data follow (type-2a and type-2b records); "3" means one type-3 record follows, "4" indicates that description of pumped storage project follows (type 4a and 4b records).
	3-6	A	NAMEP	Name of the hydroelectric project.
2a[10]	9-12	A	NAMET	Code name of the hydroelectric plant type for the hydro project; must be equal to NAMH(1) or NAMH(2) of type-A record.
	13-18	F	HMW	Installed capacity (MW) of the hydro project; a negative value is used for retirements.
	19-24	F	PV	Energy storage capacity (GWh) of hydro project.

Table 4.1. (page 5) Types of data records used in FIXSYS

Record type	Columns	Format[1]	Fortran name	Information
				Hydro-condition 1:
	1-5	F	EA	Period inflow energy (GWh) of the hydro project.
	6-10	F	EMIN	Minimum generation in base in the period (GWh).
2b[11]	11-15	F	HMWC	Available capacity in period (MW) of the project.
				Hydro-conditioin 2:
	16-20	F	EA	Period inflow energy (GWh) of the hydro project.
	21-25	F	EMIN	Minimum generation in base in the period (GWh).
	26-30	F	HMWC	Available capacity in period (MW) of the project.
				Continue up to last hydro-conditioin defined (maximum 5).
3	1-4	I	NS (NS=IP+2)	Number of the thermal plant in which one or more units are to be added or retired .
	5-8	I	NA	Number of units to be either added (+) or retired (-) in plant IP.
	3-6	I	NAMPS	Name of the pumped storage project
	7-12	F	CIPS	Installed capacity (MW) of the pumped storage project; a negative value is used for retirements.
4a[12]	13-18	F	EFPS	Cycle efficiency of the pumped storage project (%) (0<EFPS<100).
	19-24	F	OMPS	Fixed operating and maintenance cost of the pumped storage project ($/KW-month).
	1-5	F	CBPS	Pumping capacity (MW) of pumped storage project for the period.
4b[13]	6-10	F	CCPS	Generating capacity (MW) of pumped storage project for the period.
	10-15	F	CEPS	Maximum feasible energy generation (GWh) of pumped storage project for the period.

Notes to Table 4.1

(1) See Section 2.5 for Format description
(2) One record for each thermal plant (fuel) type in ascending order (0 to 9).
(3) If IDTXT starts with 4 blanks, the program replaces it by `NOT APPLICABLE.'
(4) One record for each hydroelectric plant type; first hydro type A, second hydro type B, obligatory.
(5) One record for each thermal plant IP.
(6) ISPIN should be defined consistently with the definitions of plant capacity blocks if the loading order is to be calculated by MERSIM (see Table 7.1).
(7) The number of record groups of type-Da and Db equals to the two real emissions (EMISNAME) described on the record of type-C. Two type-Da record obligatory.
(8) Fields 5-8, 9-12,...,77-80 give the indices of the second, third, etc. plant for the same emission/limitation.
(9) The number of record groups of type-Ea and Eb equals to the number of group-limitations (NGROUPLM) described on the record of type-C.
(10) One record for each hydroelectric project.
(11) One record per period for each hydroelectric project.
(12) One record for each pumped storage project.
(13) One record per period for each pumped storage project.

4.3. SAMPLE PROBLEM

4.3.1. Input data

Figure 4.1 shows the complete listing of the input data used for executing the FIXSYS run of the sample problem. The contents of these data are described in the following paragraphs:

The first input data line on page 1 of Fig. 4.1 is a type-X record containing in columns 1-60 the title of the study and in column 64 a number telling the computer how many type-Y records must be read next (7 in this case). The same comments made in Section 3.3 for the title of the study to be included in type-X record of LOADSY are valid for FIXSYS.

Lines 2 to 8 are the group of type-Y records necessary to describe the fuel types used by the thermal plants of FIXSYS and/or VARSYS (one record for each fuel type must be given as input even if one or more of the fuel types are not used in FIXSYS but are associated to plants that will be described in VARSYS). In each type-Y record the respective fuel is assigned a *code number*, a *code name* and a *description.*

Regarding the *code numbers*, only values 0, 1, 2, ..., 9 can be assigned in sequence to any type of fuel (ten in total) used by the thermal plants of FIXSYS and/or VARSYS. Modules 5, 6, and 7 of WASP-IV can handle up to thirteen "fuel" types, with the additional two being the composite hydro plant types, and one for composite pumped storage projects, if pumped storage projects are specified in FIXSYS and/or VARSYS. The code number of the composite hydro plants (and pumped storage projects) are assigned automatically by the program so that it is not necessary to give these code numbers in FIXSYS or VARSYS (see description of input data lines 9 and 10 below).

In the sample problem the *code number*, *code name* and *description* of thermal fuel types are as follows:

Code Number	*Code name*	*Description*
0	NUCL	Nuclear Plants
1	LIG1	Lignite-1 Plants
2	LIG2	Lignite-2 Plants
3	COAL	Coal Plants
4	FOIL	Oil Plants
5	GTGO	Gas Turbines Gas-oil
6	NGAS	Natural Gas Plants

Lines 9 and 10 in Fig. 4.1 are two type-Z records giving a code name and a description of each composite hydroelectric plant used in FIXSYS and/or VARSYS (in our sample problem the two composite hydro plants are used in both modules). The same code name must be given in the type-A record of FIXSYS and when describing the hydro projects (if any) of VARSYS. The two type-Z records must be always included in the FIXSYS input data even if no hydroelectric plants are considered in the study (in this case these records will be blank). If one type of composite hydro plant is to be used in FIXSYS and/or VARSYS, the corresponding type-Z record must contain the plant code name and description, as this information is required by module 7 (REPROBAT) for writing the report of the study.

```
DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL    7
  0 NUCL NUCLEAR PLANTS
  1 LIG1 LIGNITE-1 PLANTS
  2 LIG2 LIGNITE-2 PLANTS
  3 COAL COAL PLANTS
  4 FOIL OIL PLANTS
  5 GTGO GAS TURBINES GAS-OIL
  6 NGAS NATURAL GAS PLANTS
   HYD1 HYDRO PLANTS GROUP 1
   HYD2 HYDRO PLANTS GROUP 2
1998  4  6  3 HYD1  .55 HYD2  .55  .45  .3  .25
FLG1 4 150. 270. 3300. 2850. 600.  0. 110 10. 56 280.    4.06 4.9
  1800.0    2.5    1.0  {heat values and polluting % for the plants}
FLG2 9 150. 276. 2900. 2550. 495.  0. 210 8.9 56 280.    1.91 2.0
  1800.0    2.5    1.0  {heat values and polluting % for the plants}
FCOA 1 400. 580. 2800. 2300. 800.  0. 310 8.0 48 600.    2.92 5.0
  6000.0    1.0    2.0
FOIL 7 80. 145. 2450. 2150.  0. 833. 410 7.3 42 140.    4.57 1.6
  10000.0    1.0    3.0
F-GT 4 50. 50. 3300. 3300. 420.  0. 5 0 6.0 42 50.    8.35 1.6
  10000.0    0.5    0.5
F-CC 1 87. 174. 2048. 2048.  0.1266. 6 0 15. 28 180.    2.1 5.0
  11000.0    0.0    0.5
 4            SO2 NOx 1 2 3 1 0 {ngrouplm, ipnlt, pnlt-lolp, -ens, emisname, measindx}
  6                   {real emis.1: number of plants involved}
  6                   {real emis.1: number of plants involved}
  1  0  10000.                        { 1 plant involved in group limit # 1}
  8
  5  0   600.                        { 5 plants involved in group limit # 2}
  3  4  5  6  7
  6  0   1000.                        { 6 plants involved in group limit # 3}
  2  0  20000.                        { 2 plants involved in group limit # 4}
  3  4
  2
 FHY1 HYD1 1250. 2000.
1200. 460. 850. 950. 470. 700.1450. 440. 900.
1250. 460. 860.1000. 470. 720.1500. 440. 950.
1350. 460. 890.1100. 470. 740.1600. 440.1000.
1400. 460. 920.1200. 470. 780.1700. 440.1250.
  2
 FHY2 HYD1 100. 10.4
 50.9  0. 85. 41.8  0. 75. 60.1  0. 90.
 50.9  0. 85. 41.8  0. 75. 60.1  0. 90.
 50.9  0. 85. 41.8  0. 75. 60.1  0. 90.
 50.9  0. 85. 41.8  0. 75. 60.1  0. 90.
  2
 FHY3 HYD1 300. 168.5
 84.1  0. 240. 73.2  0. 220. 110.  0. 260.
 84.1  0. 240. 73.2  0. 220. 110.  0. 260.
 84.1  0. 240. 73.2  0. 220. 110.  0. 260.
 84.1  0. 240. 73.2  0. 220. 110.  0. 260.
  2
 FHY4 HYD2 66.4 40.7
 25.2  0. 62. 12.1  0. 50. 38.2  0. 66.
 25.2  0. 62. 12.1  0. 50. 38.2  0. 66.
 25.2  0. 62. 12.1  0. 50. 38.2  0. 66.
 25.2  0. 62. 12.1  0. 50. 38.2  0. 66.
  2
 FHY5 HYD2 140. 102.
 76.9  0. 125. 57.8  0. 110. 95.9  0. 140.
 76.9  0. 125. 57.8  0. 110. 95.9  0. 140.
 76.9  0. 125. 57.8  0. 110. 95.9  0. 140.
 76.9  0. 125. 57.8  0. 110. 95.9  0. 140.
  1      (END OF YEAR 1998)
  3
  5  1
  1      (END OF YEAR 1999)
  2
 FHY6 HYD2 180. 92.4
 83.7  0. 155. 68.7  0. 140.103.6  0. 165.
 83.7  0. 155. 68.7  0. 140.103.6  0. 165.
 83.7  0. 155. 68.7  0. 140.103.6  0. 165.
 83.7  0. 155. 68.7  0. 140.103.6  0. 165.
  3
  8  1
  1      (END OF YEAR 2000)
  3
  8  1
  1      (END OF YEAR 2001)
  2
 FH-1 HYD1-1250. 2000.
1200. 460. 850. 950. 470. 700.1450. 440. 900.
1250. 460. 860.1000. 470. 720.1500. 440. 950.
1350. 460. 890.1100. 470. 740.1600. 440.1000.
1400. 460. 920.1200. 470. 780.1700. 440.1250.
  1      (END OF YEAR 2002)
```

Figure 4.1. (page 1) WASP-IV FIXSYS input for the sample problem.

```
 3
 3 -1
 1      (END OF YEAR 2003)
 1      (END OF YEAR 2004)
 1      (END OF YEAR 2005)
 3
 4 -1
 1      (END OF YEAR 2006)
 2
FH-2 HYD1 -100. 10.4
50.9  0. 85. 41.8  0. 75. 60.1  0. 90.
50.9  0. 85. 41.8  0. 75. 60.1  0. 90.
50.9  0. 85. 41.8  0. 75. 60.1  0. 90.
50.9  0. 85. 41.8  0. 75. 60.1  0. 90.
 1      (END OF YEAR 2007)
 1      (END OF YEAR 2008)
 3
 4 -1
 3
 7 -1
 1      (END OF YEAR 2009)
 1      (END OF YEAR 2010)
 1      (END OF YEAR 2011)
 3
 6 -1
 1      (END OF YEAR 2012)
 3
 6 -1
 1      (END OF YEAR 2013)
 3
 3 -1
 3
 4 -1
 1      (END OF YEAR 2014)
 1      (END OF YEAR 2015)
 1      (END OF YEAR 2016)
 1      (END OF YEAR 2017)
```

Figure 4.1. (page 2) WASP-IV FIXSYS input for the sample problem.

The *code name* and *description* of the two composite hydro plants used for our sample problem are as follows:

Code name	*Description*
HYD1	Hydro Plants Group 1
HYD2	Hydro Plants Group 2

Apart from the restrictions mentioned above, the code number, code name and description of the fuel types and code name and description of composite hydro plants to be used for a case study may be assigned by the user at his/her own convenience while respecting the corresponding fields and formats.

The next input line in Fig. 4.1 is a type-A record specifying the *first year of study* (1998 in this case); the *number of periods* in each year (4); the *number of thermal plants* in FIXSYS (i.e. the number of type-B records to be read next, 6 in this case); the *number of hydrological conditions* (3); the *code names of the two composite hydroelectric* plants (HYD1 and HYD2, respectively) and their associated *operation and maintenance costs* (0.55 and 0.55 $/kW-month); and finally, the *probabilities of the hydrological conditions* (0.45, 0.3 and 0.25) summing up to 1.0. (see Table 4.1 (page 1) to fill in the data on the type-A record).

The following lines are six groups of type-B and type-Ba records describing each thermal plant. Each group contains code name and 14 parameters on type-B record, and three additional parameters on type-Ba record for the thermal plant being described (see Table 4.1 (page 2) to fill in the type-B and type-Ba records and for explanation of each piece of information required).

After the last group of type-B and type-Ba records, the next line is a type-C record describing the number of group limitations (NGROUPLM=4 in this case), index for changing default penalty factors (IPNLT=0, not changed in this case), two values of penalty factors (blank in this case), names of two types of pollutants, default are SO2 and NOx, and lastly the index numbers of the type of group limits imposed, (1 2 3 1 0 in the present case means that the four group limits imposed are: 1st group limit: fuel limit; 2nd group limit: SO2; 3rd group limit: NOx, and 4th group limit: fuel limit also, whereas 0 stands for unused 5th group limit). (For description of types group limits, see page 3 of table 4.1).

The next lines are two type-Da records; specifying number of plants involved in real emissions of the two pollutant described on type-C record, (in this case, both type-Da records contain 6, which means all thermal plants, therefore no type-Db record is needed for both of the pollutants).

The following lines are as many sets of type-Ea and type-Eb records as the number of group limitations specified on type-C record (four sets in this case). Each set contains, on type-Ea record, the number of plants taking role in this group limit, index for changing period fractions, the annual value of the limit and period fractions if default is not used; and on type-Eb record, the index numbers of plants taking role in this group limit. In our sample problem, the first such set contains 1 0 10000 on type-Ea record and 8 on type-Eb record. This means that 1 plant is taking role in the first group limit (which is fuel limit), 0 for default period fractions and 10000 for annul fuel use limit. The second set of type-Ea and -Eb records contain 5 0 600 on type-Ea record and 3 4 5 6 7 on type-Eb record. This means that 5 plants are taking role in 2nd group limit (which is defined as SO2 on type-C record), 0 for default period fractions and 600 for annual emission limit of SO2; and plants number 3, 4, 5, 6, 7 are taking role in this limit. The third such set is only type-Ea record, because all plants in FIXSYS are taking role in the 3rd group limit (which is defined as NOx on type-C record). It contains 6 0 1000, indicating that 6 plants (all plants) are taking role in this group limit, 0 for default period fractions and 1000 for annual emission limit on NOx. The forth set of such records are for the 4th group limit (which is defined as fuel limit on type-C record). The type-Ea record of this set contains 2 0 20000, which means that 2 plants are taking role in this group limit, 0 for default period fractions and 20000 as annual limit; the type-Eb record containing 3 4 indicates that plants number 3 and 4 are the two plants taking role in this group limit.

After the last set of type-Ea and type Eb records, a type-1 record must follow to tell the computer what to do next. In general these records would be interpreted as follows: a type-1 INDEX=1 record means that no more data for current year follows and that the program should proceed to execute the calculations for the year; an INDEX=2 means that type-2a and type-2b records follow containing the parameters of a hydroelectric project to be added (or retired) in the system; INDEX=3 means that one type-3 record follows indicating an addition (or retirement) of units to (or from) a thermal station; and INDEX=4 means that a pumped storage project to be added (or retired) in the system. For the first year of study, however, it is not recommended to use the retirement option for thermal or hydro/pumped storage plants.

In Fig. 4.1 the first type-1 record is with INDEX=2 and the next line is a type-2a record. (Consult Table 4.1 (page 4 and 5) to fill in correctly the type-2a and type-2b data records). This corresponds to hydroelectric project FHY1 of plant type code name HYD1, installed capacity 1250. (MW) and energy storage capacity 2000. (GWh). The code name on this line tells the computer that this project is of the hydro plants group 1. The subsequent lines are four type-2b records containing information for hydro project FHY1 applicable in each of the four periods of the year and the three hydrological conditions specified; there is one type-2b record for each period and each record gives information for all hydrological conditions considered.

For example, the first line in this group corresponds to period 1 and contains in columns 1 to 15 the data for the first hydrological condition (1200. GWh of inflow energy; 460. GWh minimum out flow; and 850. MW available capacity); in cols. 16-30 the data for the second hydrological condition (950. GWh inflow energy, 470. GWh minimum out flow and 700. MW available capacity); and in cols. 31-45 the data for the last hydro-condition (1450. GWh inflow energy, 440. GWh min. out flow and 900. MW available capacity). Columns 46-75 (reserved in this record type for hydrological conditions 4 and 5) are blank since only 3 hydro-conditions are defined for the study.

In a similar way, the next three lines specify the data applicable to hydro project FHY1 in periods 2, 3, and 4, respectively, and for each of the hydro-conditions used.

The next groups of input lines consist of one type-1 INDEX=2 record followed by one type-2a and four type-2b records. The first two groups provide the data for hydro projects FHY2 and FHY3, respectively, of plant code name HYD1. Similarly, the next two groups are used to specify the data for projects FHY4 and FHY5 of plant code name HYD2. Each group of type-2a and type-2b records contain similar information as previously described for hydro project FHY1[1].

The next line is the first type-1 INDEX=1 record meaning end of the year, in other words, that all information for the current year, 1998 in this case, has been completed. As can be seen in Fig. 4.1, this record (and all type-1 INDEX=1 records) have been identified with the corresponding year. As stated in Section 3.3 this information is not necessary but has been introduced for convenience.

The input data for the next year of study follows. These consist of one type-1 INDEX=3 record followed by one type-3 record, indicating that changes are to be made to the number of units of the thermal plants in FIXSYS in this year (1999). The type-3 record indicates on columns 1-4 of the record, the thermal plant number in the FIXSYS list for which an addition (+) or a retirement (-) of one or more units is to be made. For example in our case, the type-3 record contains 5 in column 4 and 1 in column 8, meaning that one unit is to be added to plant number 5 (FCOA). The next line is a type-1 INDEX=1 record indicating end of data for current year (1999). Notice that the thermal plant number to be used is the sequence number increased by two (position 1 and 2 are reserved for the base blocks of the two hydro types).

Next is a type-1 record with INDEX=2, followed by a set of type 2a and 2b record for a hydro project FHY6 of HYD2 type to be added in the year 2000. After this set, there is a type-1 record with INDEX=3 followed by type-3 record for addition of one unit of thermal plant number 8, and finally, a type-1 with INDEX=1 record to indicate end of current year data.

The data for year 2001 show addition of one more unit of thermal plant 8. In the year 2002 there is a set of type-2a and 2b records for hydro project FH-1. This set has been used to retire one hydro project already included in the first year (FHY1), as all the values are same except that the installed capacity is negative, which means that the hydro project FH-1 will retire in this year.

[1] It should be emphasized that the ordering of period and hydro-condition data must be consistent from project to project; otherwise it will lead to wrong calculations of the characteristics of the composite hydro plants. Also, as mentioned in Section 3.1, the ordering of the periods must be consistent with the order used in Modules 1 and 3.

In year 2003, there is retirement of one unit of thermal plant number 3, indicated with type-1 record with INDEX=3 , followed by type-3 record. The rest of the input data for the remaining years follows a similar pattern; when no changes are to be made in the composition of the Fixed System, only one type-1 INDEX=1 record is included in the input for that year, and when a change is required it is effected through same procedure as explained above for other years.

4.3.2. Printout

Figure 4.2 illustrates parts of the printout resulting from execution of the FIXSYS for the sample problem. Page 1 is the cover page printed by FIXSYS to identify the run. This contains: the *title of the study* and a list of the different "fuel" types used in the study, starting with the thermal plants fuel types followed by the two composite hydroelectric plants and composite pumped storage plant. Each list shows the *fuel type*, *code name*, and *description*. At the end of the composite hydroelectric plants, the output lists the hydro plant cases (mode of operation) considered by the program. These modes of operation are identified by a KEY (number 1 to 7) and the description of each case.

Each time input data for a hydroelectric project (addition or retirement) are read in, the program calls a special subroutine (HYRUN) to calculate the mode of operation of the project for each period and hydro-condition defined. This is determined by HYRUN using the given input data and according to a set of main assumptions. Using this information, HYRUN distributes the available energy for the hydro project in "base" and "peak" portions as required for simulation purposes. The resulting base and peak capacities of the hydro project are included in the FIXSYS printout for the corresponding year, identifying with the corresponding KEY the mode of operation of the project. This should be checked by the user to make sure that the project "operates" in the intended mode and that no errors exist in the input data (particularly for KEY=5 and KEY=6).

Next on the cover page is information about composite pumped storage plants; if such plants are specified in the system, the module 5 (MERSIM) of WASP-IV, while simulating the system, will merge two composite hydro types into one, renaming it HYDR and will use the other space for composite pumped storage plant.

The printout continues with a list of the record image of the input data information for the first year of study (1998), including: *general information* for the run; *thermal plant characteristics*, *information related to group limitations, the changes made to the composite hydroelectric plants and changes made to the composite pumped storage plant for this year*. This information has been included in the output to assist user checking correctness of the inputs supplied by him/her. Pages 2 and 3 of Fig. 4.2 illustrates this portion of the output for the case example.

The next piece of information produced as output corresponds to the FIXSYS results for the year. Pages 4 and 5 of Fig. 4.2 show these results and the Fixed System description for year 1998.

This part of the output starts with the number of periods and hydro-conditions; followed by the input characteristics and calculated parameters of the thermal plants which are displayed in a table. **Column 1** of the table gives the plant number (starting with 3 and finishing with NTHPL+2, in this case 8; plant NTHPL+3 will be the first of the plants in VARSYS). **Column 2** gives the code name of the thermal plants and **Column 3** the number of sets in this year.

Columns 4 to 16 are a repetition of the characteristics of the respective units. Finally, the **six right-hand columns** of the table are output values which are actually calculated by FIXSYS; they give the full load heat rate and the domestic and foreign components of unit generation costs at base load and full load; the last column (**Col. 22**) gives the total, domestic plus foreign, unit generation costs at full load. This value is used by the program to define the economic loading order also included in the printout.

Following the table of thermal plants, a summary of thermal capacity by fuel type is included in the printout (see page 4). In this case, no nuclear plants are included in FIXSYS[2], thus a 0 is given for the nuclear fuel; 1080 MW for fuel type 1 (LIG1), 2484 MW of fuel type 2 (LIG2), 580 MW of fuel type 3 (COAL), 1015 MW of fuel type 4 (FOIL), 200 MW of gas turbines fuel type 5 (GTGO), and 174 MW for fuel type 6 (NGAS). The total thermal capacity in this year is of 5533 MW.

Next, the printout contains information on real emissions (the number, type and plants involved for each pollutant), followed by information on group limitations.

Next, the program reports the economic loading order of the thermal plants used, in ascending order of total full load generation cost (col. 22 of thermal plant table). This information, together with the similar one from VARSYS will be used by CONGEN to calculate the basic economic loading order of the combined FIXSYS and VARSYS plants that is required by MERSIM.

Following the thermal plant information are characteristics of hydro projects (if any) of each plant type (as shown on page 5 of Figure 4.2). In this case hydro type A (code name HYD1) with operation and maintenance costs 0.55 $/kW-month includes 3 projects. For each project, the printout shows the base and peak capacities (MW), peaking energy GWh), hours per day (during working days) in which the plant can provide peaking energy and finally the mode of operation calculated by HYRUN. This information is given for each period and hydro condition defined by the user.

Once the calculated information for the individual characteristics of all projects of a hydro plant type has been reported, the program prints the characteristics (capacities and energies per period and hydro-condition) of the composite hydro plant. In this case, 3 projects are composed in hydro plant type A (HYD1) with total installed capacity 1650. MW. The base and peak capacity, available energy for peaking and total available capacity of the composite hydro plant are also printed for each period and each hydro-condition. The above values are calculated as the algebraic sum of the individual values for the hydro projects composed; retirements being handled as negative capacities and energies. For the composite hydro plant no KEY of operation type is given since this only applies for individual projects.

Next information on page 5 corresponds to the characteristics of those individual projects composed in the hydro plant type B (HYD2), followed by the parameters of the composite hydro plant.

A similar output to the one described for year 1998 and shown in pages 2 to 5 of Fig. 4.2 is produced for each year of the study, starting with the listing of the record image of the input data for the respective year. If no change is to be made to the FIXSYS for the year, the program

[2] The thermal fuel type NUCL, needs to be defined in FIXSYS since it is expected to be used in VARSYS.

simply prints INDEX=1 and then proceeds to print the Fixed System description for the year, but without repeating the individual characteristics of the hydro projects composed in each plant type. If a change is made to FIXSYS in the year, the program prints the record image of input data and then proceeds with the report for the year as above. If the change concerns only thermal additions or retirements, the new number of sets of the corresponding plant will be printed in column 3 of the table of thermal plants and the summary of thermal capacity is revised accordingly.

If any change is made to the composite pumped storage plant and/or composite hydro plants (additions or retirements), the program will print first the corresponding record images along with any other input data and then the report with the description of the fixed system for the year. The latter will include the characteristics calculated by the program for the pumped storage/hydro project being added or retired, followed by the resulting parameters for the composite pumped storage/hydro plant affected.

The FIXSYS printout should be checked with great care to make sure that all reported numbers are those intended by the user. Each number is to be checked carefully as some errors will not be identified as such by the WASP code until the CONGEN or MERSIM modules are run (e.g. inconsistencies between LOADSY and FIXSYS input data), and some other errors will never be identified by the computer (e.g. the addition or retirement of some units from the "wrong" plant). At least some internal inconsistencies in FIXSYS input data will result in interruption of program execution and the printing of an error message in the output. Some other inconsistencies will result in an error message being printed (without stopping program execution) to warn the user about the potential sources of errors in his/her input data. Error and warning messages applicable to FIXSYS are described in Chapter 13.

```
       WASP COMPUTER PROGRAM PACKAGE

            FIXSYS MODULE

             CASE STUDY

  DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL

**********************************************************
*          THERMAL  PLANTS          *
*   TYPE  NAME  DESCRIPTION             *
*                            *
*    0  NUCL  NUCLEAR PLANTS           *
*    1  LIG1  LIGNITE PLANTS           *
*    2  LIG2  LIGNITE PLANTS           *
*    3  COAL  COAL PLANTS            *
*    4  FOIL  OIL PLANTS            *
*    5  GTGO  GAS TURBINES GAS-OIL        *
*    6  NGAS  NATURAL GAS PLANTS         *
*                            *
**********************************************************
*         HYDROELECTRIC PLANTS         *
*   TYPE  NAME  DESCRIPTION             *
*                            *
*    A  HYD1  HYDRO PLANTS GROUP 1        *
*    B  HYD2  HYDRO PLANTS GROUP 2        *
*                            *
* IDENTIFICATION OF HYDROPLANT CASES:        *
* KEY         DESCRIPTION          *
*  1  RUN OF RIVER-RESERVOIR EMPTY IN LESS THAN 2 HRS *
*  2  DAILY REGULATING RESERVOIR           *
*  3  WEEKLY REGULATING RESERVOIR          *
*  4  SEASONAL REGULATING RESERVOIR         *
*  5  INFLOW ENERGY EXCEEDS PLANT GENER. CAPABILITY  *
*  6  MINIMUM REQUIRED ENERGY EXCEEDS INFLOW ENERGY  *
*  7  PLANT OPERATES IN PEAK MORE THAN 5 DAYS/WEEK   *
**********************************************************
*         PUMPED STORAGE PLANTS         *
*   TYPE  NAME  DESCRIPTION             *
*      PUMP  COMPOSITE P-S PLANT         *
*                            *
*  FOR SIMULATION OF SYSTEM GENERATION ONLY:      *
*                            *
*   - SYSTEM WITHOUT PUMPED STORAGE PLANTS       *
*      TWO HYDRO TYPES A, B           *
*                            *
*   - SYSTEM WITH  PUMPED STORAGE PLANTS       *
*      HYDR COMPOSITE A+B PLANT          *
*      PUMP COMPOSITE P-S PLANT          *
*                            *
**********************************************************
```

Figure 4.2. (page 1) FIXSYS printout for the sample problem — cover page.

```
FIXED SYSTEM INPUT DATA INFORMATION OF YEAR 1998

    INIT.  NO.OF NO.THERMAL HYDRO *** HYDRO PLANT TYPES ***    PROBABILITY OF HYDRO-CONDITIONS
    YEAR  PERIODS PLANTS  COND. NAME  O&M   NAME  O&M   1    2    3    4    5

    1998    4    6    3  HYD1  0.55  HYD2  0.55  0.450  0.300  0.250  0.000  0.000

                HEAT RATE   FUEL COSTS     S FRCD
        NO. MIN.  CAP-  BASE  AVGE    CENTS/      P OUTAGE DAYS MAIN O&M  O&M
        OF LOAD  CITY  LOAD  INCR  MILLION KCAL FUEL R RATE SCHL CLAS (FIX) (VAR) HEAT VALUE  EMISSION
FACTOR
     NAME SETS MW   MW   KCAL/ KWH  DMSTC  FORGN TYPE %  %  MAIN  MW $/KWM $/MWH  KCAL/KG    WT % OF FUEL

     FLG1  4 150.  270.  3300. 2850. 600.0   0.0  1 10 10.0  56  280. 4.06 4.90  1800.00   2.50   1.00
     FLG2  9 150.  276.  2900. 2550. 495.0   0.0  2 10  8.9  56  280. 1.91 2.00  1800.00   2.50   1.00
     FCOA  1 400.  580.  2800. 2300. 800.0   0.0  3 10  8.0  48  600. 2.92 5.00  6000.00   1.00   2.00
     FOIL  7  80.  145.  2450. 2150.  0.0  833.0  4 10  7.3  42  140. 4.57 1.60  10000.00   1.00   3.00
     F-GT  4  50.  50.  3300. 3300. 420.0   0.0  5  0  6.0  42  50. 8.35 1.60  10000.00   0.50   0.50
     F-CC  1  87.  174.  2048. 2048.  0.0 1266.0  6  0 15.0  28  180. 2.10 5.00  11000.00   0.00   0.50

 NGROUPLM IPNLT PNLTLOLP PNLTENS EMISNAME  MEASIND
   4   1   0.000  1.000  SO2 NOx  1  2  3  1

 *** REAL EMISSION ***

 NPLANTS  6

 NPLANTS  6

 *** GROUP LIMITATION ***

       INDIV  GRLIMIT
 NPLANTS  1  0   10000.0
 PLANTIND  8

       INDIV  GRLIMIT
 NPLANTS  5  0    600.0
 PLANTIND  3  4  5  6  7

       INDIV  GRLIMIT
 NPLANTS  6  0   1000.0

       INDIV  GRLIMIT
 NPLANTS  2  0   20000.0
 PLANTIND  3  4
```

Figure 4.2. (page 2) FIXSYS printout for the sample problem. Input information for year 1998.

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INDEX  2

PROJECT  1 (NAME: FHY1) OF HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 1250. MW  REG. ENERGY: 2000.00 GWH

 HYDRO-CONDITION 1  HYDRO-CONDITION 2  HYDRO-CONDITION 3
 EA  EMIN  MWC  EA  EMIN  MWC  EA  EMIN  MWC

1200.0 460.0 850.0 950.0 470.0 700.0 1450.0 440.0 900.0
1250.0 460.0 860.0 1000.0 470.0 720.0 1500.0 440.0 950.0
1350.0 460.0 890.0 1100.0 470.0 740.0 1600.0 440.0 1000.0
1400.0 460.0 920.0 1200.0 470.0 780.0 1700.0 440.0 1250.0

INDEX  2

PROJECT  2 (NAME: FHY2) OF HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 100. MW  REG. ENERGY:  10.40 GWH

 HYDRO-CONDITION 1  HYDRO-CONDITION 2  HYDRO-CONDITION 3
 EA  EMIN  MWC  EA  EMIN  MWC  EA  EMIN  MWC

 50.9  0.0  85.0  41.8  0.0  75.0  60.1  0.0  90.0
 50.9  0.0  85.0  41.8  0.0  75.0  60.1  0.0  90.0
 50.9  0.0  85.0  41.8  0.0  75.0  60.1  0.0  90.0
 50.9  0.0  85.0  41.8  0.0  75.0  60.1  0.0  90.0

INDEX  2

PROJECT  3 (NAME: FHY3) OF HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 300. MW  REG. ENERGY: 168.50 GWH

 HYDRO-CONDITION 1  HYDRO-CONDITION 2  HYDRO-CONDITION 3
 EA  EMIN  MWC  EA  EMIN  MWC  EA  EMIN  MWC

 84.1  0.0 240.0  73.2  0.0 220.0 110.0  0.0 260.0
 84.1  0.0 240.0  73.2  0.0 220.0 110.0  0.0 260.0
 84.1  0.0 240.0  73.2  0.0 220.0 110.0  0.0 260.0
 84.1  0.0 240.0  73.2  0.0 220.0 110.0  0.0 260.0

INDEX  2

PROJECT  1 (NAME: FHY4) OF HYDRO TYPE *** HYD2 *** INSTALLED CAP.:  66. MW  REG. ENERGY:  40.70 GWH

 HYDRO-CONDITION 1  HYDRO-CONDITION 2  HYDRO-CONDITION 3
 EA  EMIN  MWC  EA  EMIN  MWC  EA  EMIN  MWC

 25.2  0.0  62.0  12.1  0.0  50.0  38.2  0.0  66.0
 25.2  0.0  62.0  12.1  0.0  50.0  38.2  0.0  66.0
 25.2  0.0  62.0  12.1  0.0  50.0  38.2  0.0  66.0
 25.2  0.0  62.0  12.1  0.0  50.0  38.2  0.0  66.0

INDEX  2

PROJECT  2 (NAME: FHY5) OF HYDRO TYPE *** HYD2 *** INSTALLED CAP.: 140. MW  REG. ENERGY: 102.00 GWH

 HYDRO-CONDITION 1  HYDRO-CONDITION 2  HYDRO-CONDITION 3
 EA  EMIN  MWC  EA  EMIN  MWC  EA  EMIN  MWC

 76.9  0.0 125.0  57.8  0.0 110.0  95.9  0.0 140.0
 76.9  0.0 125.0  57.8  0.0 110.0  95.9  0.0 140.0
 76.9  0.0 125.0  57.8  0.0 110.0  95.9  0.0 140.0
 76.9  0.0 125.0  57.8  0.0 110.0  95.9  0.0 140.0

INDEX  1
```

Figure 4.2. (page 3) FIXSYS printout for the sample problem. Input information for year 1998.

```
FIXED SYSTEM OF YEAR 1998 (YEAR NUMBER 1 OF THE STUDY)
              4 PERIODS
              3 HYDRO CONDITIONS
HEAT RATE   FUEL COSTS     S FRCD             FLD   UNIT GENERATION
        NO. MIN.  CAP-  BASE  AVGE    CENTS/      P OUTAGE DAYS MAIN O&M  O&M HEAT RT  COSTS ($/MWH)
 SEQ.     OF LOAD  CITY  LOAD  INCR  MILLION KCAL FUEL R RATE SCHL CLAS (FIX)  (VAR) KCAL/ BASE BASE FLD FLD
FLD
 NO.  NAME SETS MW   MW   KCAL/ KWH  DMSTC  FORGN TYPE %  %  MAIN  MW $/KWM $/MWH  KWH  DOM FRGN DOM FRGN
TOT
  3   FLG1  4 150.  270.  3300. 2850. 600.0   0.0  1 10 10.0  56  280. 4.06 4.90 3100. 24.7 0.0 23.5 0.0
23.5
  4   FLG2  9 150.  276.  2900. 2550. 495.0   0.0  2 10  8.9  56  280. 1.91 2.00 2740. 16.4 0.0 15.6 0.0
15.6
  5   FCOA  1 400.  580.  2800. 2300. 800.0   0.0  3 10  8.0  48  600. 2.92 5.00 2645. 27.4 0.0 26.2 0.0
26.2
  6   FOIL  7  80.  145.  2450. 2150.  0.0  833.0  4 10  7.3  42  140. 4.57 1.60 2316.  1.6 20.4 1.6 19.3
20.9
  7   F-GT  4  50.  50.  3300. 3300. 420.0   0.0  5  0  6.0  42  50. 8.35 1.60 3300. 15.5 0.0 15.5 0.0 15.5
  8   F-CC  1  87.  174.  2048. 2048.  0.0 1266.0  6  0 15.0  28  180. 2.10 5.00 2048.  5.0 25.9 5.0 25.9
30.9

 THERMAL CAPACITY SUMMARY: FUEL DESCRIPTION       MW
              TYPE
               0  NUCLEAR PLANTS      0.
               1  LIGNITE PLANTS     1080.
               2  LIGNITE PLANTS     2484.
               3  COAL PLANTS       580.
               4  OIL PLANTS       1015.
               5  GAS TURBINES GAS-OIL  200.
               6  NATURAL GAS PLANTS   174.
               7  NOT APPLICABLE      0.
               8  NOT APPLICABLE      0.
               9  NOT APPLICABLE      0.
                     TOTAL     5533.

 *** REAL EMISSION ***
NO. TYPE PLANTS INVOLVED (PLANT SEQUENCE NUMBER)

 1 SO2  * * *  A L L  * * *
 2 NOx  * * *  A L L  * * *

 *** GROUP LIMITATION ***

 PENALTY FACTOR : LOLP =  0.000
          ENS =  1.000

 NO. TYPE MEASIND UNIT LIMIT/YR PERIOD LIMITS
 1 FUEL  1   kT  10000.0 DISTRIBUTION / PERIOD CALCULATED
 2 SO2   2   kT   600.0 DISTRIBUTION / PERIOD CALCULATED
 3 NOx   3   kT   1000.0 DISTRIBUTION / PERIOD CALCULATED
 4 FUEL  1   kT  20000.0 DISTRIBUTION / PERIOD CALCULATED

 NO. TYPE PLANTS INVOLVED (PLANT SEQUENCE NUMBER)
 1 FUEL  8
 2 SO2   3  4  5  6  7
 3 NOx  * * *  A L L  * * *
 4 FUEL  3  4

 ECONOMIC LOADING ORDER DEFINED IN ASCENDING ORDER OF TOTAL FULL LOAD UNIT GENERATION COSTS

  7  4  6  3  5  8
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Figure 4.2. (page 4) FIXSYS printout for the sample problem. Fixed system description for year 1998.

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 FOLLOWING HYDRO PROJECTS ARE OF TYPE *** HYD1 ***  O&M (FIX) =  0.55 $/KW-MONTH
 ************************************************************************************************************************
PROJECT 1  INSTALLED CAP.: 1250. MW  REG. ENERGY: 2000.00 GWH

    HYDRO-CONDITION 1  *   HYDRO-CONDITION 2  *   HYDRO-CONDITION 3  *
  BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY
  MW  MW  GWH  HR    MW  MW  GWH  HR    MW  MW  GWH  HR

  210. 640. 740. 17.7 4 215. 485. 480. 15.2 4 201. 699. 1010. 22.2 4
  210. 650. 790. 18.6 4 215. 505. 530. 16.1 4 201. 749. 1060. 21.7 4
  210. 680. 890. 20.1 4 215. 525. 630. 18.4 4 201. 799. 1160. 22.3 4
  210. 710. 940. 20.3 4 215. 565. 730. 19.8 4 201. 1049. 1260. 18.4 4

 PROJECT 2  INSTALLED CAP.: 100. MW  REG. ENERGY:  10.40 GWH
HYDRO-CONDITION 1  *   HYDRO-CONDITION 2  *   HYDRO-CONDITION 3  *
  BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY
  MW  MW  GWH  HR    MW  MW  GWH  HR    MW  MW  GWH  HR

   0.  85.  51. 9.2 4  0.  75.  42. 8.6 4  0.  90.  60. 10.2 4
   0.  85.  51. 9.2 4  0.  75.  42. 8.6 4  0.  90.  60. 10.2 4
   0.  85.  51. 9.2 4  0.  75.  42. 8.6 4  0.  90.  60. 10.2 4
   0.  85.  51. 9.2 4  0.  75.  42. 8.6 4  0.  90.  60. 10.2 4

 PROJECT 3  INSTALLED CAP.: 300. MW  REG. ENERGY: 168.50 GWH

    HYDRO-CONDITION 1  *   HYDRO-CONDITION 2  *   HYDRO-CONDITION 3  *
  BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY
  MW  MW  GWH  HR    MW  MW  GWH  HR    MW  MW  GWH  HR

   0. 240.  84. 5.4 4  0. 220.  73. 5.1 4  0. 260. 110. 6.5 4
   0. 240.  84. 5.4 4  0. 220.  73. 5.1 4  0. 260. 110. 6.5 4
   0. 240.  84. 5.4 4  0. 220.  73. 5.1 4  0. 260. 110. 6.5 4
   0. 240.  84. 5.4 4  0. 220.  73. 5.1 4  0. 260. 110. 6.5 4

 3 PROJECTS COMPOSED IN HYDRO TYPE *** HYD1 ***   INSTALLED CAP.: 1650. MW
 ************************************************   ************************

    HYDRO-CONDITION 1  *   HYDRO-CONDITION 2  *   HYDRO-CONDITION 3  *
  BASE PEAK P-ENG AVAIL  BASE PEAK P-ENG AVAIL  BASE PEAK P-ENG AVAIL
  MW  MW  GWH  MW    MW  MW  GWH  MW    MW  MW  GWH  MW

  210. 965. 875. 1175.  215. 780. 595. 995.  201. 1049. 1180. 1250.
  210. 975. 925. 1185.  215. 800. 645. 1015.  201. 1099. 1230. 1300.
  210. 1005. 1025. 1215.  215. 820. 745. 1035.  201. 1149. 1330. 1350.
  210. 1035. 1075. 1245.  215. 860. 845. 1075.  201. 1399. 1430. 1600.

 FOLLOWING HYDRO PROJECTS ARE OF TYPE *** HYD2 ***  O&M (FIX) =  0.55 $/KW-MONTH
 ************************************************************************************************************************
PROJECT 1  INSTALLED CAP.:  66. MW  REG. ENERGY:  40.70 GWH
HYDRO-CONDITION 1  *   HYDRO-CONDITION 2  *   HYDRO-CONDITION 3  *
  BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY
  MW  MW  GWH  HR    MW  MW  GWH  HR    MW  MW  GWH  HR

   0.  62.  25. 6.2 4  0.  50.  12. 3.7 4  0.  66.  38. 8.9 4
   0.  62.  25. 6.2 4  0.  50.  12. 3.7 4  0.  66.  38. 8.9 4
   0.  62.  25. 6.2 4  0.  50.  12. 3.7 4  0.  66.  38. 8.9 4
   0.  62.  25. 6.2 4  0.  50.  12. 3.7 4  0.  66.  38. 8.9 4

 PROJECT 2  INSTALLED CAP.: 140. MW  REG. ENERGY: 102.00 GWH

    HYDRO-CONDITION 1  *   HYDRO-CONDITION 2  *   HYDRO-CONDITION 3  *
  BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY
  MW  MW  GWH  HR    MW  MW  GWH  HR    MW  MW  GWH  HR

   0. 125.  77. 9.4 4  0. 110.  58. 8.1 4  0. 140.  96. 10.5 4
   0. 125.  77. 9.4 4  0. 110.  58. 8.1 4  0. 140.  96. 10.5 4
   0. 125.  77. 9.4 4  0. 110.  58. 8.1 4  0. 140.  96. 10.5 4
   0. 125.  77. 9.4 4  0. 110.  58. 8.1 4  0. 140.  96. 10.5 4

 2 PROJECTS COMPOSED IN HYDRO TYPE *** HYD2 ***   INSTALLED CAP.: 206. MW
 ************************************************   ***********************

    HYDRO-CONDITION 1  *   HYDRO-CONDITION 2  *   HYDRO-CONDITION 3  *
  BASE PEAK P-ENG AVAIL  BASE PEAK P-ENG AVAIL  BASE PEAK P-ENG AVAIL
  MW  MW  GWH  MW    MW  MW  GWH  MW    MW  MW  GWH  MW

   0. 187. 102. 187.   0. 160.  70. 160.   0. 206. 134. 206.
   0. 187. 102. 187.   0. 160.  70. 160.   0. 206. 134. 206.
   0. 187. 102. 187.   0. 160.  70. 160.   0. 206. 134. 206.
   0. 187. 102. 187.   0. 160.  70. 160.   0. 206. 134. 206.

 * * * * * * * * * * * * END OF DATA FOR YEAR 1998 * * * * * * * * * * * *
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Figure 4.2. (page 5) FIXSYS printout for the sample problem. Fixed system description for year 1998.

Chapter 5

EXECUTION OF VARSYS

5.1. INPUT/OUTPUT FILES

Like the FIXSYS module, VARSYS also uses five files, one input file and four output files. The input file is "VARSYS.DAT" which has to be supplied by the user and prepared exactly according to the format described in the next section. "VARPLANT.BIN" and "VARSYSGL.WRK" are generated to store information to be used by other modules of WASP-IV, while "VARSYSGL.DBG" is a debug file. The results of VARSYS are reported in "VARSYS.REP" file. This file must be reviewed by the user to confirm successful execution of this module before proceeding to next modules.

5.2. INPUT DATA PREPARATION

VARSYS uses up to 13 types of data records, depending on the types of candidate plants to be considered for expansion of the system. If only thermal candidate plants are considered, the data records of types -X, -A, -B, -Ba, -C, -Da, -Db, -Ea and -Eb are used. (The records type-Ea and -Eb will not be required if no group limitation is imposed on the system). If hydro projects are also to be considered as candidates, then groups of type-2a and type-2b records should also be given for each hydro plant, and if pumped storage plants are also expansion candidates, then groups of type-4a and type-4b records should be supplied for each pumped storage project. Table 5.1 lists all of these record types and describes what data they contain, in sequence, along with the required format for each input data item.

The data records are arranged in the input file "VARSYS.DAT" in the following sequence:

First line: One type-X record with the title of the study and print option.

Second line: One type-A record with the general information for the study.

Next lines: As many groups of type-B and type-Ba records as thermal plants need to be described in VARSYS (total number of groups (of type-B and type-Ba records) equal to number of thermal plants used as expansion candidates (NTHPL on the type-A record)).

Next line: One type-C record specifying number of group limitations and other related information as described in Table 5.1. (The number of group limitations (NGROUPLM), names of materials emitted (EMISNAME(I)) and the index number of each group limit (MEASIND(N)) specified here must be the same as defined in FIXSYS).

Following lines: Two groups of type-Da and type-Db records for specifying the number of plants (NPLANTS(I)) and the indices of plants (PLANTIND(I,K)) taking role in the emissions of corresponding pollutants; if for any of the real emissions NPLANTS(I)=0 or NPLANTS(I)=NTHPL, record type-Db will not be required.

Table 5.1. (page 1) Types of data records used in VARSYS

Record type	Columns	Format[1]	Fortran name	Information
X	1–60 65–68	A I	IDENT IODBG	Title of study (centered to columns 30–31). Print option for debug file VARSYSGL.DBG
	5–8	I	NPER	Number of periods per year (maximum 12). [Must be equal to NPER in FIXSYS].
	9–12	I	NTHPL	Number of thermal plants used as system expansion candidates (maximum 12, if P-S active, maximum 11). If =0, no record type B, Ba, C, D, E required.
	13–16	I	IHYDIS	Number of hydro-conditions (maximum 5). *This field and the rest of the record, except NUPS, must be blank if hydro is not used in VARSYS.*
	19–22	A	NAMH(1)	Code name of hydroelectric plant type A (same as in FIXSYS); this field must be blank if not used in VARSYS.
A	23–28	F	HOM(1)	Fixed operating and maintenance costs of hydro plant type A ($/kW-month). (same as in FIXSYS).
	31–34	A	NAMH(2)	Code name of hydroelectric plant type B (same as in FIXSYS); this field must be blank if not used in VARSYS.
	35–40	F	HOM(2)	Fixed operating and maintenance costs of hydro plant type B ($/kW-month). (same as in FIXSYS).
	41–46 47–52 53–58 59–64 65–70	F F F F F	PROBH	Probability of hydro-conditions 1 to 5; same sequence and values as in FIXSYS (the sum of these probabilities must be equal to 1.0).
	71–73	I	NUH(1)	Number of candidate hydro projects of hydro plant type A (maximum 30).
	74–76	I	NUH(2)	Number of candidate hydro projects of hydro plant type B (maximum 30).
	77–79	I	NUPS	Number of pumped storage projects used as system expansion candidates (maximum 30).

Table 5.1. (page 2) Types of data records used in VARSYS

Record type	Columns	Format[1]	Fortran name	Information
	1–4	A	NAME	Code name for the thermal plant used as expansion candidate.
	8–12	F	MWB	Minimum operating level (MW).
	13–17	F	MWC	Maximum operating level (MW).
	18–24	F	BHRT	Heat rate at minimum operating level (kcal/kWh).
	25–31	F	CRMHRT	Average incremental heat rate between minimum and maximum operating levels (kcal/kWh).
	32–36	F	FCST	Domestic fuel costs (c/10^6 kcal).
B[2]	37–41	F	FCSTF	Foreign fuel costs (c/10^6 kcal).
	42–44	I	NTYPE	Plant type number (0, 1, 2, ... 9).
	45–46	I	ISPIN[3]	Spinning reserve as % of MWC.
	47–51	F	FOR	Forced outage rate (%).
	52–54	I	MAINT	Number of days per year required for scheduled maintenance.
	55–59	F	MAINCL	Maintenance class size (MW).
	66–70	F	OMA	Fixed component of non-fuel operation and maintenance cost ($/kW-month) (assumed to be a domestic cost).
	71–75	F	OMB	Variable component of non-fuel operation and maintenance cost ($/MWh) (assumed to be a domestic cost).
	1–10	F	HEATVALU	heat value of the fuel used by plant, measuring the heat equivalent of 1 kg fuel used (kcal/kg).
Ba[4]	11–20	F	POLLUT(1)	percentage of polluting emission, the ratio of emitted first material (default: SO_2) and fuel used in plant (%).
	21–30	F	POLLUT(2)	percentage of polluting emission, the ratio of emitted second material (default: NO_X) and fuel used in plant (%).

Table 5.1. (page 3) Types of data records used in VARSYS

Record type	Columns	Format[1]	Fortran name	Information
	1–2	I	NGROUPLM	number of group-limitations, this number equals to the number of type-E records to be read next (max. 5) if =0, group limits not active in FIXSYS and VARSYS.
	26–28	I	EMISNAME(1)	text of three characters, abbreviating the name of the first emitted material. If left blank, the default name is SO2. (This must be same as specified in FIXSYS).
	30–32	I	EMISNAME(2)	text of three characters, abbreviating the name of the second emitted material. If left blank, the default name is NOx. (This must be same as specified in FIXSYS).
C	33–34 35–36 37–38 39–40 41–42	I	MEASIND(N)	index number; defining the type of limit used. "1" indicates that the corresponding limit concerns the **fuel** used for energy generation, the unit is kT; "2" indicates that the emitted **EMISNAME(1)** is limited, the unit is kT; "3" indicates that the emitted **EMISNAME(2)** is limited, the unit is kT; "4" indicates that the used **heat** is limited, the unit is Tcal; "5" indicates that the **generation** is directly limited, the unit is GWh.
Da[5]	1–4	I	NPLANTS(I)	for real emission I, if =0 (not active), if=NTHPL (all thermal plants in VARSYS); in both cases no Db record follows
Db[5,6]	1–4 5–8	I I	PLANTIND(I,K)	index of plant taking role in the real emission I, I=1,2 and K=1,... NPLANTS(I). (Value of PLANTIND(I,K)=IP
Ea[7]	1–4	I	NPLANTS(N)	number of plants taking role in the corresponding limitation, if=0 this group limit is only active in FIXSYS, if=NTHPL all thermal plants in VARSYS; in both cases no type-Eb record required.
Eb[6,7]	1–4, 5–8 9–12, ...	I	PLANTIND(N,K)	index of plant taking role in the limitation N, for K=1,...,NPLANTS(N) and N=1,...,NGROUPLM (Value of PLANTIND(I,K)=IP

Table 5.1. (page 4) Types of data records used in VARSYS

Recor d type	Columns	Format[1]	Fortran name	Information
	3–6	A	NAMEP	Name of the hydroelectric project
2a[8]	9–12	A	NAMET	Code name of the hydroelectric plant type for the hydro project; must be equal to NAMH(1) or NAMH(2) of record type-A.
	13–18	F	HMW	Installed capacity of hydro project (MW).
	19–24	F	PV	Energy storage capacity of project (GWh).
	25–30	I	JAV	First year the project is available to be considered as expansion candidate.
2b[9]	1–5 6–10 11–15	F F F	EA EMIN HMWC	*Hydro-condition 1:* Period inflow energy (GWh) of the hydro project. Minimum generation in base in the period (GWh). Available capacity in period (MW) of the project.
	16–20 21–25 26–30	F F F	EA EMIN HMWC	*Hydro-condition 2:* Period inflow energy (GWh) of the hydro project. Minimum generation in base in the period (GWh). Available capacity in period (MW) of the project.
				Continue up to last hydro-condition defined (maximum 5).
4a[10]	13–18	F	EFPS	Cycle efficiency of the pumped storage project (%) (0<EFPS<100).
	19–24	F	OMPS	Fixed operating and maintenance cost of the pumped storage project ($/KW-month).
	25–30	I	JRAVPS	First year the project is available to be considered as expansion candidate.
	1–5	F	CBPS	Pumping capacity (MW) of pumped storage project for the period.
4b[11]	6–10	F	CCPS	Generating capacity (MW) of pumped storage project for the period.
	10–15	F	CEPS	Maximum feasible energy generation (GWh) of pumped storage project for the period.

Notes to Table 5.1

(1) See Section 2.5 for Format description.
(2) One record for each thermal plant IP.
(3) ISPIN should be defined consistently with definitions of plant capacity blocks if the loading order is to be calculated by MERSIM (see Table 7.1).
(4) One record for each thermal plant following the corresponding record of type-B.
(5) The number of record groups of type-Da and Db equals to the two real emissions (EMISNAME) described on the record type-C. Two type-Da records obligatory.
(6) Fields 5–8, 9–12,.77–80 give the indices of the second, third, etc. plant for the same emission/limitation.
(7) The number of record groups of type-Ea and Eb equals to the number of group-limitations (NGROUPLM) described on the record of type-C.
(8) One record for each hydroelectric project.
(9) One record per period for each hydroelectric project.
(10) One record for each pumped storage project.
(11) One record per period for each pumped storage project.

Next lines: As many groups of type-Ea and type-Eb records as the number of group limitations (NGROUPLM) specified on record type-C above. Each type-Ea record will contain the number of plants (NPLANTS(N)) taking role in group limitation N, followed by type-Eb record containing plant indices (PLANTIND(N,K)) of these plants. If for any of the group limitation specified the NPLANTS(N) is zero or equal to NTHPL then record type-Eb is not required for that group limitation.

Following lines: As many groups of type-2a and type-2b records as hydroelectric projects are to be considered in VARSYS (for each hydro project type (NUH(1) and NUH(2)) respectively). The group of records needed for each hydro project is composed of one type-2a record and as many type-2b records as periods per year (NPER on record type-A); each type-2b record should contain the hydro project data on capacity and energy in the period for each hydro condition specified (total equal to IHYDIS on record type-A).

Next lines: Finally, as many groups of type-4a and type-4b records as pumped storage projects considered as expansion candidates (NUPS on record A). Each group comprises one type-4a record and as many type-4b records as the number of periods per year (NPER on type-A record).

5.3. SAMPLE PROBLEM

5.3.1. Input data

Figure 5.1 shows the input data used for the VARSYS run of the sample problem. The first data record in this figure is a type-X record with the title of study. The same comments made in Section 3.3 for the title of study to be used in the type-X data record of LOADSY are valid for VARSYS.

The second input line in Fig. 5.1 is a type-A record used to specify the general information for the VARSYS run.

The type-A record in this case specifies the *number of periods* per year (4 in this case); *number of thermal plants* in VARSYS (i.e. the number of type-B and type-Ba records to be read next) which are to be used as expansion candidates (5 here); *number of hydrological conditions* (3); the *code names of the two composite hydroelectric plants* (HYD1 and HYD2) and their *fixed operation and maintenance* (O&M) costs (0.55 and 0.55 \$/kW-month, respectively); the *probabilities of the hydro-conditions* (0.45, 0.30 and 0.25), the number of candidate hydro projects of the two hydro types (2 and 2 respectively for hydro types A and B) and finally, the number of candidate pumped storage projects (0 in this case). See Table 5.1 (page 1) to fill in the data of record type-A. This type-A record is similar to the type-A data record of FIXSYS except that in VARSYS columns 1–4 are left blank and columns 71–79 contain number of hydro projects of type A and B and pumped storage projects to be considered as expansion candidates. Although FIXSYS and VARSYS are independent, the input information given in the respective type-A record *must be consistent*; otherwise it will lead to *interruption of execution of any of the subsequent modules*. For example, the number of periods per year must be the same in both modules and in the respective type-A data records.

Concerning the use of hydro plant types, it must be emphasized that when *a type of hydro plant is to be used* in both, FIXSYS and VARSYS*, its code name and corresponding fixed*

O&M costs must be equal in both modules. Also, *if only one but different hydro plant type is used* in each module, *the number of hydro-conditions and their respective probabilities* given in the type-A records *must be consistent*. Finally, *the number and order of the periods must be consistent* with the input data to LOADSY (see Section 3.2).

The next lines in Fig. 5.1 are five groups of type-B and type-Ba records describing each thermal plant candidate for system expansion by its code name and 16 parameters (13 parameters on type-B record and 3 parameter on type-Ba record). These type-B and type-Ba records are similar to the type-B and type-Ba data records of FIXSYS, except for cols. 5–7 which are left blank in VARSYS (i.e. no number of sets is specified for the expansion candidates).

```
DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL
    4  5  3 HYD1  .55 HYD2  .55  .45  .3  .25       2 2 0
V-CC  300. 600. 1950. 1950.  0.1200. 6 0 10. 28 600.    2.1  4.
  11000.0    0.0    0.5
VLG1  150. 280. 3100. 2700. 710.  0. 110 10. 56 280.    2.7  6.
  1800.0    2.5    1.0  {heat values and polluting % for the plants}
VLG2  150. 280. 3000. 2600.1100.  0. 210 10. 56 280.    2.7  6.
  1800.0    2.5    1.0  {heat values and polluting % for the plants}
VCOA  400. 580. 2600. 2200.  0. 800. 310  8. 48 600.    2.92  5.
  6000.0    1.0    2.0
NUCL  300. 600. 2600. 2340. 0. 194.  0 7 10.0 42 600.    2.50  .50
     0     0     0
 4            SO2 NOx 1 2 3 1 0 {ngrouplm, emisname, measindx}
  4                  {real emis.1: number of plants involved}
  1  2  3  4
  4                  {real emis.1: number of plants involved}
  1  2  3  4
  1
  3             {plant indices involved}
  3
  2  3  4         {plant indices involved}
  4
  1  2  3  4       {plant indices involved}
  0
 VHY1 HYD2 120. 157. 2002
 67.5  0. 100. 51.4  0. 80. 83.7  0. 120.
 67.5  0. 100. 51.4  0. 80. 83.7  0. 120.
 67.5  0. 100. 51.4  0. 80. 83.7  0. 120.
 67.5  0. 100. 51.4  0. 80. 83.7  0. 120.
 VHY2 HYD1 200. 100. 2003
 70.3  0. 160. 42.6  0. 140. 98.  0. 200.
 70.3  0. 160. 42.6  0. 140. 98.  0. 200.
 70.3  0. 160. 42.6  0. 140. 98.  0. 200.
 70.3  0. 160. 42.6  0. 140. 98.  0. 200.
 VHY3 HYD1 650. 300. 2004
 620. 300. 490. 560. 400. 490. 700. 200. 550.
 720. 200. 520. 600. 300. 515. 790. 100. 560.
 820. 150. 550. 660. 100. 530. 950. 50. 650.
 760. 200. 540. 620. 300. 525. 850. 100. 600.
 VHY4 HYD2 193.4  65. 2005
 88.6  0. 120. 63.  0. 100.114.3  0. 140.
 88.6  0. 120. 63.  0. 100.114.3  0. 140.
 88.6  0. 120. 63.  0. 100.114.3  0. 140.
 88.6  0. 120. 63.  0. 100.114.3  0. 140.
```

Figure 5.1. WASP IV — VARSYS input data for the sample problem.

The thermal expansion candidates considered for the sample problem are: 600 MW coal-fired plants (V-CC); 280 MW lignite-1 based plants (VLG1); 280 MW lignite-2 based plants (VLG2); 580 MW imported coal based power plants and 600 MW nuclear plants (NUCL).

After the last group of type-B and type-Ba records, the next line is a type-C record describing the number of group limitations (NGROUPLM=4 in this case), the names of pollutants (SO2 and NOx) and the index numbers of the type of group limits imposed, (1 2 3 1 0 in the present case means that the four group limits imposed are: 1st group limit : fuel limit, 2nd group limit : SO2, 3rd group limit, NOx, and 4th group limit : fuel limit also, whereas 0 stands for unused 5th group limit). (The number of group limitations and the index numbers of the type of group limits should be the same as specified in FIXSYS).

The next lines are two sets of type-Da and type-Db records; first specifying number of plants involved in real emission of 1st pollutant (described on type-C record), and the index numbers of corresponding plants, and then same information for the 2nd pollutant. (If no plant in the VARSYS is involved in real emission of any one or both pollutants then the corresponding type-Da record will contain zero and no type-Db record will follow, and in case all plants are involved, then, again, the type-Db record will be omitted).

The following lines are as many sets of type-Ea and type-Eb records as the number of group limitations specified on type-C record (four sets in this case). Each set contains, on type-Ea record the number of plants taking role in this group limit, and on type-Eb record the index numbers of plants taking role in this group limit. In our sample problem, the first such set contains 1 on type-Ea record (i.e. one plant is taking role in the 1st group limitation) and 3 on type-Eb record (i.e. plant number 3 is the plant for this group limit). Again, if no plant in VARSYS is involved in any one of the group limits then the corresponding type-Ea record will contain zero and no type-Eb record will follow (as is the case for 4th group limitation in this sample problem).

It may be noted that type-Ea records of VARSYS are similar to those for FIXSYS with some differences that on type-Ea records of VARSYS only the number of plants taking role in the group limit are specified, the rest of the record is blank.

After the last set of type-Ea and type-Eb records, the subsequent lines in Fig. 5.1 form the group required to define hydroelectric projects used as expansion candidate. (See Table 5.1 (page 2) to correctly fill in the data of type-2a and type-2b records.) The first line in this group is a type-2a record giving the *name* (VHY1), *plant code name* (HYD2), *installed capacity* (120.MW), the *energy regulation capacity* (157.GWh) and the *first year the hydro project* VHY1 is available to be considered as expansion candidate (2002 in this case). This type-2a record is similar to type-2a of FIXSYS, except that in VARSYS the year from which the hydro project can be considered as candidate plant must be specified. The next lines of input are four type-2b records which contain the information for project VHY1 applicable for each period in each hydrological condition.

There is one record type-2b per period and each one gives the data for all hydro conditions: Columns 1 to 15 for hydro condition 1; 16 to 30 for hydro condition 2; and 31 to 45 for hydro condition 3. No information is given for hydro conditions 4 and 5 (cols. 46–60 and 61–75) since only 3 hydro conditions were specified in record type-A of VARSYS.

As many groups of type-2a and 2b records are to be used as the number of hydro candidates (in our example, there are 4 hydro candidates and hence 4 groups of type-2a and type-2b records are included).

After description of hydro projects, the next would be pumped storage candidates in VARSYS. These are described by a group consisting of one type-4a record and as many type-4b records as the number of periods. In this sample problem there is no pumped storage project as an expansion candidate.

5.3.2. Printout

Figure 5.2 shows the printed output resulting from execution of the VARSYS module for the sample problem.

Page 1 of Fig. 5.2 is the cover page printed by VARSYS giving the title of the study. This is followed by the list of the record images of the input data used in the run. Page 2 of the figure shows this part of the printout for the sample problem. This include in sequence: the *general information* for the case study; the *thermal plant characteristics* and the *parameters describing the hydro projects* used as expansion candidates (there is no pumped storage project in this case, if such projects are also included in the input as candidates, these will be described after hydro projects).

The next pages of the output list the description of the Variable System which will be used by Modules 3 to 6 of WASP. Pages 3 to 4 of Fig. 5.2 show the VARSYS description for the case example. It contains first, the *number of periods* per year (4) and *number of hydro-conditions* (3); then the *characteristics of the candidate thermal plants* are displayed following a similar format to the one used by FIXSYS (see page 4 of Figure 4.2), except that in VARSYS column 3 of the list of thermal plants includes zeroes for the number of sets. Similar to the case in FIXSYS, the values calculated by the program for full load heat rate, unit generation costs base and full load (domestic, foreign), and the full load total generation costs are reported in the last 6 columns of each line for the candidate thermal plants. The full load total generation costs (last column to the right of the thermal plant list) are used to define the economic loading order of these plants.

Next is the information on real emissions and group limitations. The last item on page 3 of figure 5.2 is the economic loading order calculated by the program (as stated in Section 4.4, this information will be used by CONGEN for calculating the basic economic loading order of the combined FIXSYS and VARSYS plants).

The page 4 of figure 5.2 shows the calculated characteristics of the hydroelectric projects, if any, of each plant type, first for hydro type A and then hydro type B. For each group, the individual hydro projects are listed separately. These are printed in a similar fashion as in FIXSYS with the difference that in VARSYS the year of availability of the project is added[1]. For example, hydro project 1 (VHY2) of the HYD1 type is available for expansion from 2003 onward while the second hydro project of the same type (VHY4) is available in year 2004. But this has to be taken care in the placement of input order.

[1] For each hydro plant type the individual hydro projects are listed and used in the sequence of input and not ascending order of year of availability of the projects.

Additionally, the VARSYS printout contains the characteristics of the composite hydroelectric plant types resulting from the combination of the individual characteristics of the projects of the respective type considering all projects up to the current project; in other words they are given: for the first project, for the first and the second, for the first, second and third, and so on, up to the last project of the type. This information is printed immediately after the individual characteristics of each hydro project have been reported in the output (see page 4 of Fig. 5.2). These characteristics of composite hydro plants are also reported in a similar fashion as in FIXSYS (see Section 4.4).

If there were any pumped storage projects included in the input as candidates, the characteristics of such individual projects and of the corresponding composite pumped storage would be printed after hydro.

The printout of VARSYS for the user's case study should be checked with great care to make sure that the reported numbers are those intended by the user. Each number should be verified carefully as some errors will not be identified by the WASP code until the subsequent modules are run (e.g. inconsistencies between FIXSYS and VARSYS input data), and some will never be identified by the computer (e.g. a "wrong" data for the year of availability of one hydro or P-S project).

At least some internal inconsistencies in the input data are checked by the program and in case of incompatibility with the capabilities of calculation, they will cause interruption of program execution and an error message is printed. Some other inconsistencies will simply produce an error (or warning) message being printed, in order to warn the user of the potential sources of error for the subsequent WASP modules due to the input data used in VARSYS. The error and warning messages applicable to VARSYS are treated in Section 3 of Chapter 13.

```
                WASP COMPUTER PROGRAM PACKAGE

                    VARSYS MODULE

                     CASE STUDY

           DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL
```

Figure 5.2. (page 1) VARSYS printout for the sample problem. Cover page.

```
VARIABLE SYSTEM INPUT DATA INFORMATION

   INIT.  NO.OF NO.THERMAL HYDRO *** HYDRO PLANT TYPES ***    PROBABILITY OF HYDROCONDITIONS    NO. OF PROJECTS
   YEAR  PERIODS PLANTS  COND. NAME  O&M   NAME  O&M   1    2    3    4    5   HYD1 HYD2 PUMP

    0    4    5    3  HYD1  0.55  HYD2  0.55  0.450  0.300  0.250  0.000  0.000   2  2   0

                HEAT RATE   FUEL COSTS     S FRCD
       NO. MIN.  CAP-  BASE  AVGE    CENTS/      P OUTAGE DAYS MAIN O&M  O&M
       OF LOAD  CITY  LOAD  INCR  MILLION KCAL FUEL R RATE SCHL CLAS (FIX) (VAR) HEAT VALUE  EMISSION FACTOR
    NAME SETS MW   MW   KCAL/ KWH  DMSTC  FORGN TYPE %  %  MAIN  MW $/KWM $/MWH  KCAL/KG    WT % OF FUEL

    V-CC  0 300.  600.  1950. 1950.  0.0 1200.0  6  0 10.0  28  600. 2.10 4.00  11000.00   0.00   0.50
    VLG1  0 150.  280.  3100. 2700. 710.0   0.0  1 10 10.0  56  280. 2.70 6.00  1800.00   2.50   1.00
    VLG2  0 150.  280.  3000. 2600. 1100.0   0.0  2 10 10.0  56  280. 2.70 6.00  1800.00   2.50   1.00
    VCOA  0 400.  580.  2600. 2200.  0.0  800.0  3 10  8.0  48  600. 2.92 5.00  6000.00   1.00   2.00
    NUCL  0 300.  600.  2600. 2340.  0.0  194.0  0  7 10.0  42  600. 2.50 0.50    0.00   0.00   0.00

NGROUPLM  EMISNAME  MEASIND
  4   SO2 NOx  1  2  3  1

*** REAL EMISSION ***

NPLANTS  4
PLANTIND  1  2  3  4

NPLANTS  4
PLANTIND  1  2  3  4

*** GROUP LIMITATION ***

NPLANTS  1
PLANTIND  3

NPLANTS  3
PLANTIND  2  3  4

NPLANTS  4
PLANTIND  1  2  3  4

NPLANTS  0

PROJECT  1 (NAME: VHY1) OF HYDRO TYPE *** HYD2 *** INSTALLED CAP.: 120. MW  REG. ENERGY: 157.00 GWH  AVAILABLE YEAR: 2002

 HYDROCONDITION 1  HYDROCONDITION 2  HYDROCONDITION 3
 EA  EMIN  MWC  EA  EMIN  MWC  EA  EMIN  MWC

 67.5  0.0 100.0  51.4  0.0  80.0  83.7  0.0 120.0
 67.5  0.0 100.0  51.4  0.0  80.0  83.7  0.0 120.0
 67.5  0.0 100.0  51.4  0.0  80.0  83.7  0.0 120.0
 67.5  0.0 100.0  51.4  0.0  80.0  83.7  0.0 120.0

PROJECT  1 (NAME: VHY2) OF HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 200. MW  REG. ENERGY: 100.00 GWH  AVAILABLE YEAR: 2003

 HYDROCONDITION 1  HYDROCONDITION 2  HYDROCONDITION 3
 EA  EMIN  MWC  EA  EMIN  MWC  EA  EMIN  MWC

 70.3  0.0 160.0  42.6  0.0 140.0  98.0  0.0 200.0
 70.3  0.0 160.0  42.6  0.0 140.0  98.0  0.0 200.0
 70.3  0.0 160.0  42.6  0.0 140.0  98.0  0.0 200.0
 70.3  0.0 160.0  42.6  0.0 140.0  98.0  0.0 200.0

PROJECT  2 (NAME: VHY3) OF HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 650. MW  REG. ENERGY: 300.00 GWH  AVAILABLE YEAR: 2004

 HYDROCONDITION 1  HYDROCONDITION 2  HYDROCONDITION 3
 EA  EMIN  MWC  EA  EMIN  MWC  EA  EMIN  MWC

 620.0 300.0 490.0 560.0 400.0 490.0 700.0 200.0 550.0
 720.0 200.0 520.0 600.0 300.0 515.0 790.0 100.0 560.0
 820.0 150.0 550.0 660.0 100.0 530.0 950.0  50.0 650.0
 760.0 200.0 540.0 620.0 300.0 525.0 850.0 100.0 600.0

PROJECT  2 (NAME: VHY4) OF HYDRO TYPE *** HYD2 *** INSTALLED CAP.: 193. MW  REG. ENERGY:  65.00 GWH  AVAILABLE YEAR: 2005

 HYDROCONDITION 1  HYDROCONDITION 2  HYDROCONDITION 3
 EA  EMIN  MWC  EA  EMIN  MWC  EA  EMIN  MWC

 88.6  0.0 120.0  63.0  0.0 100.0 114.3  0.0 140.0
 88.6  0.0 120.0  63.0  0.0 100.0 114.3  0.0 140.0
 88.6  0.0 120.0  63.0  0.0 100.0 114.3  0.0 140.0
 88.6  0.0 120.0  63.0  0.0 100.0 114.3  0.0 140.0
```

Figure 5.2. (page 2) VARSYS printout for the sample problem. Input information.

```
VARIABLE SYSTEM, RESULT OF THE STUDY
             4 PERIODS
             3 HYDRO CONDITIONS

                HEAT RATE   FUEL COSTS     S FRCD              FLD   UNIT GENERATION
       NO. MIN.  CAP-  BASE  AVGE    CENTS/      P OUTAGE DAYS MAIN O&M  O&M HEAT RT  COSTS ($/MWH)
SEQ.     OF LOAD  CITY  LOAD  INCR  MILLION KCAL FUEL R RATE SCHL CLAS (FIX) (VAR) KCAL/ BASE BASE FLD FLD  FLD
NO.  NAME SETS MW   MW   KCAL/ KWH  DMSTC  FORGN TYPE %  %  MAIN  MW $/KWM $/MWH  KWH  DOM FRGN DOM FRGN TOT

 1   V-CC  0 300.  600.  1950. 1950.  0.0 1200.0  6  0 10.0  28  600. 2.10 4.00 1950.  4.0 23.4 4.0 23.4 27.4
 2   VLG1  0 150.  280.  3100. 2700. 710.0   0.0  1 10 10.0  56  280. 2.70 6.00 2914. 28.0 0.0 26.7 0.0 26.7
 3   VLG2  0 150.  280.  3000. 2600. 1100.0   0.0  2 10 10.0  56  280. 2.70 6.00 2814. 39.0 0.0 37.0 0.0 37.0
 4   VCOA  0 400.  580.  2600. 2200.  0.0  800.0  3 10  8.0  48  600. 2.92 5.00 2476.  5.0 20.8 5.0 19.8 24.8
 5   NUCL  0 300.  600.  2600. 2340.  0.0  194.0  0  7 10.0  42  600. 2.50 0.50 2470.  0.5 5.0 0.5 4.8 5.3

*** REAL EMISSION ***

NO. TYPE PLANTS INVOLVED (PLANT SEQUENCE NUMBER)

1 SO2   1  2  3  4
2 NOx   1  2  3  4

*** GROUP LIMITATION ***

NO. TYPE PLANTS INVOLVED (PLANT SEQUENCE NUMBER)

1 FUEL  3
2 SO2   2  3  4
3 NOx   1  2  3  4
4 FUEL  * * * N O N E * * *


ECONOMIC LOADING ORDER DEFINED IN ASCENDING ORDER OF TOTAL FULL LOAD UNIT GENERATION COSTS

 5  4  2  1  3
```

Figure 5.2. (page 3) VARSYS printout for the sample problem. Description of variable system.

```
FOLLOWING HYDRO PROJECTS ARE OF TYPE *** HYD1 ***  O&M (FIX) =  0.55 $/KW-MONTH
**************************************************************************************************************************
PROJECT 1  INSTALLED CAP.: 200. MW  REG. ENERGY: 100.00 GWH  AVAILABLE YEAR: 2003

   HYDROCONDITION 1  *   HYDROCONDITION 2  *   HYDROCONDITION 3  *
 BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY
 MW  MW  GWH  HR    MW  MW  GWH  HR    MW  MW  GWH  HR

  0. 160.  70. 6.7 4  0. 140.  43. 4.7 4  0. 200.  98. 7.5 4
  0. 160.  70. 6.7 4  0. 140.  43. 4.7 4  0. 200.  98. 7.5 4
  0. 160.  70. 6.7 4  0. 140.  43. 4.7 4  0. 200.  98. 7.5 4
  0. 160.  70. 6.7 4  0. 140.  43. 4.7 4  0. 200.  98. 7.5 4

1 PROJECTS COMPOSED IN HYDRO TYPE *** HYD1 ***   INSTALLED CAP.: 200. MW
************************************************   ************************
   HYDROCONDITION 1  *   HYDROCONDITION 2  *   HYDROCONDITION 3  *
 BASE PEAK P-ENG AVAIL  BASE PEAK P-ENG AVAIL  BASE PEAK P-ENG AVAIL
 MW  MW  GWH  MW    MW  MW  GWH  MW    MW  MW  GWH  MW

  0. 160.  70. 160.   0. 140.  43. 140.   0. 200.  98. 200.
  0. 160.  70. 160.   0. 140.  43. 140.   0. 200.  98. 200.
  0. 160.  70. 160.   0. 140.  43. 140.   0. 200.  98. 200.
  0. 160.  70. 160.   0. 140.  43. 140.   0. 200.  98. 200.

PROJECT 2  INSTALLED CAP.: 650. MW  REG. ENERGY: 300.00 GWH  AVAILABLE YEAR: 2004

   HYDROCONDITION 1  *   HYDROCONDITION 2  *   HYDROCONDITION 3  *
 BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY
 MW  MW  GWH  HR    MW  MW  GWH  HR    MW  MW  GWH  HR

 137. 353. 320. 13.9 4 183. 307. 160. 8.0 4  91. 459. 500. 16.7 4
 91. 429. 520. 18.6 4 137. 378. 300. 12.2 4  46. 514. 690. 20.6 4
 68. 482. 670. 21.3 4  46. 484. 560. 17.7 4  23. 627. 900. 22.0 4
 91. 449. 560. 19.1 4 137. 388. 320. 12.7 4  46. 554. 750. 20.8 4

2 PROJECTS COMPOSED IN HYDRO TYPE *** HYD1 ***   INSTALLED CAP.: 850. MW
************************************************   ************************
   HYDROCONDITION 1  *   HYDROCONDITION 2  *   HYDROCONDITION 3  *
 BASE PEAK P-ENG AVAIL  BASE PEAK P-ENG AVAIL  BASE PEAK P-ENG AVAIL
 MW  MW  GWH  MW    MW  MW  GWH  MW    MW  MW  GWH  MW

 137. 513. 390. 650.  183. 447. 203. 630.   91. 659. 598. 750.
 91. 589. 590. 680.  137. 518. 343. 655.   46. 714. 788. 760.
 68. 642. 740. 710.   46. 624. 603. 670.   23. 827. 998. 850.
 91. 609. 630. 700.  137. 528. 363. 665.   46. 754. 848. 800.

FOLLOWING HYDRO PROJECTS ARE OF TYPE *** HYD2 ***  O&M (FIX) =  0.55 $/KW-MONTH
**************************************************************************************************************************
PROJECT 1  INSTALLED CAP.: 120. MW  REG. ENERGY: 157.00 GWH  AVAILABLE YEAR: 2002

   HYDROCONDITION 1  *   HYDROCONDITION 2  *   HYDROCONDITION 3  *
 BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY
 MW  MW  GWH  HR    MW  MW  GWH  HR    MW  MW  GWH  HR

  0. 100.  68. 10.4 4  0.  80.  51. 9.9 4  0. 120.  84. 10.7 4
  0. 100.  68. 10.4 4  0.  80.  51. 9.9 4  0. 120.  84. 10.7 4
  0. 100.  68. 10.4 4  0.  80.  51. 9.9 4  0. 120.  84. 10.7 4
  0. 100.  68. 10.4 4  0.  80.  51. 9.9 4  0. 120.  84. 10.7 4

1 PROJECTS COMPOSED IN HYDRO TYPE *** HYD2 ***   INSTALLED CAP.: 120. MW
************************************************   ************************
   HYDROCONDITION 1  *   HYDROCONDITION 2  *   HYDROCONDITION 3  *
 BASE PEAK P-ENG AVAIL  BASE PEAK P-ENG AVAIL  BASE PEAK P-ENG AVAIL
 MW  MW  GWH  MW    MW  MW  GWH  MW    MW  MW  GWH  MW

  0. 100.  68. 100.   0.  80.  51.  80.   0. 120.  84. 120.
  0. 100.  68. 100.   0.  80.  51.  80.   0. 120.  84. 120.
  0. 100.  68. 100.   0.  80.  51.  80.   0. 120.  84. 120.
  0. 100.  68. 100.   0.  80.  51.  80.   0. 120.  84. 120.

PROJECT 2  INSTALLED CAP.: 193. MW  REG. ENERGY:  65.00 GWH  AVAILABLE YEAR: 2005

   HYDROCONDITION 1  *   HYDROCONDITION 2  *   HYDROCONDITION 3  *
 BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY BASE PEAK P-ENG P-HR KEY
 MW  MW  GWH  HR    MW  MW  GWH  HR    MW  MW  GWH  HR

  0. 120.  89. 11.3 4  0. 100.  63. 9.7 4  0. 140. 114. 12.5 4
  0. 120.  89. 11.3 4  0. 100.  63. 9.7 4  0. 140. 114. 12.5 4
  0. 120.  89. 11.3 4  0. 100.  63. 9.7 4  0. 140. 114. 12.5 4
  0. 120.  89. 11.3 4  0. 100.  63. 9.7 4  0. 140. 114. 12.5 4

2 PROJECTS COMPOSED IN HYDRO TYPE *** HYD2 ***   INSTALLED CAP.: 313. MW
************************************************   ************************
   HYDROCONDITION 1  *   HYDROCONDITION 2  *   HYDROCONDITION 3  *
 BASE PEAK P-ENG AVAIL  BASE PEAK P-ENG AVAIL  BASE PEAK P-ENG AVAIL
 MW  MW  GWH  MW    MW  MW  GWH  MW    MW  MW  GWH  MW

  0. 220. 156. 220.   0. 180. 114. 180.   0. 260. 198. 260.
  0. 220. 156. 220.   0. 180. 114. 180.   0. 260. 198. 260.
  0. 220. 156. 220.   0. 180. 114. 180.   0. 260. 198. 260.
  0. 220. 156. 220.   0. 180. 114. 180.   0. 260. 198. 260.
```

Figure 5.2. (page 4) VARSYS printout for the sample problem. Description of variable system.

Chapter 6

EXECUTION OF CONGEN

6.1. INPUT/OUTPUT FILES

CONGEN uses 8 input/output files. The user supplied input file is "CONGEN.DAT", which should be prepared by the user exactly according to the format described in the next section. The other input files are: "LOADDUCU.BIN" produced by LOADSY module, "FIXPLANT.BIN" produced by FIXSYS module and "VARPLANT.BIN" produced by VARSYS module. When executed for second and subsequent iterations, CONGEN also uses a "SIMULOLD.BIN" file, which contains information on configurations simulated by MERSIM module in all previous iterations. CONGEN generates an intermediate file, "EXPANALT.BIN" to be used by other modules of WASP-IV. The results are reported in an output file called "CONGEN.REP", which should be reviewed by the user to confirm successful execution before proceeding further.

6.2. INPUT DATA PREPARATION

CONGEN uses up to 6 types of data records, depending on the constraint options selected by the user to generate system configurations in each year of study. Table 6.1 lists the 6 types of data records of CONGEN, showing also what data they contain and the corresponding field, formats and Fortran names of the variables.

The type-X record is required once at the beginning of the input data. A type-1 INDEX=1 record is the end of year record indicating that all data for current year have been completed and that the calculations for the year must be done next (this should be the last record for each year of the study period). The records type-1 with INDEX=2, 3, 4, or 8 are used to tell the computer that the next input line to be read is a record of type equal to the INDEX number, for example one type-1 record with INDEX=4 must be followed by a type-4 record. (INDEX=5,6 and 7 are not used). Therefore, it is important to check that the proper sequence of data records is used; otherwise it will lead to wrong calculations or interruption of the CONGEN execution and the printing of an error message (see Section 5 of Chapter 13).

Each type-1 record with INDEX=2 (3, 4, or 8), followed by a record type-2 (3, 4, or 8) will constitute a group. These groups may appear in the input data in any order for a year. Some of these groups of data records *must be* always provided as input, at least for the first year of study, unless the user does not want to change the default values for the respective variables in CONGEN. For example, if the user wants to define MINST and ITWTH greater than the default values ("0"), type-2 and type-3 records *must be* used (at least for the first year). In this case, one type-1 INDEX=2 record followed by a type-2 record are included to define the minimum number of sets (or projects for hydro and pumped storage candidates) for each Variable System expansion candidate that can be contained in any acceptable configuration for the year. Similarly, a type-1 INDEX=3 and a type-3 records are used to define the maximum acceptable number (in addition to the minimum required) of sets or projects of each expansion candidate. If no type-2 or type-3 records are used in a particular CONGEN run, the only configuration which can be examined for each year is the one containing zeroes for all expansion candidates (i.e. no expansion of the system is permitted).

A type-1 INDEX=4 record and a type-4 record *must be* included in the input data (at least for the first year) to tell the computer what are the values for the minimum and maximum reserve margins to be respected by each configuration of the system. If no record type-4 is used in a particular CONGEN run, the only configuration which can be examined by CONGEN in each year is the one having zero reserve margin since the default values for RSVMN and RSVMX are both zero. This is not mentioned in Table 6.1 in order to *emphasize the need to use the type-4 record as input for the run.*

Finally, a type-1 record with INDEX=8 and a type-8 record *may be* used to change the number of the hydro-condition for which the critical period and reserve margins of the system configurations are to be calculated (the default value is 1).

These records in the input file of CONGEN are arranged in the following sequence:

(a) For the first year:

First line: One type-X record with the title of the study and the file printing option chosen for the run.

Following lines: Groups of records type-1 with INDEX=2, 3 or 4, each one followed by a record of type-2, -3 or -4, respectively, defining the constraints for the number of sets or projects of each expansion candidate and for the reserve margins.

Next lines: Group of records type-1 INDEX=8, followed by a record type-8, if the user wants to modify the default values in the program for number of hydro-condition for which critical period and reserve margins are to be calculated (IHCRIT).

As mentioned earlier, the above groups of records may appear in any order.

Last line: One type-1 INDEX=1 record (end of the year).

(b) For the second and subsequent years:

Groups of records type-1 with INDEX=2, 3, or 4 each one followed by the corresponding record of type equal to the INDEX number for each change to be introduced to the respective values applicable in the preceding year.

In principle, a record type-1 INDEX=8 (followed by a type-8 record) may be included each year to change the number of the hydro-condition for which critical period and reserve margins are to be calculated. For planning purposes, however, it is advisable to maintain the same hydro-condition throughout all years of study in a single CONGEN run (and throughout the WASP study).

Last line: One type-1 INDEX=1 record (end of the year).

Table 6.1. Types of data records used in CONGEN

Record type	Columns	Format[1]	Fortran name	Information
X	1–60	A	IDENT	Title of study (centered to columns 30–31).
	61–64	I	IOFILE	File printing option; equal 1 to print files from FIXSYS and VARSYS (default value = 0, i.e. no printing of files).
1	1–4	I	INDEX	Index number; 1 indicates end of data for the current year; 2, 3, 4 or 8 indicates that a record follows of type equal to the index number[2].
2	1–4 5–8 etc.	I	MINST(J)	Each number is the *minimum number of sets* of variable system expansion candidate type J *required* to be in service during current year (J maximum =14)[3] (default values =0).
3	1–4 5–8 etc.	I	ITWTH(J)	*Maximum number of sets* of the expansion candidate type J permitted for expansion in addition to MINST(J)[3]. It is also called the tunnel width (default values = 0).
4	1–10	F	RSVMN	Minimum permissible reserve margin (% of the peak load) in critical period[4]. (default values =0).
	11–20	F	RSVMX	Maximum permissible reserve margin (% of the peak load) in critical period[4]. (default values =0).
8	1–4	I	IHCRI	Number of the hydro condition for which critical period and reserve margins are to be calculated. [default value equals 1]

Notes to Table 6.1:
(1) See Section 2.5 for format description.
(2) INDEX=5, 6 and 7 is not available in CONGEN.
(3) The order of the expansion candidates is: first, the thermal plants in the same order they were read in VARSYS (from 1 to NTHPL); followed by hydro projects type A (if they exist in VARSYS), hydro projects type B (if they exist in VARSYS), and finally pumped storage projects PUMP (if they exist in VARSYS).
(4) *Critical period*: The period of the year in which the difference between the corresponding available generating capacity and the peak load is the smallest.

6.3. SAMPLE PROBLEM

Sometimes, it is convenient to carry out a WASP run with a predetermined expansion plan (i.e. one single configuration per year) in order to examine such aspects as cash flows, value of the objective function as a function of varying economic parameters, and comparison of a limited number of expansion policies. For the purposes of the discussion that follows, this type of run is called a 'fixed expansion plan'. This usually involves execution in sequential order of modules 4 to 6 (and sometimes Module 7).

Carrying out a WASP run for a fixed expansion plan has also the advantage of permitting to check up the accuracy of data records used by Modules 4 to 6 (and 7), as well as the files created by each preceding module which are called upon during program execution. This is particularly valid for the first runs of CONGEN (MERSIM and DYNPRO) under the user's case name. The following paragraphs describe how a fixed expansion plan is carried out with the CONGEN module and presents the sample data for the first CONGEN run of DEMOCASE. The corresponding printout for this run is presented in Section 6.3.2, while the subsequent MERSIM and DYNPRO runs for this fixed expansion plan are presented in Sections 7.3.1 and 7.3.2 for MERSIM, and in Sections 8.3.1 and 8.3.2 for DYNPRO. The use of CONGEN to generate alternative configurations each year (called a dynamic or variable expansion run) which are to be, first, simulated by MERSIM, and then compared by the dynamic programming algorithm of DYNPRO is discussed in Sections 6.3.3 and 6.3.4.

6.3.1. Input data for a fixed expansion plan (CONGEN Run-1)

Figure 6.1 represents the input data prepared for a fixed expansion plan of the sample problem, corresponding to the first CONGEN run for DEMOCASE, therefore identified as CONGEN Run-1.

The first input line in Fig. 6.1 is a type-X record containing in columns 1–60 the title of study and in column 64 the selected option for printing of the FIXSYS and VARSYS files (in this case a 1 asks for printing of this information). In principle all comments made in Section 3.3 for the title of study to be used in the type-X record of LOADSY are also valid for CONGEN. Also, as stated in that section, the same title of the study is used along all runs of our sample problem. However, since this title is only used by CONGEN to print the cover page of the output for the run, the user may change the title for subsequent runs in order to identify the sequence followed, for quick reference. This is particularly useful in the search for the optimal solution when many sequential variable expansion runs of modules CONGEN-MERSIM-DYNPRO are executed. During such process, the user may identify each sequential run of these three modules (called an iteration) by a corresponding number to be included in the title of study data for these modules.

The second line of data is a type-1 INDEX=4 record and is followed by a type-4 record, which is used to specify the minimum and maximum reserve margins in the critical period, in percent (%) of peak load.

For a predetermined expansion plan it is recommended that the minimum and maximum reserve margins are such that they permit a wide range of acceptable capacity for the configurations, so that the predetermined plan is not excluded in any year. In the example, a minimum reserve margin of 15% and a maximum of 50% have been specified[1].

The next data lines are a type-1 INDEX=8 record, followed by one type-8 record telling the computer that the reserve margins of the configurations are to be calculated for hydro condition 1 (This set of records could have been omitted since the default value is also 1).

[1] For a case, if the capacity of fixed system (FIXSYS) in the initial years is insufficient and new capacity (VARSYS) cannot be added for these years (i.e. total capacity below the peak load of the critical period), a negative value for the minimum reserve margin can be used to guarantee that the configurations (with zero additions) are accepted.

The following two lines are one type-1 INDEX=2 and one type-2 records giving the minimum number of sets (or projects in the case of hydro and pumped storage plants) of each candidate plant that can be included in the yearly configurations. This set of numbers will normally determine the so-called "minimum configuration" required by the program in the given year; however, since this is a predetermined expansion plan, in this case they determine the system configuration for the year. The order of the expansion candidates is the same as in the VARSYS listing shown in Figures 5.1 and 5.2. Hence, column 4 applies to the V-CC plant; column 8 to the VLG1 plant and so on, with the last two columns applying to the two composite hydro plants (HYD1 and HYD2). In the sample problem all columns are shown as zeroes meaning that no addition of VARSYS candidates is considered in this year.

The next group of input lines are one type-1 INDEX=3 and one type-3 records giving the maximum number of sets (or projects) of each expansion candidate permitted for addition to the system, above the minimum number of sets (or projects) specified in the type-2 record. The set of numbers in the type-3 record will normally determine the so-called "tunnel-width"; however, since this is a predetermined expansion plan, the minimum and maximum number of units or projects permitted are the same (i.e. the tunnel width is zero for all candidates). Therefore, the type-3 record shows a zero for each expansion candidate being considered. This tunnel width will remain the same until a new group of one type-1 INDEX=3 and one type-3 records showing a change are used. For a predetermined expansion plan, the tunnel width for each expansion candidate remains zero, so that no further records of type-3 are required.

The last line of input for this year (1998) is a record type-1 INDEX=1 (end of the year record). Similarly as explained for the previous WASP modules, CONGEN will read the "1" in column 4 and will proceed to execute the calculations for the year. For the convenience of the user, however, the year is shown in this record (columns 16 to 28) to indicate the end of input information for the year being considered.

The input data for the second year (1999) includes a type-1 INDEX=2 record to indicate that another type-2 record follows. This record shows a 0 in all columns (again no addition of VARSYS candidates is made in this year). These are followed by a type-1 INDEX=1 record to tell the computer that the data for 1999 have been completed. Exactly same data records are given for year 2000.

The first addition of VARSYS candidates is made in year 2001. This is shown in the subsequent type-2 record which includes a 1 in the 1st column, corresponding to addition of one unit of the first thermal plant (V-CC) .

```
DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL        1
   4
       15.       50.
   8
   1
   2
   0   0   0   0   0   0   0
   3
   0   0   0   0   0   0   0
   1          (END OF YEAR 1998)
   2
   0   0   0   0   0   0   0
   1          (END OF YEAR 1999)
   2
   0   0   0   0   0   0   0
   1          (END OF YEAR 2000)
   2
   1   0   0   0   0   0   0
   1          (END OF YEAR 2001)
   2
   1   1   0   1   0   0   1
   1          (END OF YEAR 2002)
   2
   2   1   0   1   0   1   1
   1          (END OF YEAR 2003)
   2
   3   1   0   1   0   2   1
   4
       20.       40.
   1          (END OF YEAR 2004)
   2
   3   2   0   1   0   2   2
   1          (END OF YEAR 2005)
   2
   3   2   0   2   1   2   2
   1          (END OF YEAR 2006)
   2
   3   2   1   3   1   2   2
   1          (END OF YEAR 2007)
   2
   3   2   1   3   1   2   2
   1          (END OF YEAR 2008)
   2
   3   2   1   4   1   2   2
   1          (END OF YEAR 2009)
   2
   3   2   2   5   1   2   2
   1          (END OF YEAR 2010)
   2
   3   2   3   5   2   2   2
   1          (END OF YEAR 2011)
   2
   3   2   3   6   2   2   2
   1          (END OF YEAR 2012)
   2
   3   3   4   7   2   2   2
   1          (END OF YEAR 2013)
   2
   3   3   5   8   2   2   2
   1          (END OF YEAR 2014)
   2
   3   3   5   8   3   2   2
   1          (END OF YEAR 2015)
   2
   3   4   5   9   3   2   2
   1          (END OF YEAR 2016)
   2
   3   4   6   9   4   2   2
   1          (END OF YEAR 2017)
```

Figure 6.1. (Page 1) WASP-IV — CONGEN input data for a fixed expansion for the sample problem. CONGEN Run-1.

The same sequence of records (one type-1 INDEX=2, a type-2 and a type-1 INDEX=1 records) follows up to the end of the study describing each year's configurations and giving the data for that year. The number of units of each candidate to be specified as minimum additions on the type-2 record are the cumulative numbers. For example the configuration in the last year of study (2017) includes 3 4 6 9 4 2 2 meaning that up to this year 3 × 600 MW combined cycle units (plant V-CC); 4 × 280 MW lignite-1 based units (plant VLG1); 6 × 280 MW lignite-2 based units (plant VLG2); 9 × 580 MW coal based units (plant VCOA); 4 × 600 nuclear units, 2 hydro projects of the HYD1 type, and 2 hydro projects of the HYD2 type have been added.

It may be noted that in the year 2004, there is one type-1 record with INDEX=4, followed by a type-4 record containing new values for minimum and maximum reserve margins. Such records may be used for changing the reserve margins.

6.3.2. Printout for a fixed expansion plan (CONGEN Run-1)

Figure 6.2 shows a sample of the printed output of the CONGEN run using the data of Fig. 6.1. Since the file printing option has been set to "1" for this run, the output begins with a listing of the information read by CONGEN from the FIXSYS and VARSYS files. Pages 1 to 2 of Fig. 6.2 show these listings for the CONGEN Run-1 of the sample case.

Page 1 contains the description of the Fixed System for year 1998, as it was written by the latest run of FIXSYS on the FIXPLANT file labeled "DEMOCASE". The same information is used by CONGEN while generating the configurations of the system for this year[2]. The top part starts with the title of the study as given in FIXSYS, followed by a listing of the "fuel" types used in the study (first the thermal plant fuel types, and then the two composite hydro plants).

The lower part in page 1 lists the actual description of the Fixed System for the year, starting with the number of the year (1 for first year of study), followed by the number of records read in (35 in this case), the corresponding year (1998), and the general information which was given on record type-A of FIXSYS (see Figure 4.2). Lines 2 to 7 show the state of the FIXSYS thermal plants in this year. Line 8 corresponds to the summary of thermal capacity by type of fuel and number of composed projects of hydro type A and B (3 and 2 respectively); line 9 is the basic economic loading order of the FIXSYS thermal plants; and line 10 lists the full load total operating costs of these plants. The next group of lines shows the characteristics of the two composite hydro plants. Starting with hydro type A first period first hydro-condition, followed by the remaining hydro-conditions. This block of lines (3 in this case) is repeated for each period (total of 4 times). Then same for hydro type B. The sequence of the data included in each line is as follows: name of the hydro plant type name; number of projects composed; year of this information; total installed capacity; the base, peak, and total available capacity; and the base, peak, and total available energy. (This information is the same one shown in pages 3 and 4 of Fig. 4.2, except that for hydroelectric plants, only the characteristics of each composite plant are included. The individual characteristics of the hydro projects of each type are indeed not required for the calculations carried out by CONGEN, MERSIM or DYNPRO).

The printout continues with the Variable System description as it will be used by CONGEN. Page 2 of Fig. 6.2 shows this part of the printout for CONGEN Run-1 of the sample problem. Comparing this information with the one shown in page 2 of Fig. 5.2, it can be seen that they are basically the same, except that in the CONGEN printout only the characteristics of each composite hydro plant are included (combining up to the first, up to the second, and up to the last project of the corresponding type). It should also be noticed that the information listed in this page follows the same sequence described for the state of the Fixed System discussed above, except that in VARSYS the year shown in the listing of hydro plant corresponds to the latest year of availability of the projects combined in the respective plant type.

[2] The information shown in this page actually spreads over two separate pages of the printout. These have been compressed into a single page to reduce the size of the manual.

Page 3 of Fig. 6.2, on top, shows the cover page printed by CONGEN (which serves to identify the run) showing the title of the study and the list of the Variable System expansion candidates which is read from the VARSYS file. This list starts with the thermal plants, followed by the two hydro plants defined for the sample problem. (In case a P-S candidate is present, this will be listed next). Each expansion candidate is identified by its code name and a number corresponding to the sequential number in which the candidates were defined in VARSYS. The same sequential order is used throughout the printout to define the system configurations.

The next piece of output produced by CONGEN in this particular run consists of the basic economic loading order calculation using the individual list of FIXSYS and VARSYS thermal plants and contains all the information read from these two modules for the associated plants. This is shown in the middle part of page 3 of Fig. 6.2. The last two lines of this part list, in sequence, the resulting basic economic loading order and the full load total generation costs for the combined FIXSYS and VARSYS systems. This information will be passed by CONGEN onto MERSIM where it can be used for calculation of the actual loading order of the blocks of capacity of thermal plants, if the user so desires, (hydro plants will be handled automatically).

The bottom part of page 3 of Fig. 6.2 shows the results of the CONGEN analysis for the first year of study (1998). It starts with the number of Fourier coefficients (read from the LOADSY file), followed by the INDEX number of the data records type-1 in the sequence read for the year, and the constraints used to generate the configurations. These include the constraints on the minimum required number of sets (or projects) and the maximum additional number of sets (or projects) of each expansion candidate, followed by the minimum and maximum acceptable values for reserve margins. Next, the output reports the hydro-condition (1 in this case) for which the critical period and reserve margin of the configurations are to be calculated. This is followed by a summary of the Fixed System capacity by period, also broken down into thermal plants and the two composite hydro plants (in case P-S plants are present, their capacity will also be listed next), together with the information on the period peak loads (as read from the LOADSY file). The critical period (4 in this case) is next identified in the printout, and the minimum and maximum acceptable capacities (based on the reserve margins specified) in this period are listed. This is followed by the total capacity of the "minimum configuration" of the year (i.e. capacity of all plants in FIXSYS plus the capacities of all units or projects defined as minimum required shown above) in the critical period. The next output line is the minimum number of Fourier coefficients required for accurate LOLP calculation for the maximum reserve margin capacity (5 in this case). This value is an indication of how far is the maximum reserve margin capacity from the limit of validity of the Fourier Series approximation to the inverted load duration curve (this limit is equal to Peak load + 2*Min. load). A too high value of this required number of Fourier coefficients (i.e. close to the number defined in LOADSY or later in MERSIM) will indicate the user that the maximum reserve margin should be lowered if accurate calculation of LOLP is required for all configurations.

```
DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL
    0  NUCL  NUCLEAR PLANTS
    1  LIG1  LIGNITE PLANTS
    2  LIG2  LIGNITE PLANTS
    3  COAL  COAL PLANTS
    4  FOIL  OIL PLANTS
    5  GTGO  GAS TURBINES GAS-OIL
    6  NGAS  NATURAL GAS PLANTS
    7  ****  NOT APPLICABLE
    8  ****  NOT APPLICABLE
    9  ****  NOT APPLICABLE
   10  HYD1  HYDRO PLANTS GROUP 1
   11  HYD2  HYDRO PLANTS GROUP 2
----------------------------------------------------------------------------------------------


    1   35 1998    4    6    3 HYD1 HYD2    0.55    0.55 0.4500 0.3000 0.2500 0.0000 0.0000
  0
 FLG1    4  150.  270. 3300. 2850.  600.    0.   1   10  10.0   56  280.    4.06    4.90
 FLG2    9  150.  276. 2900. 2550.  495.    0.   2   10   8.9   56  280.    1.91    2.00
 FCOA    1  400.  580. 2800. 2300.  800.    0.   3   10   8.0   48  600.    2.92    5.00
 FOIL    7   80.  145. 2450. 2150.    0.  833.   4   10   7.3   42  140.    4.57    1.60
 F-GT    4   50.   50. 3300. 3300.  420.    0.   5    0   6.0   42   50.    8.35    1.60
 F-CC    1   87.  174. 2048. 2048.    0. 1266.   6    0  15.0   28  180.    2.10    5.00
  5533.    0. 1080. 2484.  580. 1015.  200.  174.    0.    0.    0.    3     2
      7     4     6     3     5     8
  15.46 15.56 20.89 23.50 26.16 30.93

  NAMH  NCH  JAV    CMWI    CMWB    CMWP    CMWC     CEM     CEP     CEA
  HYD1    3 1998  1650.0   210.0   965.0  1175.0   460.0   875.0  1335.0
  HYD1    3 1998  1650.0   214.6   780.4   995.0   470.0   595.0  1065.0
  HYD1    3 1998  1650.0   200.9  1049.1  1250.0   440.0  1180.1  1620.1
  HYD1    3 1998  1650.0   210.0   975.0  1185.0   460.0   925.0  1385.0
  HYD1    3 1998  1650.0   214.6   800.4  1015.0   470.0   645.0  1115.0
  HYD1    3 1998  1650.0   200.9  1099.1  1300.0   440.0  1230.1  1670.1
  HYD1    3 1998  1650.0   210.0  1005.0  1215.0   460.0  1025.0  1485.0
  HYD1    3 1998  1650.0   214.6   820.4  1035.0   470.0   745.0  1215.0
  HYD1    3 1998  1650.0   200.9  1149.1  1350.0   440.0  1330.1  1770.1
  HYD1    3 1998  1650.0   210.0  1035.0  1245.0   460.0  1075.0  1535.0
  HYD1    3 1998  1650.0   214.6   860.4  1075.0   470.0   845.0  1315.0
  HYD1    3 1998  1650.0   200.9  1399.1  1600.0   440.0  1430.1  1870.1
  HYD2    2 1998   206.4     0.0   187.0   187.0     0.0   102.1   102.1
  HYD2    2 1998   206.4     0.0   160.0   160.0     0.0    69.9    69.9
  HYD2    2 1998   206.4     0.0   206.0   206.0     0.0   134.1   134.1
  HYD2    2 1998   206.4     0.0   187.0   187.0     0.0   102.1   102.1
  HYD2    2 1998   206.4     0.0   160.0   160.0     0.0    69.9    69.9
  HYD2    2 1998   206.4     0.0   206.0   206.0     0.0   134.1   134.1
  HYD2    2 1998   206.4     0.0   187.0   187.0     0.0   102.1   102.1
  HYD2    2 1998   206.4     0.0   160.0   160.0     0.0    69.9    69.9
  HYD2    2 1998   206.4     0.0   206.0   206.0     0.0   134.1   134.1
  HYD2    2 1998   206.4     0.0   187.0   187.0     0.0   102.1   102.1
  HYD2    2 1998   206.4     0.0   160.0   160.0     0.0    69.9    69.9
  HYD2    2 1998   206.4     0.0   206.0   206.0     0.0   134.1   134.1
  1998
```

Figure 6.2. (page 1) CONGEN printout for a fixed expansion plan of the sample problem. Thermal fuel types and fixed system description for the year 1998 (from FIXSYS file).

```
     DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL
    0   58    0    4    5    3 HYD1 HYD2    0.55    0.55 0.4500 0.3000 0.2500 0.0000 0.0000
 0
V-CC    0  300.   600. 1950. 1950.    0. 1200.    6    0  10.0   28  600.    2.10    4.00
VLG1    0  150.   280. 3100. 2700.  710.    0.    1   10  10.0   56  280.    2.70    6.00
VLG2    0  150.   280. 3000. 2600. 1100.    0.    2   10  10.0   56  280.    2.70    6.00
VCOA    0  400.   580. 2600. 2200.    0.  800.    3   10   8.0   48  600.    2.92    5.00
NUCL    0  300.   600. 2600. 2340.    0.  194.    0    7  10.0   42  600.    2.50    0.50
    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     2     2
     5     4     2     1     3
  5.29 24.81 26.69 27.40 36.96
```

NAMH	NCH	JAV	CMWI	CMWB	CMWP	CMWC	CEM	CEP	CEA
HYD1	1	2003	200.0	0.0	160.0	160.0	0.0	70.3	70.3
HYD1	1	2003	200.0	0.0	140.0	140.0	0.0	42.6	42.6
HYD1	1	2003	200.0	0.0	200.0	200.0	0.0	98.0	98.0
HYD1	1	2003	200.0	0.0	160.0	160.0	0.0	70.3	70.3
HYD1	1	2003	200.0	0.0	140.0	140.0	0.0	42.6	42.6
HYD1	1	2003	200.0	0.0	200.0	200.0	0.0	98.0	98.0
HYD1	1	2003	200.0	0.0	160.0	160.0	0.0	70.3	70.3
HYD1	1	2003	200.0	0.0	140.0	140.0	0.0	42.6	42.6
HYD1	1	2003	200.0	0.0	200.0	200.0	0.0	98.0	98.0
HYD1	1	2003	200.0	0.0	160.0	160.0	0.0	70.3	70.3
HYD1	1	2003	200.0	0.0	140.0	140.0	0.0	42.6	42.6
HYD1	1	2003	200.0	0.0	200.0	200.0	0.0	98.0	98.0
HYD1	2	2004	850.0	137.0	513.0	650.0	300.0	390.3	690.3
HYD1	2	2004	850.0	182.6	447.4	630.0	400.0	202.6	602.6
HYD1	2	2004	850.0	91.3	658.7	750.0	200.0	598.0	798.0
HYD1	2	2004	850.0	91.3	588.7	680.0	200.0	590.3	790.3
HYD1	2	2004	850.0	137.0	518.0	655.0	300.0	342.6	642.6
HYD1	2	2004	850.0	45.7	714.3	760.0	100.0	788.0	888.0
HYD1	2	2004	850.0	68.5	641.5	710.0	150.0	740.3	890.3
HYD1	2	2004	850.0	45.7	624.3	670.0	100.0	602.6	702.6
HYD1	2	2004	850.0	22.8	827.2	850.0	50.0	998.0	1048.0
HYD1	2	2004	850.0	91.3	608.7	700.0	200.0	630.3	830.3
HYD1	2	2004	850.0	137.0	528.0	665.0	300.0	362.6	662.6
HYD1	2	2004	850.0	45.7	754.3	800.0	100.0	848.0	948.0
HYD2	1	2002	120.0	0.0	100.0	100.0	0.0	67.5	67.5
HYD2	1	2002	120.0	0.0	80.0	80.0	0.0	51.4	51.4
HYD2	1	2002	120.0	0.0	120.0	120.0	0.0	83.7	83.7
HYD2	1	2002	120.0	0.0	100.0	100.0	0.0	67.5	67.5
HYD2	1	2002	120.0	0.0	80.0	80.0	0.0	51.4	51.4
HYD2	1	2002	120.0	0.0	120.0	120.0	0.0	83.7	83.7
HYD2	1	2002	120.0	0.0	100.0	100.0	0.0	67.5	67.5
HYD2	1	2002	120.0	0.0	80.0	80.0	0.0	51.4	51.4
HYD2	1	2002	120.0	0.0	120.0	120.0	0.0	83.7	83.7
HYD2	1	2002	120.0	0.0	100.0	100.0	0.0	67.5	67.5
HYD2	1	2002	120.0	0.0	80.0	80.0	0.0	51.4	51.4
HYD2	1	2002	120.0	0.0	120.0	120.0	0.0	83.7	83.7
HYD2	2	2005	313.4	0.0	220.0	220.0	0.0	156.1	156.1
HYD2	2	2005	313.4	0.0	180.0	180.0	0.0	114.4	114.4
HYD2	2	2005	313.4	0.0	260.0	260.0	0.0	198.0	198.0
HYD2	2	2005	313.4	0.0	220.0	220.0	0.0	156.1	156.1
HYD2	2	2005	313.4	0.0	180.0	180.0	0.0	114.4	114.4
HYD2	2	2005	313.4	0.0	260.0	260.0	0.0	198.0	198.0
HYD2	2	2005	313.4	0.0	220.0	220.0	0.0	156.1	156.1
HYD2	2	2005	313.4	0.0	180.0	180.0	0.0	114.4	114.4
HYD2	2	2005	313.4	0.0	260.0	260.0	0.0	198.0	198.0
HYD2	2	2005	313.4	0.0	220.0	220.0	0.0	156.1	156.1
HYD2	2	2005	313.4	0.0	180.0	180.0	0.0	114.4	114.4
HYD2	2	2005	313.4	0.0	260.0	260.0	0.0	198.0	198.0

```
    0
```

Figure 6.2. (page 2) CONGEN printout for a fixed expansion plan of the sample problem. Variable system description (from VARSYS file).

```
                             WASP  COMPUTER  PROGRAM  PACKAGE

                                      CONGEN  MODULE

                                       CASE  STUDY

                    DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL

                                 **************************************
                                 *                                    *
                                 *   LIST OF VAR. EXPAN. CANDIDATES   *
                                 *                                    *
                                 **************************************
                                 *          THERMAL   PLANTS          *
                                 *                                    *
                                 *      SEQU.NUMBER       NAME        *
                                 *           1            V-CC        *
                                 *           2            VLG1        *
                                 *           3            VLG2        *
                                 *           4            VCOA        *
                                 *           5            NUCL        *
                                 *                                    *
                                 **************************************
                                 *        HYDROELECTRIC PLANTS        *
                                 *                                    *
                                 *      SEQU.NUMBER       NAME        *
                                 *           6            HYD1        *
                                 *           7            HYD2        *
                                 *                                    *
                                 **************************************
ECON. L.O. = ECONOMIC LOADING ORDER DEFINED IN ASCENDING ORDER OF TOTAL FULL LOAD UNIT GENERATION COSTS
 TOTAL FLD  = TOTAL FULL LOAD UNIT GENERATION COSTS

 FIXED    SYSTEM :
 *****************
 ECON. L.O.      7      4      6      3      5      8

 TOTAL FLD   15.46  15.56  20.89  23.50  26.16  30.93

 VARIABLE SYSTEM :
 *****************
 ECON. L.O.     13     12     10      9     11

 TOTAL FLD    5.29  24.81  26.69  27.40  36.96

 COMBINED SYSTEM :
 *****************
 ECON. L.O.     13      7      4      6      3     12      5     10      9      8     11

 TOTAL FLD    5.29  15.46  15.56  20.89  23.50  24.81  26.16  26.69  27.40  30.93  36.96



 NUMBER OF FOURIER COEFF. IS    50
 INDEX READ    4
 INDEX READ    8
 INDEX READ    2
 INDEX READ    3
 INDEX READ    1
 CONDITIONS GOVERNING ALTERNATIVE GENERATION  *  *  *  *  *  *  YEAR 1998  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*
 MINIMUM REQUIRED OF EACH ALTERNATIVE    0   0   0   0   0   0   0
 MAXIMUM ADDITIONAL EACH  ALTERNATIVE    0   0   0   0   0   0   0
 RESERVE RANGE PERMITTED IN CRITICAL PERIOD (%)    15.00   50.00
 CALCULATION OF CRITICAL PERIOD IS BASED ON HYDRO CONDITION  1

       TOTAL CAPAC.                                        PERIOD
 PER    IN FIXSYS    --- THERMAL  HYDRO 1  HYDRO 2 ---    PEAK LOAD
  1        6895.0         5533.0   1175.0    187.0         5400.0
  2        6905.0         5533.0   1185.0    187.0         5220.0
  3        6935.0         5533.0   1215.0    187.0         5580.0
  4        6965.0         5533.0   1245.0    187.0         6000.0
 CRITICAL PERIOD IS   4
 CAPACITY RANGE IN CRITICAL PERIOD IS       6900.0           9000.0
 COMMITTED CAPACITY SPECIFIED IN CRIT PERIOD        6965.0

 MINIMUM NUMBER OF FOURIER COEFF. CORRESPONDING TO MAXIMUM RESERVE MARGIN IN CRIT PER IS    5

 STATE IC   CAP     ACCEPTED CONFIGURATION

    1   1   6965.   0   0   0   0   0   0   0
 CONFIGURATIONS THIS YEAR             1
 CONFIGURATIONS THROUGH THIS YEAR     1
 *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  END OF YEAR 1998  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
```

Figure 6.2. (page 3) CONGEN printout for a fixed expansion plan of the sample problem. Cover page, economic loading order for FIXSYS/VARSYS thermal plants, and results for the year 1998.

```
7   33 2004    4    6    3 HYD1 HYD2    0.55    0.55 0.4500 0.3000 0.2500 0.0000 0.0000    0
 FLG1    3  150.  270. 3300. 2850.  600.    0.    1   10  10.0   56  280.    4.06    4.90
 FLG2    9  150.  276. 2900. 2550.  495.    0.    2   10   8.9   56  280.    1.91    2.00
 FCOA    2  400.  580. 2800. 2300.  800.    0.    3   10   8.0   48  600.    2.92    5.00
 FOIL    7   80.  145. 2450. 2150.    0.  833.    4   10   7.3   42  140.    4.57    1.60
 F-GT    4   50.   50. 3300. 3300.  420.    0.    5    0   6.0   42   50.    8.35    1.60
 F-CC    3   87.  174. 2048. 2048.    0. 1266.    6    0  15.0   28  180.    2.10    5.00
  6191.    0.  810. 2484. 1160. 1015.  200.  522.    0.    0.    0.    4     3

  NAMH  NCH  JAV    CMWI    CMWB    CMWP    CMWC     CEM     CEP     CEA
  HYD1    4 2004   400.0     0.0   325.0   325.0     0.0   135.0   135.0
  HYD1    4 2004   400.0     0.0   295.0   295.0     0.0   115.0   115.0
  HYD1    4 2004   400.0     0.0   350.0   350.0     0.0   170.1   170.1
  HYD1    4 2004   400.0     0.0   325.0   325.0     0.0   135.0   135.0
  HYD1    4 2004   400.0     0.0   295.0   295.0     0.0   115.0   115.0
  HYD1    4 2004   400.0     0.0   350.0   350.0     0.0   170.1   170.1
  HYD1    4 2004   400.0     0.0   325.0   325.0     0.0   135.0   135.0
  HYD1    4 2004   400.0     0.0   295.0   295.0     0.0   115.0   115.0
  HYD1    4 2004   400.0     0.0   350.0   350.0     0.0   170.1   170.1
  HYD1    4 2004   400.0     0.0   325.0   325.0     0.0   135.0   135.0
  HYD1    4 2004   400.0     0.0   295.0   295.0     0.0   115.0   115.0
  HYD1    4 2004   400.0     0.0   350.0   350.0     0.0   170.1   170.1
  HYD2    3 2004   386.4     0.0   342.0   342.0     0.0   185.8   185.8
  HYD2    3 2004   386.4     0.0   300.0   300.0     0.0   138.6   138.6
  HYD2    3 2004   386.4     0.0   371.0   371.0     0.0   237.7   237.7
  HYD2    3 2004   386.4     0.0   342.0   342.0     0.0   185.8   185.8
  HYD2    3 2004   386.4     0.0   300.0   300.0     0.0   138.6   138.6
  HYD2    3 2004   386.4     0.0   371.0   371.0     0.0   237.7   237.7
  HYD2    3 2004   386.4     0.0   342.0   342.0     0.0   185.8   185.8
  HYD2    3 2004   386.4     0.0   300.0   300.0     0.0   138.6   138.6
  HYD2    3 2004   386.4     0.0   371.0   371.0     0.0   237.7   237.7
  HYD2    3 2004   386.4     0.0   342.0   342.0     0.0   185.8   185.8
  HYD2    3 2004   386.4     0.0   300.0   300.0     0.0   138.6   138.6
  HYD2    3 2004   386.4     0.0   371.0   371.0     0.0   237.7   237.7
  2004

 INDEX READ    2
 INDEX READ    4
 INDEX READ    1
 CONDITIONS GOVERNING ALTERNATIVE GENERATION  *  *  *  *  *  *  YEAR 2004  *  *  *  *  *  *  *  *  *
*  *  *  *  *  *  *  *  *  *
 MINIMUM REQUIRED OF EACH ALTERNATIVE    3   1   0   1   0   2   1
 MAXIMUM ADDITIONAL EACH  ALTERNATIVE    0   0   0   0   0   0   0
 RESERVE RANGE PERMITTED IN CRITICAL PERIOD (%)    20.00   40.00
 CALCULATION OF CRITICAL PERIOD IS BASED ON HYDRO CONDITION  1

       TOTAL CAPAC.                                        PERIOD
 PER    IN FIXSYS    --- THERMAL  HYDRO 1  HYDRO 2 ---    PEAK LOAD
  1        6858.0        6191.0    325.0    342.0          7473.8
  2        6858.0        6191.0    325.0    342.0          7224.7
  3        6858.0        6191.0    325.0    342.0          7722.9
  4        6858.0        6191.0    325.0    342.0          8304.2
 CRITICAL PERIOD IS   4
 CAPACITY RANGE IN CRITICAL PERIOD IS       9965.1        11625.9
 COMMITTED CAPACITY SPECIFIED IN CRIT PERIOD       10318.0

 MINIMUM NUMBER OF FOURIER COEFF. CORRESPONDING TO MAXIMUM RESERVE MARGIN IN CRIT PER IS    4

 STATE IC   CAP     ACCEPTED CONFIGURATION

    7   1  10318.   3   1   0   1   0   2   1
 CONFIGURATIONS THIS YEAR            1
 CONFIGURATIONS THROUGH THIS YEAR     7
* * * * * * * * * * * * * * * * * * * END OF YEAR 2004 * * * * * * * * * * * * * * * * * *
```

Figure 6.2. (page 4) CONGEN printout for a fixed expansion plan of the sample problem. Fixed system description and results for the year 2004.

```
LIST OF # OF CONFIGURATIONS PER YEAR

  YEAR        #C      #CCUM
  1998         1          1
  1999         1          2
  2000         1          3
  2001         1          4
  2002         1          5
  2003         1          6
  2004         1          7
  2005         1          8
  2006         1          9
  2007         1         10
  2008         1         11
  2009         1         12
  2010         1         13
  2011         1         14
  2012         1         15
  2013         1         16
  2014         1         17
  2015         1         18
  2016         1         19
  2017         1         20

 TOTAL        20
```

Figure 6.2. (page 5) COGEN printout of a fixed expansion plan of the sample problem. List of number of configurations generated by CONGEN Run-1.

The printout proceeds with the actual list of configurations generated by CONGEN for this year while respecting all above mentioned constraints. The information for each configuration (state) is reported in one line of the output as follows (with reference to the state on page 3 of Fig. 6.2): The first column (STATE) is the number of the configuration throughout the run (1); the second column (IC) the state number of the year (1); the third column (CAP) the capacity of the state (6965. MW) in the critical period (notice it is within the range reported above). The right hand columns list the accepted configurations for the year. Since this is a predetermined expansion plan, only one configuration has been accepted. This is identified with "0" for all expansion candidates reported on top. The remaining information consists of the number of configurations for the year and the total number of accepted configurations accumulated through the current year (both 1 in this case).

A similar output is produced for each year of the study with the only difference that the information read by CONGEN from the VARSYS file will not be repeated. However, the Fixed System description for the year will be listed. As an example, page 4 of Fig. 6.2 shows the output for year 2004. Since some changes were made to thermal and hydro plants of FIXSYS up to this year (see Fig. 4.2 page 4), these have been reported in the Fixed System description. (Note the value of STATE is cumulative (7) as is the last line of results (7)).

After reporting information for all years, at the end of the printout, a list of the number of configurations generated within the constraints for each year is included. For a predetermined expansion plan run, there must be one and only one accepted configuration per year as shown in page 5 of Fig. 6.2. This is also an indication of successful run of CONGEN for a predetermined expansion plan. If for any year an error message “NO STATE DEFINED” appears, it would mean that the total capacity for that year does not fall in the required capacity range determined by reserve margins (the user may consult Chapter 13 for correcting the inputs in such a case). Other features of the CONGEN printout are described in the discussion of the variable expansion runs for the sample problem (see Section 6.3.4).

6.3.3. Input data for dynamic expansion plans

Sections 6.3.1 and 6.3.2 describe the first CONGEN run for the sample problem which corresponds to a fixed expansion plan of DEMOCASE for which CONGEN was not actually used as an alternative configuration generator but, rather, to set up the EXPANALT file to be used by MERSIM (and DYNPRO), and to evaluate a predetermined expansion plan generated by the user. In addition, such a run (or runs) permitted to verify that the files created by Modules 1 to 3 include the intended information and that the data records used in CONGEN input file are correct. This section concentrates on a discussion of the input data required for dynamic expansion plans (or variable expansion plans) in which CONGEN is used to generate all alternative configurations which will satisfy the user-imposed constraints on reserve margins and the number of units (or projects) of each expansion candidate.

Section 6.3.3.1 discusses the input data for the first of such dynamic expansion plans (referred to as CONGEN Run-2), and Section 6.3.3.2 the input data for the last of a series of runs (referred to as CONGEN Run-3) made while searching for the optimal solution for the expansion of the hypothetical system represented by the Sample problem DEMOCASE. The corresponding printouts for these two CONGEN runs are discussed in Section 6.3.4.

6.3.3.1. Input data for the first dynamic expansion plan (CONGEN Run-2)

Figure 6.3 shows the input data prepared for the first variable expansion CONGEN run of the sample problem. The first data record is a type-X record specifying the title of the study (kept the same along all runs as stated in Section 6.3.1), and the printing option for the FIXSYS and VARSYS files read by CONGEN, which in this case has been set to 0 so as to reduce the printout for the run. (Note that the FIXPLANT and VARPLANT files have already been checked while executing the fixed expansion CONGEN run or runs).

The second input line in Fig. 6.3 is a type-1 INDEX=4 record followed by a type-4 record specifying the minimum and maximum reserve margins (in % of peak load) in the critical period. The minimum and maximum reserve margin requirements should be set so that those configurations with a capacity outside this range will not be "accepted" by CONGEN. This will allow saving computer time in the execution of Modules 4 to 6, and eliminating from the economic comparison those system configurations considered to be not competitive[3] . In the sample problem, since this is the first variable expansion CONGEN run, the minimum and maximum reserve margins have been set to 15% and 50% respectively, for first few years of study and changed to 20% and 40% later (2004) in order not to eliminate too many configurations[4] (The number of accepted configurations is kept reduced in the sample run by means of the constraints on the number of sets or projects of the expansion candidates).

[3] Too-low reserve margins will lead to system configurations with LOLP considerably greater than the maximum allowed (i.e. not technically acceptable) whereas too-high reserve margins will lead to system configurations having excessive installed capacity (i.e. not economically competitive).

[4] The reserve margins for variable expansion CONGEN runs of a WASP study must be carefully selected by the user after having executed several fixed expansion CONGEN runs, and applying past experience on "acceptable" reserve margins for the power system under study, in order not to reject those configurations which might represent the optimal solution for the expansion planning study. By looking at the output of the first variable expansion run, one can usually estimate what the reserve range for a case study should be. As the plant sizes in the system become larger, the reserve margin necessary for an acceptable LOLP also increases; thus, the reserve margin requirements should be future-oriented.

```
DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL        0
   4
       15.       50.
   2
   0   0   0   0   0   0   0
   3
   0   0   0   0   0   0   0
   1           (END OF YEAR 1998)
   1           (END OF YEAR 1999)
   1           (END OF YEAR 2000)
   3
   2   0   0   0   0   0   0
   1           (END OF YEAR 2001)
   3
   2   2   0   2   0   0   1
   1           (END OF YEAR 2002)
   2
   1   0   0   0   0   0   0
   3
   2   2   0   2   0   1   1
   1           (END OF YEAR 2003)
   2
   2   0   0   0   0   0   0
   3
   2   2   0   2   0   2   1
   4
       20.       40.
   1           (END OF YEAR 2004)
   2
   2   1   0   0   0   1   1
   3
   2   2   0   2   0   1   1
   1           (END OF YEAR 2005)
   2
   2   1   0   1   0   2   1
   3
   2   2   0   2   1   0   1
   1           (END OF YEAR 2006)
   2
   2   1   0   2   0   2   2
   3
   2   2   2   2   1   0   0
   1           (END OF YEAR 2007)
   2
   2   1   0   2   0   2   2
   3
   2   2   2   2   1   0   0
   1           (END OF YEAR 2008)
   2
   2   1   0   3   0   2   2
   3
   2   2   2   2   1   0   0
   1           (END OF YEAR 2009)
   2
   2   1   1   4   0   2   2
   3
   2   2   2   2   1   0   0
   1           (END OF YEAR 2010)
   2
   2   1   2   4   0   2   2
   3
   2   2   2   2   2   0   0
   1           (END OF YEAR 2011)
   2
   2   1   2   5   0   2   2
   3
   2   2   2   2   2   0   0
   1           (END OF YEAR 2012)
   2
   2   2   3   6   0   2   2
   3
   2   2   2   2   2   0   0
   1           (END OF YEAR 2013)
   2
   2   2   4   7   0   2   2
   3
   2   2   2   2   2   0   0
   1           (END OF YEAR 2014)
   2
   2   2   4   7   1   2   2
   3
   2   2   2   2   2   0   0
   1           (END OF YEAR 2015)
   2
   2   3   4   8   1   2   2
   3
   2   2   2   2   2   0   0
   1           (END OF YEAR 2016)
   2
   2   3   5   7   2   2   2
   3
   2   2   2   2   2   0   0
   1           (END OF YEAR 2017)
```

Figure 6.3. CONGEN (Run-2) input data for the first variable expansion for the sample problem (DEMOCASE).

The next input line is a type-1 INDEX=2 record. This is followed by a type-2 record which indicates the minimum number of sets (or projects) of each VARSYS plant that can be contained in the configurations for this year. In the sample problem, no set or project from the VARSYS candidates is required beyond those in FIXSYS in 1998. Thus, the type-2 record gives a zero for all expansion candidates. It should be noted that these are equal to the respective default values so that these two input lines could have been omitted.

The subsequent two lines in Fig. 6.3 are a type-1 INDEX=3 record and a type-3 record, which are used to specify the maximum number of expansion candidates units (or projects) permitted in addition to the minimum number required (given on the type-2 record above). The type-3 record, in other words, shows the "tunnel width" for the year. This is usually a number between 0 and 2; otherwise there would be too many configurations (possible combinations of all alternatives allowed) generated. This, in turn, will increase the computer time required for execution of modules 5 and 6. In the sample problem, the tunnel width in 1998 is held to zero for all VARSYS candidates. Finally, the last line for this year is a type-1 INDEX=1 record (the information in cols. 16–28 of the record is not read by the computer) instructing the computer to carry out the calculations for this year.

The input for the next two years of study (1999, 2000) contains only one type-1 INDEX=1 record each, meaning that the information provided for the first year also applies to these years (as it has been assumed that no addition of new capacity will be possible in these years also). The data for 4th year (2001) begin with a type-1 INDEX=3 record followed by a type-3 record. This opens the tunnel width to "2" for the VARSYS plant number 1 (V-CC), while that for all the remaining candidates is kept constant to "0". The subsequent line is a type-1 INDEX=1 record, indicating end of input data for the year. Since no other type of data record was used for this year, all other constraints which were specified for the preceding year are still applicable for this year.

It may be pointed out that while preparing the input for the first dynamic (variable) expansion run of CONGEN, a general rule can be applied; tunnel width for each expansion candidate may be opened by introducing type-3 record to the input of the fixed expansion run, and while doing this, the number of units (projects) specified on type-2 record of the fixed expansion run may be reduced by one and a tunnel width of two may be opened for the respective candidate(s). However, the physical limits on allowing additional units (projects) should be respected, e.g. if only one additional hydro or P-S project is available in a year then maximum allowed additional number would be one for that year (obey year of availability).

Following the above rule, the remaining input data in Fig. 6.3 define constraints in the expansion schedule up to the last year of the study (2017) by means of the corresponding records type-1 INDEX=2 (and/or INDEX=3), each one followed by the respective record type-2 (and/or type-3), introducing changes to the minimum required number of sets or projects (and/or to the tunnel width) for each expansion candidate in the applicable year. In each case, a record type-1 INDEX=1 is used to indicate end of input information for the year.

As illustrated in this CONGEN run, groups of a type-1 INDEX=2 and a type-2 records and a type-1 INDEX=3 and a type-3 records may be used for any year in order to direct the area of optimization. However, the changes made by these records must be introduced with care in order to allow the possibility of transition from one year to the next. In this respect, the following rules should be kept in mind:

Each number included in the new type-2 should be greater than, or equal to the respective number on the last type-2 record previously used for the preceding years.

The sum of the numbers given in the type-2 and type-3 records for each expansion candidate should always be greater than, or equal to, the sum of the respective numbers applicable for the preceding year.

It should be mentioned here that the selection of adequate values to be used as minimum required number of sets (type-2 record) and tunnel widths (type-3 record) for the first variable expansion plan of a WASP case study usually involves execution of several CONGEN runs until a satisfactory number of configurations is obtained for each year, without exceeding the program capabilities (500 per year and 5000 in a single run).

For the first of such runs it is convenient to make some hand calculations of the capacity involved and required additions on a year-by-year basis. The screening curve approach (see Section 10.2) may also be useful in the determination of the first guess as to the preferred candidates and the total capacity of each plant to be accepted each year. Furthermore, the series of fixed expansion runs of CONGEN-MERSIM-DYNPRO may help the user in the selection of the first guess. In the case of the sample problem, the first variable expansion run of CONGEN was determined after three runs of the program for several changes in the definitions of type-2 and type-3 records from year to year.

The use of constraints on the number of sets or projects of the expansion candidates that can be contained in system configurations for the year, permits the user to direct the area of study towards the range of configurations which are believed to be the most economical for the power system under study. Later, the report of the DYNPRO module will tell the user if any of the restrictions imposed in the current CONGEN run acted as a constraint on the solution found. If this is the case, the user can simply redefine these restrictions and perform a new optimization iteration (a new variable expansion plan) involving sequential runs of Modules 4 to 6 in the same order (CONGEN — MERSIM — DYNPRO). This procedure would continue until the user found a solution which was free of user-imposed constraints. Chapter 8 describes how to proceed in order to obtain the optimal solution free of user-imposed constraints.

6.3.3.2. Input data for the last dynamic expansion plan (CONGEN Run-3)

Before discussing the last dynamic expansion plan for the case example, it is necessary to discuss the rules set up for the determination of the optimal solution. These take into account other issues rather than the pure economic ones, based on planning guidelines and regulations applicable to the hypothetical country and power system under study. They include the following:

No more than 4 units of the expansion candidate number 1 (V-CC) are to be included in the reference optimal solution to reflect energy policies of the hypothetical country relating to the use of natural gas for power generation.

A maximum of 4 Nuclear power plants can be introduced during the study period, starting from the year 2006.

With these rules in mind, several variable expansion runs were performed for the DEMOCASE. Figure 6.4 illustrates the input data used for the last variable expansion

CONGEN run (CONGEN Run-3). It can be seen in this figure that the first 13 lines (up to year 2001) are all identical to the respective records used for CONGEN Run-2. Thus, all constraints imposed for the years 1998–2001, in this run, are exactly the same as in CONGEN Run-2.

From year 2002 onwards, however, the constraints on reserve margins or on expansion schedule differ from the ones imposed in CONGEN Run-2. For example, the first input line for this year is type-1 INDEX=2 record followed by type-2 record to specify the "minimum configuration" for year 2002. Comparing it to the data of Fig. 6.3, it can be seen that there was no type-2 record for this year in CONGEN Run-2, meaning that the data for the previous year were applicable. Based on various iterations, it was found that the first expansion candidate (V-CC) was favoured and more units of this type were required by the system. This was allowed in the CONGEN Run-3 by introducing one unit as the minimum configuration and allowing two more in the tunnel width. The tunnel width for all candidates in this year are identical in the two runs. Note that the tunnel width of candidate number 5 (NUCL) is maintained to zero taken into consideration that this plant requires 7 years of construction time. Similarly, the tunnel width of candidate number 6 (HYD1) is also zero since the first hydro project of this type (VHY2) is available for expansion in year 2003. The usual type-1 INDEX=1 record is used to indicate end of input information for the year.

The remaining records in Figure 6.4 define constraints on the expansion schedule up to the last year of study. All changes introduced in the constraints for expansion schedule and reserve margins are the result of interpreting the messages given in the printout of Module 6, after several dynamic expansion plans (7 in the case of the sample problem DEMOCASE) had been executed. Chapter 8 describes how to interpret the messages in the DYNPRO printout and to proceed to a new dynamic optimization iteration of WASP Modules 4 to 6. As explained earlier, the use of reserve margin constraints helps reducing the number of configurations which have not been included in the best solutions found through the dynamic optimization process; thus reducing considerably the computer time required for execution of these modules as explained in Chapters 7 and 8.

On the other hand, the values of the minimum and maximum reserve margins to be used in any variable expansion CONGEN run must be carefully selected by the user in order not to reject any configuration which has been found economically competitive during the optimization process. By moving the reserve margins in one direction or another, the user is able to focus the area of interest for the next optimization run. Nevertheless, such moves have to be made with great care and the results of CONGEN be revised accordingly. In this revision, it is important to ensure that sufficient competition exists between the alternative expansion candidates and that no short cuts are being imposed by the user. For example, too narrow gaps between the minimum and maximum reserve margins may lead to a DYNPRO solution free of messages that is far from the optimum even if the tunnel widths in CONGEN are wide open. This can be found out by reviewing the CONGEN output, where most probably the number of configurations in one or several years is too low or the possible expansion paths can follow only one single configuration in a given year.

```
DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL        0
   4
      15.       50.
   2
   0   0   0   0   0   0   0
   3
   0   0   0   0   0   0   0
   1          (END OF YEAR 1998)
   1          (END OF YEAR 1999)
   1          (END OF YEAR 2000)
   3
   2   0   0   0   0   0   0
   1          (END OF YEAR 2001)
   2
   1   0   0   0   0   0   1
   3
   2   2   0   2   0   0   0
   1          (END OF YEAR 2002)
   2
   2   0   0   0   0   1   1
   3
   2   2   0   2   0   0   0
   1          (END OF YEAR 2003)
   2
   2   0   0   0   0   2   1
   3
   2   2   0   2   0   0   0
   4
      20.       40.
   1          (END OF YEAR 2004)
   2
   2   0   0   0   0   2   2
   3
   2   2   0   2   0   0   0
   1          (END OF YEAR 2005)
   2
   2   0   0   0   0   2   2
   3
   2   2   0   2   1   0   0
   1          (END OF YEAR 2006)
   2
   2   0   0   1   0   2   2
   3
   2   2   2   2   1   0   0
   1          (END OF YEAR 2007)
   2
   2   0   0   2   0   2   2
   3
   2   2   2   2   1   0   0
   1          (END OF YEAR 2008)
   2
   2   0   0   3   0   2   2
   3
   2   2   2   2   1   0   0
   1          (END OF YEAR 2009)
   2
   2   0   0   4   0   2   2
   3
   2   2   2   2   1   0   0
   1          (END OF YEAR 2010)

   . . . . . . . . . some text deleted . . . . . .

   2   0   0   5   0   2   2
   3
   2   2   2   2   2   0   0
   1          (END OF YEAR 2012)
   2
   2   0   1   6   0   2   2
   3
   2   2   2   2   2   0   0
   1          (END OF YEAR 2013)
   2
   2   0   3   7   0   2   2
   3
   2   2   2   2   2   0   0
   1          (END OF YEAR 2014)
   2
   2   0   4   7   1   2   2
   3
   2   2   2   2   2   0   0
   1          (END OF YEAR 2015)
   2
   2   0   4   8   1   2   2
   3
   2   2   2   2   2   0   0
   1          (END OF YEAR 2016)
   2
   2   0   5   8   2   2   2
   3
   2   2   2   2   2   0   0
   1          (END OF YEAR 2017)
```

Figure 6.4. CONGEN (Run-3) input data for the last variable expansion for the sample problem (DEMOCASE).

6.3.4. Printouts for dynamic expansion plans

The CONGEN printouts for the variable expansion runs, using the data listed in figures 6.3 and 6.4, are essentially the same as for fixed expansion runs (see Section 6.3.2) with some differences: Firstly, since the file printing option (IOFILE) chosen for variable expansion runs was "0," the printouts do not include the listing of the information on the FIXSYS and VARSYS files. Secondly, variable expansion runs usually include more than one configuration per year as can be seen in Figures 6.5 and 6.6. Lastly, since the configurations simulated by MERSIM in the previous iteration have been saved in SIMULOLD.BIN file, the CONGEN printout will identify the "new" configurations for the run, i.e. those states generated by CONGEN not contained in the current SIMULOLD file and which are expected to be simulated in the subsequent MERSIM run.

Figure 6.5 shows a sample of the printout produced by CONGEN for the first variable expansion run (using the data of Fig. 6.3) and Figure 6.6 of the one produced for the last variable expansion run (using the data of Fig. 6.4) of our DEMOCASE. The printout for some typical years (1998 and 2002) is shown in each figure.

As can be seen in both figures, the printout for the year reports the data on capacities and the conditions governing acceptance of the configurations, along with the number of the critical period, and the minimum number of Fourier coefficients corresponding to the maximum reserve capacity margin in the critical period.

The printout for the year continues with the list of accepted configurations in the year. Here again, *STATE* is the number of the configuration as counted from the first year of study; *IC* is the configuration number within the year; *CAP* is the installed capacity in the critical period; and finally under *ACCEPTED CONFIGURATION* each configuration is identified by the number of sets or projects of each expansion candidate considered. As can be seen in both figures, an additional column is printed next to *IC* with a header *NEW*. Here the printout identifies which are the new configurations for this run. Configurations marked with asterisks under this column correspond to states already simulated in previous MERSIM runs (see page 1 of Fig. 6.5).

Both figures show also the total number of "accepted" configurations which were generated in the run (1336 for CONGEN Run-2, and 578 for CONGEN Run-3). This listing appears immediately after the printout for the last year of study under a header *#OF CONFIGURATIONS* shown at the bottom of these figures. They summarize the number of total accepted and new configurations per year. Note that in the case of CONGEN Run-3 no new configuration was generated in the run.

Before proceeding to execute the runs for the subsequent WASP-IV modules, the user should revise very carefully the printout for the current CONGEN run in order to make sure that the intended configurations are included in the EXPANALT file created by this run, and that no ERROR (or WARNING) messages appear in the printout. Section 5 of chapter 13 discusses the error and warning messages applicable to CONGEN.

```
NUMBER OF FOURIER COEFF. IS    50
 INDEX READ    4
 INDEX READ    2
 INDEX READ    3
 INDEX READ    1
 CONDITIONS GOVERNING ALTERNATIVE GENERATION  *  *  *  *  *  *  YEAR 1998  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
 MINIMUM REQUIRED OF EACH ALTERNATIVE    0   0   0   0   0   0   0
 MAXIMUM ADDITIONAL EACH  ALTERNATIVE    0   0   0   0   0   0   0
 RESERVE RANGE PERMITTED IN CRITICAL PERIOD (%)    15.00   50.00
 CALCULATION OF CRITICAL PERIOD IS BASED ON HYDRO CONDITION  1

       TOTAL CAPAC.                                        PERIOD
 PER    IN FIXSYS    --- THERMAL  HYDRO 1  HYDRO 2 ---    PEAK LOAD
  1        6895.0         5533.0   1175.0    187.0          5400.0
  2        6905.0         5533.0   1185.0    187.0          5220.0
  3        6935.0         5533.0   1215.0    187.0          5580.0
  4        6965.0         5533.0   1245.0    187.0          6000.0
 CRITICAL PERIOD IS   4
 CAPACITY RANGE IN CRITICAL PERIOD IS       6900.0          9000.0
 COMMITTED CAPACITY SPECIFIED IN CRIT PERIOD        6965.0

 MINIMUM NUMBER OF FOURIER COEFF. CORRESPONDING TO MAXIMUM RESERVE MARGIN IN CRIT PER IS    5

 STATE IC NEW   CAP     ACCEPTED CONFIGURATION

    1   1 ***   6965.   0   0   0   0   0   0   0
 CONFIGURATIONS THIS YEAR            1
 CONFIGURATIONS THROUGH THIS YEAR     1
 NEW CONFIG.(S) THROUGH THIS YEAR     0
 *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  END OF YEAR 1998  *  *  *  *  *  *  *  *  *  *  *  *  *
---------------------------------------------------------------------------------------------------------------------------



INDEX READ    2
 INDEX READ    3
 INDEX READ    1
 CONDITIONS GOVERNING ALTERNATIVE GENERATION  *  *  *  *  *  *  YEAR 2002  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
 MINIMUM REQUIRED OF EACH ALTERNATIVE    0   0   0   0   0   0   0
 MAXIMUM ADDITIONAL EACH  ALTERNATIVE    2   2   0   2   0   0   1
 RESERVE RANGE PERMITTED IN CRITICAL PERIOD (%)    15.00   50.00
 CALCULATION OF CRITICAL PERIOD IS BASED ON HYDRO CONDITION  1

       TOTAL CAPAC.                                        PERIOD
 PER    IN FIXSYS    --- THERMAL  HYDRO 1  HYDRO 2 ---    PEAK LOAD
  1        7128.0         6461.0    325.0    342.0          6746.8
  2        7128.0         6461.0    325.0    342.0          6521.9
  3        7128.0         6461.0    325.0    342.0          6971.7
  4        7128.0         6461.0    325.0    342.0          7496.5
 CRITICAL PERIOD IS   4
 CAPACITY RANGE IN CRITICAL PERIOD IS       8620.9         11244.7
 COMMITTED CAPACITY SPECIFIED IN CRIT PERIOD        7128.0

 MINIMUM NUMBER OF FOURIER COEFF. CORRESPONDING TO MAXIMUM RESERVE MARGIN IN CRIT PER IS    5

 STATE IC NEW   CAP     ACCEPTED CONFIGURATION

    6   1   1   8888.   2   2   0   0   0   0   0
    7   2   2   8908.   2   0   0   1   0   0   0
    8   3   3   9188.   2   1   0   1   0   0   0
    9   4   4   8868.   1   2   0   1   0   0   0
   10   5   5   9468.   2   2   0   1   0   0   0
   11   6   6   8888.   1   0   0   2   0   0   0
   12   7   7   9488.   2   0   0   2   0   0   0
   13   8   8   9168.   1   1   0   2   0   0   0
   14   9   9   9768.   2   1   0   2   0   0   0
   15  10  10   9448.   1   2   0   2   0   0   0
   16  11  11  10048.   2   2   0   2   0   0   0
   17  12 ***   8708.   2   1   0   0   0   0   1
   18  13 ***   8988.   2   2   0   0   0   0   1
   19  14 ***   9008.   2   0   0   1   0   0   1
   20  15 ***   8688.   1   1   0   1   0   0   1
   21  16 ***   9288.   2   1   0   1   0   0   1
   22  17 ***   8968.   1   2   0   1   0   0   1
   23  18 ***   9568.   2   2   0   1   0   0   1
   24  19 ***   8988.   1   0   0   2   0   0   1
   25  20 ***   9588.   2   0   0   2   0   0   1
   26  21 ***   9268.   1   1   0   2   0   0   1
   27  22 ***   9868.   2   1   0   2   0   0   1
   28  23 ***   9548.   1   2   0   2   0   0   1
   29  24 ***  10148.   2   2   0   2   0   0   1
 CONFIGURATIONS THIS YEAR           24
 CONFIGURATIONS THROUGH THIS YEAR    29
 NEW CONFIG.(S) THROUGH THIS YEAR    11
 *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  END OF YEAR 2002  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
```

Figure 6.5. (page 1) Sample of the CONGEN printout for the first variable expansion run of the sample problem (DEMOCASE). CONGEN RUN-2.

```
LIST OF # OF CONFIGURATIONS PER YEAR

  YEAR        #C     #CNEW   #NEWCUM
  1998         1         0         0
  1999         1         0         0
  2000         1         0         0
  2001         2         0         0
  2002        24        11        11
  2003        51        38        49
  2004        67        49        98
  2005        49        39       137
  2006        94        75       212
  2007       114        72       284
  2008        88        39       323
  2009        70        33       356
  2010        87        58       414
  2011       112        93       507
  2012       103        89       596
  2013       137       127       723
  2014       105        91       814
  2015        79        61       875
  2016       103       103       978
  2017        48        48      1026

 TOTAL      1336
```

Figure 6.5. (page 2) Sample of the CONGEN printout for the first variable expansion run of the sample problem (DEMOCASE). CONGEN RUN-2. List of configurations.

```
NUMBER OF FOURIER COEFF. IS    50
 INDEX READ    4
 INDEX READ    2
 INDEX READ    3
 INDEX READ    1
 CONDITIONS GOVERNING ALTERNATIVE GENERATION  *  *  *  *  *  *  YEAR 1998  *  *  *  *  *  *  *  *  *  *  *
*  *  *  *  *  *  *  *
 MINIMUM REQUIRED OF EACH ALTERNATIVE    0   0   0   0   0   0   0
 MAXIMUM ADDITIONAL EACH  ALTERNATIVE    0   0   0   0   0   0   0
 RESERVE RANGE PERMITTED IN CRITICAL PERIOD (%)     15.00   50.00
 CALCULATION OF CRITICAL PERIOD IS BASED ON HYDRO CONDITION  1

       TOTAL CAPAC.                                        PERIOD
 PER    IN FIXSYS    --- THERMAL  HYDRO 1  HYDRO 2 ---    PEAK LOAD
  1        6895.0         5533.0   1175.0    187.0          5400.0
  2        6905.0         5533.0   1185.0    187.0          5220.0
  3        6935.0         5533.0   1215.0    187.0          5580.0
  4        6965.0         5533.0   1245.0    187.0          6000.0
 CRITICAL PERIOD IS   4
 CAPACITY RANGE IN CRITICAL PERIOD IS       6900.0          9000.0
 COMMITTED CAPACITY SPECIFIED IN CRIT PERIOD        6965.0

 MINIMUM NUMBER OF FOURIER COEFF. CORRESPONDING TO MAXIMUM RESERVE MARGIN IN CRIT PER IS    5

 STATE IC NEW   CAP     ACCEPTED CONFIGURATION

    1   1 ***   6965.   0   0   0   0   0   0   0
 CONFIGURATIONS THIS YEAR             1
 CONFIGURATIONS THROUGH THIS YEAR     1
 NEW CONFIG.(S) THROUGH THIS YEAR     0
* * * * * * * * * * * * * * * * * * * END OF YEAR 1998 * * * * * * * * * * * * * * * * * *
```

Figure 6.6. (page 1) Sample of the CONGEN printout for the last variable expansion run of the sample problem (DEMOCASE). CONGEN RUN-3.

```
INDEX READ    2
 INDEX READ    3
 INDEX READ    1
 CONDITIONS GOVERNING ALTERNATIVE GENERATION  *  *  *  *  *  *  YEAR 2002  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  *  *  *  *  *
 MINIMUM REQUIRED OF EACH ALTERNATIVE    1   0   0   0   0   0   1
 MAXIMUM ADDITIONAL EACH  ALTERNATIVE    2   2   0   2   0   0   0
 RESERVE RANGE PERMITTED IN CRITICAL PERIOD (%)    15.00   50.00
 CALCULATION OF CRITICAL PERIOD IS BASED ON HYDRO CONDITION  1

       TOTAL CAPAC.                                          PERIOD
 PER    IN FIXSYS    --- THERMAL  HYDRO 1  HYDRO 2 ---    PEAK LOAD
  1        7128.0         6461.0    325.0    342.0          6746.8
  2        7128.0         6461.0    325.0    342.0          6521.9
  3        7128.0         6461.0    325.0    342.0          6971.7
  4        7128.0         6461.0    325.0    342.0          7496.5
 CRITICAL PERIOD IS   4
 CAPACITY RANGE IN CRITICAL PERIOD IS       8620.9         11244.7
 COMMITTED CAPACITY SPECIFIED IN CRIT PERIOD        7828.0

 MINIMUM NUMBER OF FOURIER COEFF. CORRESPONDING TO MAXIMUM RESERVE MARGIN IN CRIT PER IS    5

 STATE IC NEW   CAP     ACCEPTED CONFIGURATION

    6   1 ***   9028.  3   0   0   0   0   0   1
    7   2 ***   8708.  2   1   0   0   0   0   1
    8   3 ***   9308.  3   1   0   0   0   0   1
    9   4 ***   8988.  2   2   0   0   0   0   1
   10   5 ***   9588.  3   2   0   0   0   0   1
   11   6 ***   9008.  2   0   0   1   0   0   1
   12   7 ***   9608.  3   0   0   1   0   0   1
   13   8 ***   8688.  1   1   0   1   0   0   1
   14   9 ***   9288.  2   1   0   1   0   0   1
   15  10 ***   9888.  3   1   0   1   0   0   1
   16  11 ***   8968.  1   2   0   1   0   0   1
   17  12 ***   9568.  2   2   0   1   0   0   1
   18  13 ***  10168.  3   2   0   1   0   0   1
   19  14 ***   8988.  1   0   0   2   0   0   1
   20  15 ***   9588.  2   0   0   2   0   0   1
   21  16 ***  10188.  3   0   0   2   0   0   1
   22  17 ***   9268.  1   1   0   2   0   0   1
   23  18 ***   9868.  2   1   0   2   0   0   1
   24  19 ***  10468.  3   1   0   2   0   0   1
   25  20 ***   9548.  1   2   0   2   0   0   1
   26  21 ***  10148.  2   2   0   2   0   0   1
   27  22 ***  10748.  3   2   0   2   0   0   1
 CONFIGURATIONS THIS YEAR            22
 CONFIGURATIONS THROUGH THIS YEAR    27
 NEW CONFIG.(S) THROUGH THIS YEAR     0
 *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  END OF YEAR 2002  *  *  *  *  *  *  *  *  *  *  *  *  *
 *  *  *  *  *  *


LIST OF # OF CONFIGURATIONS PER YEAR

  YEAR        #C     #CNEW   #NEWCUM
  1998         1         0         0
  1999         1         0         0
  2000         1         0         0
  2001         2         0         0
  2002        22         0         0
  2003        22         0         0
  2004        19         0         0
  2005        13         0         0
  2006        29         0         0
  2007        64         0         0
  2008        64         0         0
  2009        46         0         0
  2010        46         0         0
  2011        50         0         0
  2012        33         0         0
  2013        33         0         0
  2014        33         0         0
  2015        33         0         0
  2016        33         0         0
  2017        33         0         0

 TOTAL       578
```

Figure 6.6. (page 2) Sample of the CONGEN printout for the last variable expansion run of the sample problem (DEMOCASE). CONGEN RUN-3.

Chapter 7

EXECUTION OF MERSIM

7.1. INPUT/OUTPUT FILES

MERSIM is the 5th module of WASP-IV. It uses 17 input/output files during its execution. The user supplied data is provided in the input file called "MERSIM.DAT". This file must be prepared by the user in accordance with the instructions given in the next section. Other input files used by MERSIM are generated by first four modules; LOADDUCU.BIN generated by LOADSY; FIXPLANT.BIN and FIXSYSGL.WRK by FIXSYS; VARPLANT.BIN and VARSYSGL.WRK by VARSYS; and EXPANALT.BIN by CONGEN. When executed for Variable Expansion runs, it also uses a file SIMULOLD.BIN containing results of configurations simulated by it in previous runs (see section 7.3). The results of this module are reported in four files viz. MERSIM1.REP, MERSIM2.REP, MERSIM3.REP and GROUPLIM.REP. Besides these output files, MERSIM also generates some intermediate files to store information needed by next modules and/or for subsequent execution of CONGEN and MERSIM for iterations (SIMULNEW.BIN). Another intermediate file, SIMGRAPH.BIN is also generated by MERSIM, which can be used to create graphical output of some of the results. In the resimulation mode, it produces REPROGL.WRK, REPROEMI.WRK and REMERSIM.BIN for use by REPROBAT.

7.2. INPUT DATA PREPARATION

MERSIM uses up to eight types of data records as shown in Table 7.1. Similar to other WASP modules, a type-X record is required as the first data record, and records type-1 with INDEX=1, 2, 4, 5, 7, 8 or 9 will tell the program what to do next.

The type-X record of MERSIM input contains information on title of the study, printing options, and flags for telling the program which options are to be used for generating strategies for group limitations and for operation of pumped storage plants (see Table 7.1).

A record type-1 with INDEX=1 is the usual end of year record telling the computer that all data for current year have been completed and that the program can carry out the calculations for the year. A record type-1 with INDEX=2, 4, 5, 7, 8 or 9 tells the computer that the next record(s) to be read is(are) record(s) of type equal to the INDEX number[1]. Similar to the other modules, it is important to check that the proper sequence of data records is used in order to avoid wrong calculations or interruption of program execution and the printing of an error message (see Section 6 of Chapter 13). Each type-1 record with INDEX=2 (4, 5, 7, 8, or 9) record followed by the corresponding type of record(s) will constitute a group. These groups may appear in any order, and will be examined by the program in the sequence read. Execution of the year starts after INDEX=1 is read independent of order of index read.

A type-1 INDEX=2 record calls for a type-2 record, which is used to give the instructions for calculation of the loading order (SPNVAL) and, if applicable, the values of PEAKF, LBASE, and NOLO in the 1st to 4th fields of the record (each field spreads over 5 columns); the

[1] A type-1 INDEX=7 record should be followed by a sequence of as many type-7a, type-7b, type-7c and type-7d records as needed.

5th (columns 21–25) and 6th (columns 26–30) fields of the record are reserved for the spinning reserve of the hydro plants type A and type B, respectively. This spinning reserve is expressed as the percentage of the total available capacity of each hydro plant type that can be used to replace outages of the other plants in the system. This information is required when the program is asked to calculate the loading order of the plants (cases (b) and (c) of SPNVAL in Table 7.1) and it must be always given each time a new type-2 record is used, regardless of the values assigned to the other variables in the record, even if the hydro spinning reserves (the percentages) are the same for all years of the study.

Three cases are possible for the loading order instructions (SPNVAL), as shown in Table 7.1 and they are combined with the value specified for NOLO: If SPNVAL corresponds to case (a), the loading order of the plants is to be given as input data on record(s) type-2a which follow; (in this case the NOLO option is not active). Cases (b) and (c) for SPNVAL mean that the program has to calculate the loading order respecting the specified system spinning reserve requirements and following the basic economic loading order that is either given on records type-2a (if NOLO = 0), or passed by CONGEN (if NOLO = -1).

For the first year of the study and independently of the value of SPNVAL, it is necessary to specify either a predetermined loading order or the basic economic loading order, according to the case. This will require using one or more type-2a records immediately after the type-2 record to provide this information, unless NOLO = -1 and SPNVAL corresponds to case (b) or (c). Records type-2 may be used for subsequent years to change the instructions for calculation of the loading order (SPNVAL), the spinning reserve requirements of the system or the spinning reserve (%) of the hydro plants, or all of them. If the new type-2 record specifies a value of SPNVAL corresponding to case (a), additional type-2a record(s) must follow to give the predetermined loading order of the plants, even if this does not change the one applicable to preceding years. If SPNVAL corresponds to cases (b) or (c), type-2a record (or records) are to be used if there is a change in the basic economic loading order specified for preceding years. In this case, NOLO = 0 (see Table 7.1 page 1). (Note that starting from the second year, NOLO can only take a value of 0 or 1).

The predetermined (or the basic economic) loading order is given in the order in which load is to be assigned. This is described on the subsequent type-2a record (or records) by integer numbers right-adjusted (Format "I") in 5-columns fields using as many type-2a records as required (12 fields per type-2a record). Each number on the record represents one of the thermal plants considered in the same order in which they appear in the combined listing of fixed-system plants and variable-system plants, *with the fixed-system plants listed first*. It should be remembered that the first thermal plant in the fixed-system listing will be always assigned number 3 since numbers 1 and 2 are reserved by the program for hydro type A and hydro type B, respectively, even if any of these two plant types is not actually used in the case under study. If pumped storage plants are also present, they will take loading order number 1 and both of the hydro types will be combined and assigned number 2 in the loading order. The hydro and pumped storage plants are not to be included in the loading order as they are automatically handled by the program. Inclusion of any hydro/pumped storage plant in the loading order will lead to interruption of program execution.

If type-2a records are used to specify a predetermined loading order (case (a) of SPNVAL), base and peak portions of thermal plants are to be included in this loading order (L.O.), beginning with the first base loaded plant and ending with the last peaking plant. The base-load portion of plant capacity is indicated by the same number of the corresponding plant from the combined listing of fixed system and variable-system plants. The peak load portion of capacity of the plant is indicated by adding 1000 to the integer describing the base-load portion. Thermal plants for which MWB is equal to MWC appear only once in the loading order indicating only the base-load portion number, i.e. no peak-load portion is defined for these plants (Note that the plant can be operating in any portion of the load, i.e. as base-load, peaking or intermediate load plant).

If type-2a records are used to give the basic economic loading order (cases (b) and (c) of SPNVAL), the thermal plants are not split into base and peak blocks and each plant is represented only once by the same number in which they appear in the combined listing of fixed-system and variable-system plants. The economic loading order calculated by FIXSYS and VARSYS (see Figs. 4.2 and 5.2) are combined by CONGEN into a single one (see Fig. 6.2) to help the user in preparing the loading order for MERSIM.

One type-1 INDEX=4 and one type-4 record may be used to obtain different types of output. The default value ("0") calls for minimum output, and this can be changed to "1" (intermediate output) or "2" (maximum output). The use of this option will be explained when describing the MERSIM runs for the sample problem. A set of one type-1 INDEX=5 and one type-5 records may be used to change the number of Fourier coefficients to be used in the simulation. The new number of coefficients to be given in record type-5 cannot be greater than the default value, which is set by MERSIM to the value specified in Module 1 (read by the program from the LOADDUCU file).

A type-1 INDEX=7 record followed by as many type-7a through 7-d records as required can be used to specify the unit fuel consumption and unit fuel stock for each thermal plant existing in the system. (Note that the type-7 records are used only for resimulation runs.)

One type-1 record with INDEX=8 may be used in each year for controlling maintenance schedule for thermal plants. This record will be followed by one type-8a record containing number of thermal plants for which annual maintenance schedule is to be changed, followed by as many records of type-8b as the number defines on type-8a record.

Finally, a type-1 record with INDEX=9 can be used to change the group limitation, if defined in the case study. This record will be followed by one type-9 record containing information on index number of limit and the modified value of the limit.

The data records of input file for MERSIM are arranged in the following sequence:

(a) For the first year:

First record: One type-X record with the title of the study, and options for: (i) printing of FIXSYS and VARSYS files; (ii) selecting quick or slow version of group limitation algorithm (for quick option, the group limitation algorithm stops when a feasible solution has been found, while for slow option, it continues to find optimal solution); (iii) requesting minimum or maximum output of group limitation results; and (iv) selecting mode of operation for pumped storage plants.

Next records: One type-1 INDEX=2 record, followed by a type-2 record giving the loading order instructions. This must be followed by type-2a records giving the predetermined loading order (L.O.) or the basic economic L.O. of the plants according to the value of SPNVAL. The record type-1 INDEX=2 must also give the spinning reserve of the hydro plant types and, if applicable, the values for the other variables defined by this record type. (Note: If NOLO= -1 in the type-2 record, it is not permitted to specify the loading order in type-2a records)

One record type-1 INDEX=4 (or 5) followed by a type-4 (or 5) record if a printout option (or NOCOF value) different from default is required.

One type-1 INDEX=7 record followed by as many type-7a through -7d records, as necessary, to specify the unit fuel consumption and fuel stock of the thermal plants in the system, if the run corresponds to a resimulation of the current DYNPRO best solution (or ultimately the optimal solution).

One type-1 record with INDEX=8 and a group of type-8a and 8b records for controlling maintenance schedule for thermal plants.

Last record: One record type-1 INDEX=1 (end of the year).

(b) For the second and subsequent years:

Groups of a type-1 INDEX=2 and a type-2 records for each change to be made to the instructions for L.O. calculation, spinning reserve requirements of the system, or spinning reserve supplied by the hydro plants. If the value of SPNVAL in the new type-2 record corresponds to case (a), records type-2a (as necessary) must follow to give the predetermined L.O. of the plants. For cases (b) and (c) of SPNVAL, new type-2a records are only required if a change is to be made to the basic economic L.O. (NOLO=-1 is not permitted).

One record type-1 INDEX=4 and a type-4 record if the printout option for current year is different from the one applicable to the preceding year. Although additional type-1 INDEX=5 and type-5 records may be used for each year of the study to change the number of Fourier coefficients to be used in the simulations for this year, this is not recommended for planning purposes.

One record type-1 INDEX=7 and as many type-7 records as needed to give any changes in specific fuel consumption and fuel stock of the thermal plants.

One type-1 record with INDEX=8 and a group of type-8a and 8b records for making any change in the maintenance schedule for thermal plants.

Groups of type-1 INDEX=9 records for each change to be made to group limits. For each group limit one group of records, comprising one type-1 INDEX=9 record and one type-9 record, will be required.

Last record: One record type-1 INDEX=1 (end of the year).

Table 7.1. (page 1) Types of data records used in MERSIM

Record type	Columns	Format[1]	Fortran name	Information
	1–60	A	IDENT	Title of study (centered to columns 30–31).
	61–64	I	IOFILE	File printing option; equal 1 to print the FIXSYS and VARSYS files (default value = 0; i.e. no printing of files).
X	65–68	I	IQUICK	If IQUICK=1, then after having found a feasible solution, no more strategies are generated for the actual period. If IQUICK=0, then all strategies obtainable by moving the blocks taking role in specific group-limitations to the end of the loading order are generated and the optimal solution is mixed from them. The default value is 0, i.e. the 'slow' version is run.
	69–72	I	IOUTGR	Output option for selecting the minimum or maximum output concerning the group-limitations and the strategies producing the mixed strategies. The maximum output can be obtained only in 'REMERSIM' mode by setting IOUTGR to 1. The minimum output is obtained in any other case. See Section 7.3.1 for more details.
	73–76	I	IFOPS	Flag to define forced operation of P-S plants. IFOPS =1 forced operation of P-S plants IFOPS =0 economic operation of P-S plants
1	1–4	I	INDEX	Index number[2]: "1" indicates that all data for the current year have been completed. "2" indicates that one type-2 and one or more type-2a records follow, defining the LOADING ORDER "3" is not used. "4" indicates that one type-4 record follows defining the output option type number equal to the INDEX number. "5" "indicates that one type-5 record follows defining the number of Fourier coefficients to be used. "6" is not used. "7" indicates that one or more records (as needed) of types 7a, 7b, 7d, 7d defining fuel consumption and -stock will follow. "8" indicates definition of fixed maintenance schedule for thermal plants to be specified in following records type 8a and 8b. "9" indicates the change of group-limits.

Table 7.1. (page 2) Types of data records used in MERSIM

Record type	Columns	Format[1]	Fortran name	Information
2	1–5	F	SPNVAL[3]	Loading order instructions, for which three cases are possible: (a) SPNVAL < 0, the loading order (L.O.) is given as input in type-2a records. In this case, columns 6 to 20 are left blank. (b) 0 ≤ SPNVAL ≤ 5.0, L.O. is calculated by MERSIM rearranging the basic economic L.O. given at least once in type-2a records, or passed by CONGEN if so instructed (NOLO = -1), in such a way as to meet the spinning reserve (SPNRES) requirements of the system as follows: SPNRES = SPNVAL * CAP + PEAKF * PKMW where: CAP = largest unit capacity block already loaded PEAKF = multiplier of PKMW PKMW = period peak load (c) SPNVAL > 5.0. Same as case (b) described above but in this case: SPNRES = SPNVAL (constant value).
	6–10	F	PEAKF	Multiplier of period peak load (PKMW) for calculating the required spinning reserve. Leave blank for cases (a) and (c) described above.
	11–15	I	LBASE	If = 0, the loading order (L.O.) is calculated on a plant by plant basis. If = 1, the L.O. is calculated on a unit by unit basis. Leave blank for case (a) of SPNVAL described above.
	16–20	I	NOLO	If = -1, use the basic economic loading order (L.O.) passed from CONGEN (this option is only applicable in the first year and for SPNVAL ≥ 0, [3], i.e. cases (b) and (c) of SPNVAL). If = 0, the L.O. is specified in the records that follow. If = 1, no L.O. follow indicating to the program to use the L.O. from the previous year (this option is only allowed from the second year on, when other variables are altered but the L.O. may remain the same). Leave blank for case (a) of SPNVAL described above.
	21–25	I	ISPIN(1)	Part (%) of the total available hydro capacity of hydro plant type A that will be considered as spinning reserve (default = 0).
	26–30	I	ISPIN(2)	Part (%) of the total available hydro capacity of hydro plant type B that will be considered as spinning reserve (default = 0).

Table 7.1. (page 3) Types of data records used in MERSIM

Record type	Columns	Format[1]	Fortran name	Information
2a	1–5 6–10 11–15 16–20 21–25 26–30 31–35 36–40 41–45 46–50 51–55 56–60	I I I I I I I I I I I I	NORDER	Plant loading order from the combined FIXSYS plus VARSYS list of plants[4] (a) If SPNVAL < 0, base and peak blocks of thermal plants must be specified individually in the loading order: base blocks are specified by their plant order number in the combined FIXSYS plus VARSYS list of plants, whereas peak blocks are specified adding 1000 to that number. If a plant has only one block of capacity (MWB=MWC), only the base block must be specified. Hydro and P-S plants are not to be included in the loading order list since these plants are handled automatically by MERSIM. (b) If SPNVAL ≥ 0, [3], the economic loading order must be specified for thermal plants giving their plant order number in the combined FIXSYS plus VARSYS list of plants. The program will automatically dispatch base and peak blocks of the thermal plants in order to meet the spinning reserve requirements.
4	1–4	I	IOPT	Output option: 0 (zero), default value, calls for minimum output (list of the configurations); 1 calls for intermediate output (summary of annual costs for each year); 2 calls for maximum output (detail of simulation for each configuration, per period and per hydro-condition). Note: Whichever option is used, the program prints out only the results for the new configurations simulated in the current run.
5	1–4	I	NOCOF	Number of Fourier coefficients to be used in the simulation for the representation of the equivalent load duration curve (LDC), if it is desired to use fewer than in LOADSY (the default is the value specified in LOADSY). The original LDC is represented by the constant term (a0) plus NOCOF cosine terms. The equivalent LDC is represented by the constant term plus NOCOF cosine and sine terms. The recommended value for NOCOF is between 20 and 50.
7a[5]	1–8 9–16 65–72	F F F	C1CBL	Domestic fuel consumption by unit (TON/GW·h) (starting with FIXSYS: first thermal power plant is plant no. 3, continued with VARSYS). 9 entries per record. Use as many 7a records as required[6].
7b[5]	1–8 9–16 65–72	F F F	C1CBF	Foreign fuel consumption by unit (TON/GW·h) (same notes as for record 7a above) Use as many 7b records as required[6].
7c[5]	1–8 9–16 65–72	F F F	F1SL	Domestic fuel stock by unit (TON) (same notes as for record 7a above) Use as many 7c records as required[6].
7d[5]	1–8 9–16 65–72	F F F	F1SF	Foreign fuel stock by unit (TON) (same notes as for record 7a above) Use as many 7d records as required[6].

Table 7.1. (page 4) Types of data records used in MERSIM

Record type	Columns	Format[1]	Fortran name	Information
8a[7]	1–5	I	MNFNUM	Number of thermal plants for which the annual maintenance schedule is changed. If MNFNUM >0, MNFNUM records type-8b follow.
	1–5	I	MNFUN	Plant order number in the combined FIXSYS plus VARSYS set of plants.
8b[8]	6–9 10–13 14–17 … 50–53	I I I I	MNFGEN(J)	Number of fixed maintenance days for each unit of thermal plant MNFUN for each period J of the annual simulation. A negative number in the first period releases the forced maintenance scheduling of the thermal plant
	1–4	I	N	index number of group-limitation to be overwritten.
	5–8	I	INDIV(N)	index of individual period group limits =0 (default) GRLRAT ignored =1 distribute GRLIMIT with GRLRAT
9[9]	9–18	F	GRLIMIT(N)	modified upper bound value of constraint N measured in kT, kT, kT, Tcal or GW·h depending on the values of the variable MEASIND.
	19–23 24–28 etc.	F F	GRLRAT(N,J)	ratio of GRLIMIT(N) for J=1,NPER

Notes to Table 7.1

(1) See Section 2.5 for Format description.

(2) Records type-1 INDEX=3 and =6 are not used.

(3) The options for calculation of the loading order (L.O.) by MERSIM, i.e. Cases (b) and (c) for SPNVAL, should be treated with great care because the resulting L.O. will be dependent on the data given by the user, not only for the involved variables, SPNVAL, CAP, PEAKF, PKMW, but also for the capacity blocks of the various FIXSYS and VARSYS plants and their respective ISPIN.

(4) Record type 2a is used *only* if NOLO = 0. The numbering of the plants for the simulation process is as follows: 1 and 2 are reserved for the hydro plants type A and type B (even if they do not exist). Then, the thermal plants of FIXSYS, beginning with 3 (this number appears to the left of the thermal plant table included in the FIXSYS output). Finally, the thermal plants of VARSYS in the same order in which they were read (beginning with the number of the last thermal plant in FIXSYS plus 1). Note: hydroelectric and P-S plants should not be included in the loading order.

(5) Record type-1 INDEX=7 and record types 7a, 7b, 7c and 7d used *only* for RESIMULATION.

(6) These records permit separating unit fuel consumption and fuel stock into domestic and foreign components for the MERSIM and REPROBAT reports. For results on fuel consumption to be correct, the heat rates for the respective plants (in FIXSYS and VARSYS) must reflect the same distribution.

(7) One record having the number of type-8b records that follow (number of thermal plants on fixed maintenance).

(8) One record per FIXSYS +VARSYS thermal plant on fixed maintenance. Fields 6–9, 10–13, 50–53 give the number of forced maintenance days per period for each unit of the respective thermal plant. The sum of maintenance days should be equal to the number of days per year for scheduled maintenance of the respective thermal plant.

(9) Record type 9 (after INDEX 9) is like record type Ea of FIXSYS, except the first field.

7.3. SAMPLE PROBLEM

7.3.1. Input data for a fixed expansion plan (MERSIM Run-1)

Figure 7.1 lists the input data prepared for a fixed expansion plan of the Sample Problem, DEMOCASE. In effect, this was the first run of module MERSIM for the sample problem, corresponding to the predetermined expansion plan presented in Sections 6.3.1 and 6.3.2 (CONGEN Run-1). The first input data in Fig. 7.1 is the type-X record with the title of study (columns 1–60), the printout option for FIXPLANT and VARPLANT files (column 64), the option for group limitation algorithm (column 68), the output option for report of group limitation results, and option for mode of operation for pumped storage plants. The same remarks made in Section 6.3 for the title of study to be used in the type-X record of CONGEN are also valid for MERSIM. Since we are in the debugging phase of data records of the module, the "1" in column 64 asks for printing of the FIXSYS and VARSYS files, the “0” in column 68 for slow option for group limitation algorithm, the “1” in column 72 for output report of group limitation results (this will be valid for resimulation run). The last field (73–76) is left blank since there is no pumped storage project considered in this example.

The second input line is of type-1 INDEX=2 calling for a type-2 record to follow. In the sample problem, a number1.0 is shown in the 1st field of the type-2 record for value of SPNVAL, nothing in 2nd and 3rd fields for values of PEAKF and LBASE, -1 in the 4th field for the value of NOLO and nothing for 5th and 6th fields, indicating to the program that the basic economic loading order of the plants will be used, which will be passed on from CONGEN and the spinning reserve requirement is equal to the capacity of the largest block loaded, and the loading order will be calculated on plant by plant bases, and that the hydro plants will not contribute to the spinning reserves of the system.

The subsequent input line is a type-1 INDEX=4 record calling for a type-4 record to specify the print output option. A "2" on this record calls for maximum output for the current year and all subsequent years until a new record type-4 changes this option. In the sample problem, maximum output is requested for all the years.

The input line number 6 is a type-1 INDEX=5. This is followed by a type-5 record specifying the number of Fourier coefficients to be used in the simulations. In the sample problem, this number was reduced from 50 (used in Module 1) to 25. This represents a good compromise between the accuracy of the simulations carried out by MERSIM and the computer time required to perform them[2].

The next input lines of Fig. 7.1 consist of one type-1 INDEX=8 followed by one type-8a record containing 2, indicating to the program that maintenance of 2 thermal plants will be specified, information which is given on next two type-8b records. The number “3” is the first such thermal whose maintenance is to be scheduled for periods 3 and 4 for 30 and 26 days respectively. Likewise, number “4” on the second type-8b record indicate the thermal plant number and then in fields 2–4 the days of maintenance for this plant in different periods.

[2] Selection of the adequate number of Fourier coefficients to be used in the simulation requires the execution of several fixed expansion runs for the case study where the execution time per configuration is to be weighed against the accuracy of the results. Of particular importance are the resulting values of LOLP and Energy not Served of the configurations.

Next in the input data for the first year is a type-1 INDEX=1 record indicating that all data for the first year of the study (1998) have been completed. The information in columns 16 to 28 of this record is for the convenience of the user and is not read by the computer.

There is no change in the input for subsequent years (only one type-1 with INDEX=1 record each has been given), except for the year 2000, in which a type=1 record with INDEX=8 followed by a group of type-8a and type-8b records is given. In this year, it has been assumed in this sample problem that the maintenance schedule for two thermal plants (number 3 and 4) is to be changed. For thermal plant number "3" the periods for scheduling maintenance have been changed from previously specified and for plant number "4" the earlier schedule has been cancelled (by giving -1 in the 2^{nd} field), and from this year on-wards the program will determine the maintenance schedule for this plant also as it will be doing for all other thermal plants not controlled by the user through type-8 records. Again, the information in columns 16 to 28 of each type-1 with INDEX=1 record is for the convenience of the user and is not read by the computer.

```
DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL    1  0  1
  2
 1.0       -1
  4
  2
  5
 25
  8
  2
  3  0  0 30 26
  4  0 20 10 26
  1      (END OF YEAR 1998)
  1      (END OF YEAR 1999)
  8
  2
  3  0 30 26  0
  4 -1
  1      (END OF YEAR 2000)
  1      (END OF YEAR 2001)
  1      (END OF YEAR 2002)
  1      (END OF YEAR 2003)
  1      (END OF YEAR 2004)
  1      (END OF YEAR 2005)
  1      (END OF YEAR 2006)
  1      (END OF YEAR 2007)
  1      (END OF YEAR 2008)
  1      (END OF YEAR 2009)
  1      (END OF YEAR 2010)
  1      (END OF YEAR 2011)
  1      (END OF YEAR 2012)
  1      (END OF YEAR 2013)
  1      (END OF YEAR 2014)
  1      (END OF YEAR 2015)
  1      (END OF YEAR 2016)
  1      (END OF YEAR 2017)
```

Figure 7.1. MERSIM input data for a fixed expansion run of the sample problem (DEMOCASE). MERSIM Run-1.

7.3.2. Printout for a fixed expansion plan (MERSIM Run-1)

Figure 7.2 illustrates the MERSIM printout for the fixed expansion plan of the sample problem (using the data of Fig. 7.1). As the file printing option for this run was set to "1", the first pages of output are in sequence: the *description of the fuel types* as read from the FIXSYS file; the *description of the Fixed System* for the first year of study (1998); and the *description of the Variable System*. None of these pages is shown in Fig. 7.2 since they include the same information displayed on pages 1 and 2 of Figure 6.2.

Page 1 of Fig. 7.2 shows part of MERSIM1.REP files and contains the cover page printed by MERSIM to identify the run. This shows the title of study and the list of the variable expansion candidates, beginning with the thermal candidates and ending with the hydro plants (followed by P-S, if active). Each candidate is identified by its code name (in the central column of the list) and two sequence numbers. The number to the left corresponds to the number of the plant in the same order as it appears in the configurations generated by CONGEN, and the one to the right gives the number in which the plant is to be considered for simulation purposes (i.e. the number in which the plant appears in the combined listing of fixed-system and variable-system plants). It can be seen that hydro type A (HYD1) and type B (HYD2) are assigned positions 1 and 2, respectively, in the simulation (Special assignment if P-S is active).

The middle part of the page 1 of figure 7.2 shows the loading order instructions given in the input and the basic economic loading order passed from CONGEN (as requested by the options in input). Followed by the output option (2) and number of Fourier coefficient (25) to be used. Further, it reports the input on maintenance schedule for the thermal plants.

The lower part on page 1 of figure 7.2 shows the annual maintenance table of thermal plants. This table is produced for each configuration in a year and for each hydro-condition. The table shown on lower part of page 1 of the figure 7.2 is for hydro-condition 1 whose probability is also reported (45%). The table includes the thermal plant names and the days of maintenance for each period. In this sample problem, thermal plants number 3 (FLG1) and 4 (FLG2) were scheduled for maintenance through the input option while the remaining were left to the program to determine their maintenance schedule (the plants with zeros for all periods in this case are not present in the system for this year).

Since the print output option was set to "2" (maximum output), the program prints the detailed results of the simulation calculations for each period and hydro-condition in each of the years. The page 2 of the figure shows these results for period 1 and hydro-condition 1 of 1998. This starts identifying: the *period*, *year* and *configuration* considered; the applicable *hydro-condition* and its *probability*. Next come the *hydro-indices* and *hydro-spinning reserves* (%); the *number of thermal plants* (11 in this case) considered in the basic economic L.O. and the *basis for calculating L.O.* Then follows data on the plants which are actually operating (those with zero sets are not included). In the sample run only plants 1 through 8 (i.e. the FIXSYS plants) are operating in 1998 since no VARSYS thermal candidate plant has been added by the configuration considered. This is tabulated in 10 further columns reporting in sequence: *number of units*, *availability (%)*, *total capacity (MW)*, *base capacity (MW)*, *spinning reserve (%)*, *spinning reserve (MW)*, and the derated values for *total*, *base*, and *peak capacity (MW)*, and *spinning reserve (MW)*.

The calculated loading order along with the number of units being loaded in each plant, the cumulative derated spinning reserve, cumulative derated capacity and required spinning reserve of the system are tabulated next[3].

If pumped storage plants are present in the system, a summary of P-S operation will be reported including, the off-loading and pumping capabilities of thermal plants (for both base and peak blocks), minimum P-S operation, and details of actual off-loading and pumping duties of thermal plants.

Next on page 2 of figure 7.2 is the operational summary, which starts with identifying the period, year the configuration simulated and hydro-condition along with its probability. Then data are listed for each plant in the system starting with the two composite hydro plants, if any, followed by the thermal plants. The data for each plant are given on 16 columns of a table under the headings of *HYDROPLANTS OPERATIONAL SUMMARY* and *THERMAL PLANTS OPERATIONAL SUMMARY*.

The *HYDROPLANTS OPERATIONAL SUMMARY* table gives for each composite hydro plant (if any) the following information: in the 1st column the *number of the plant* in the combined listing of fixed- and variable-system plants; in the 2nd column the *plant code name*; in the 3rd column the *number of projects* composed in the plant (FIXSYS plus VARSYS). The remaining columns show the results of the simulation, identifying in the 4th and 5th columns the *plant number capacity block* (base or peak) and the *unit number* of the last thermal unit which was off-loaded by the peak capacity of the given hydro plant; in columns 6th and 7th the *base* and *peak capacity* of the plant, and in column 8th the *total capacity* (sum of these two columns (all values in MW); columns 9th to 11th give in the same order the *base, peak and total energy* generated (all in GW·h) by the plant; column 12th gives the *minimum requirements of peaking energy* (GW·h) at the beginning of the simulation; column 13th shows the *spilled energy* (if any) and column 14th the *energy shortage* (if any) of the plant (both in GW·h); column 15th gives the *Operation and Maintenance (O&M) costs* in thousand $ (these are considered as local costs); and the last column (16th) shows *plant capacity factors* (expressed in %). Some additional comments on the meaning of the above information follow.

Off-loading of thermal plants by the peaking capacity of hydro plants is carried out by MERSIM as part of the simulation, trying to make use of all available hydro energy so as to reduce the total operating costs of the system. The minimum requirements for peaking energy (column 12 of the table) correspond to the value determined by MERSIM before the off-loading process begins; therefore, if this value is lower than the peaking energy (column 10) of the plant, off-loading of thermal plants by this hydro plant is possible.

Two additional cases are possible for the number reported in column 4th:

> a zero means that no off-loading of thermal plants is possible (i.e. minimum energy requirements for peak are equal or greater than the energy available for peaking);
>
> asterisks indicate that no further off-loading of thermal plants can be achieved since the peak block of the corresponding hydro plant has reached the minimum load of the period.

---

[3] Note that this loading order is the one at beginning of the simulation and therefore the peak blocks of the two hydro plant types are set at the last position of the L.O. Their final position will be found by MERSIM and reported as part of the tables with the operational summary.

Concerning the peak and total plant capacities (columns 7 and 8 of table), these values are normally equal to the peak and total capacity of the plant which are available in the period and hydro-condition considered. In some cases, however, these values can be lower than the available ones. This situation occurs when the minimum energy requirements for peaking exceed the energy available for peaking of the respective plant. In this case, MERSIM reduces the peak capacity of the plant accordingly (see description of system operational summary below):

If column 13 of the table shows a value of energy spilled greater than 0.0 (GW·h) for a given hydro plant, it means that no more off-loading of thermal capacity can be achieved with this plant as explained before.

Similarly, if column 14 shows a value of energy shortage greater than 0.0 (GW·h), this means that the minimum peaking requirements exceed the available peaking energy of the respective hydro plant. Energy shortage less than 0.0 means that surplus of energy of one hydro plant could not be used due to shortage in energy of the other hydro plant.

Finally, the plant capacity factor reported in column 16 is calculated by MERSIM dividing the total energy generated by the plant (col. 11) by the *installed capacity* of the respective hydro plant and by the total hours in the period.

If pumped storage plants are present in the system, the two hydro plant types will be merged in type 2 (and named HYDR) and the pumped storage plants will be represented in type 1 (renamed as PUMP). The information of pumped storage plants will also be similar to that for hydro plants and reported in the HYDROPLANTS OPERATIONAL SUMMARY.

The *THERMAL PLANTS OPERATIONAL SUMMARY* table is organized as follows: Columns 1 to 3 give similar information as explained before for the hydro plants, except that the numbers in column 3 are the *number of units* in the thermal plant. The 4th and 5th columns give the *unit capacities*: MWB and MWC respectively. Column 6 is th*e total plant capacity* (col. 5 times the NO. of sets in col. 3). Columns 7 to 9 are the *base, peak* and *total* energy generated by the plant. The generation of thermal plants for which MWB=MWC (appearing in the loading order list only once) is listed under BASE ENERGY (col. 7) even though they actually are peak-loaded plants because here, the term "base" refers to the MWB portion and "peak" refers to the remaining (MWC minus MWB) portion, rather than to plant position in the loading order. Columns 10 to 11 give the plant *fuel costs* in *local* and *foreign* components, and column 12 the *total plant fuel costs*; all values in 1000 $. Column 13 reports the *O&M costs* of the plant, and column 14 the plant's *maintenance probability*, i.e. the percentage of plant capacity which is accorded to maintenance in the period. Thus, the actual available capacity of plant 5 (FCOA) discounting maintenance is: $1 \times 580 \times (1-0.528) = 273.76$ MW. Column 15 lists the unit *forced outage rate* of thermal plants and column 16 the plant *capacity factor* (also referred to the installed capacity of the respective plant) in the period and hydro-condition considered. In case, pumped storage plants are present in the system, the generation by thermal plants will include the generation for pumping duty and the corresponding fuel and O&M costs.

In the operational summary tables described above, additional lines show the totals for all hydro plants and all thermal plants, respectively, but only for the applicable information (columns) in each case. After the totals for the thermal plants, MERSIM reports the *SYSTEM*

OPERATIONAL SUMMARY which lists, on the left hand side, data on system capacities and loads, and on the right hand side the summary of system generation (see bottom of page 2 of Fig. 7.2). The information on *system capacities and loads* starts with the summary of thermal and hydro capacities, broken down by plant ("fuel") type. The information on plant capacities by fuel type is followed by a summary of: *total system capacity* (sum of *installed capacity of thermal* plants plus *available hydro* capacity); the *peak* and *minimum* loads of the period; the period maintenance space (equal to the total system capacity minus period peak load); and the actual reserve capacity subtracting from the maintenance space the capacity under maintenance in the period.

If as a result of the simulation the capacity of any hydro plant type has been reduced by the program (i.e. when the minimum energy requirements for peaking exceed the energy available for peaking of the respective plant), this is shown in the summary of hydro capacity after MW, as: RED. XXXX ==>YYYY; indicating reduction of the available capacity (XXXX), and after the arrow the reduced value (YYYY) that was calculated in the simulation.

The data on *system generation* (on the right hand side of the *system operational summary*) starts with the thermal and hydro generation, also broken down by plant ("fuel") type. The report of energy generation by plant type is followed by: the *total system generation* (sum of the energy generated by all plants in the system); *energy demand* of the system (as measured from the inverted load duration curve); the *unserved energy* and *energy balance*; all values expressed in GW·h. The "unserved energy" is the value of the energy demand which cannot be served by the system and the "energy balance" is equal to the energy generated by all plants plus the energy not served minus the energy under the load duration curve. It is important that this energy balance be a small value since this represents the accuracy of the simulation. The last information in the system operational summary is the loss-of-load probability (%) for this period and hydro-condition. If pumped storage plants are present in the system, the pumped energy will also be reported.

A similar detailed output as explained before for period 1 and hydro-condition 1 is produced by MERSIM for the same period and each of the remaining hydro-conditions (in this case the second and third hydro-conditions). The same printout is also produced in sequence for the remaining periods of the year (1998 in this case). This part of the printout is not shown in the figure.

Similar results for each year of the study will be reported in the MERSIM1.REP file. This file should be studied carefully to confirm correctness of simulations.

Page 3 of figure 7.2 shows part of MERSIM2.REP file, which reports the list of configurations simulated in the present run for each year. This *listing of configurations* includes: the *number* of the configuration (STATE) as it appears in the SIMULNEW.BIN file, along with data on the corresponding *total operation costs* (COST K$); the *expected average annual LOLP* (both in % and in equivalent days/year) resulting from the simulation. After this information, the configuration is also reproduced. Finally, if applicable, the program reports: the *energy not served* (ENS GW·H) for each hydro-condition (sum of energy not served in each period for the same hydro-condition); the *hydro shortage* (HY-SH GW·H) and/or *hydro spillage* (HY-SP GW·H) per hydro-condition. At the end of each year, a -1 is printed to report successful completion of the current year, and at the end of file another -1 is printed to indicate completion of all years. The two -1 (one for the last year and the second for end of file) are also indication of a complete successful run of MERSIM.

Since the printout option for this run was set to a value "2" for all years of the study period, a summary of the yearly results for each configuration is reported in MERSIM3.REP file. A part of this file for the sample problem is shown on page 4 of the figure 7.2. The upper part of page 4 illustrates the annual summary of the cost and reliability results for the first configuration (1998). This lists the plant (installed) capacities and operational costs for each plant ("fuel") type, first for the thermal fuel types and then for the composite hydro plant types (if any), followed by the totals for the system. The summary includes also the values of unserved energy (GW·h) and the loss-of-load probability (%) for each hydro-condition along with the expected annual value of LOLP (weighted by the hydro-conditions' probabilities). The second type of annual summary of results reports the generation by each power plant in the same order as the combined listing of FIXSYS and VARSYS. The results are shown by period and for the total. This summary for year 1998 is shown at the bottom part of page 4.

If group limitations are imposed on the system, then MERSIM will produce a report file (GROUPLIM.REP) for printing results of these limitations. This file will contain detailed results for a RESIMULATION run (if the appropriate option is selected in the input). Page 5 of figure 7.2 shows a part of this file for the Fixed Expansion run of the Sample Problem. In this case, four group limitations were imposed on some of the thermal plants in the system (see FIXSYS and VARSYS chapters). As shown on page 5 of figure 7.2, the printout starts with reporting of thermal plants taking role in group limitations; the group limitation sequence number, its measure index and the names of all plants in each group limitation are printed. Then the configuration simulated is reported and after that year, period, hydro-condition, number of strategies generated and the number of strategies used (mixed for determining optimal dispatch of plant) are printed. These are reported for each configuration simulated for each year, each period and each hydro-condition. In our sample problem, for example, 23 strategies for period 1, hydro-condition 1 in year 1998, were generated by the program by re-arranging the loading order and an optimal dispatch policy was determined by mixing two of these so that all the group limitations are satisfied (see Chapter 12 for technical details). The detailed results of these strategies can be obtained by running the MERSIM in the REMERSIM mode (as shown in Section 7.3.5).

It can be realized that the amount of information printed by the computer for printout options different to "0" is quite large. Thus, it is recommended to use the intermediate and maximum output options with special care. Maximum output option may be used for some years in the debugging phase of the input MERSIM runs or when a detailed output of a fixed expansion schedule is required. Intermediate output may be asked for when only a few new configurations are included in the last current EXPANALT file. However, during the optimization process, when a series of dynamic expansion plans are examined, only minimum output for each year should be requested.

A variety of error messages may appear in the MERSIM printout. Some of these errors can be detected by careful perusal of the printout. The maintenance space, for example, should not be negative (installed capacity less than peak demand). If capacity factors exceed 100% or if the energy balance (or the unserved energy) is very large, something is clearly wrong but just what it is may not be so obvious. During program execution, MERSIM verifies the validity of some input data and the compatibility of the information of the files called upon by the program, and in case of an "error" the execution of the program will be stopped and a message is reported in the printout. Section 6 of Chapter 13 describes the error and warning messages for the MERSIM module.

```
              WASP COMPUTER PROGRAM PACKAGE

                  MERSIM MODULE

                   CASE STUDY

          DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL

         *****************************************************
         *                          *
         *    LIST OF VARIABLE EXPANSION CANDIDATES    *
         *                          *
         *****************************************************
         *         THERMAL  PLANTS         *
         *                          *
         *   SEQU.NUMBER    NAME    SEQU.NUMBER   *
         *   CONFIGURATION        IN SIMULATION   *
         *      1      V-CC       9     *
         *      2      VLG1      10     *
         *      3      VLG2      11     *
         *      4      VCOA      12     *
         *      5      NUCL      13     *
         *                          *
         *****************************************************
         *        HYDROELECTRIC  PLANTS        *
         *                          *
         *   SEQU.NUMBER    NAME    SEQU.NUMBER   *
         *   CONFIGURATION        IN SIMULATION   *
         *      6      HYD1       1     *
         *      7      HYD2       2     *
         *                          *
         *****************************************************


FILE 12 (LOADS) SUCCESSFULLY OPENED
FILE 13 (CONFIGURATIONS) SUCCESSFULLY OPENED

INDEX READ =  2   YEAR 1998

LOADING ORDER INPUT DATA:

LOADING ORDER CONTROL DATA : SPNVAL PEAKF LBASE NOLO ISPIN-1 ISPIN-2
                1.0  0.0  0  -1   0    0
LOADING ORDER CALCULATED ON A PLANT BASIS

CALCULATED LOADING ORDER BASED ON THE ECONOMIC L.O. PASSED FROM CONGEN
NORDER
    13        7        4        6        3       12
    5       10        9        8       11

INDEX READ =  4   YEAR 1998
IOPT =  2

INDEX READ =  5   YEAR 1998

NUMBER OF FOURIER COEFF. USED IN THIS SIMULATION  25

INDEX READ =  8   YEAR 1998
FIXED MAINTENANCE DATA
MNFNUM :  2
PLANT#, MNFGEN :  3   0  0 30 26
PLANT#, MNFGEN :  4   0 20 10 26



 YEAR  1998  CONFIGURATION SIMULATED  0  0  0  0  0  0  0
  HYDRO CONDITION  1    PROBABILITY  45.0 %

  ************************************ ANNUAL MAINTENANCE TABLE OF THERMAL PLANTS ********************************

  THERMAL
   PLANT           PERIODS / DAYS OF MAINTENANCE
   NAME

        1   2   3   4
  3 FLG1   0.0  0.0 30.0 26.0
  4 FLG2   0.0 20.0 10.0 26.0
  5 FCOA  48.0  0.0  0.0  0.0
  6 FOIL  37.7  4.3  0.0  0.0
  7 F-GT   0.0 41.9  0.0  0.0
  8 F-CC  28.2  0.0  0.0  0.0
  9 V-CC   0.0  0.0  0.0  0.0
  10 VLG1   0.0  0.0  0.0  0.0
  11 VLG2   0.0  0.0  0.0  0.0
  12 VCOA   0.0  0.0  0.0  0.0
  13 NUCL   0.0  0.0  0.0  0.0
```

Figure 7.2. (page 1) MERSIM printout for a fixed expansion run of the sample problem. MERSIM Run-1. Cover page, input information for 1998 and annual maintenance table (MERSIM1.REP file).

```
PERIOD  1 OF YEAR 1998  CONFIGURATION SIMULATED  0  0  0  0  0  0  0
   HYDROCONDITION   1    PROBABILITY  45.0 %

      HYDRO INDICES          1 , 2
      % SP.RES OF AVAIL. HYDRO CAP.  0  0
      PLANTS IN BASIC L.O.       11
      L. O. OPTION          0
      PEAKLOAD FACTOR (PEAKF)      0.0000

      SPINNING RESERVE (SPNVAL * MAX.BLOCK CAP. + PEAKF * PKMW) = 1.000 * CAP + (   0.0 )
PLANT UNIT AVLBTY  CAP  BASE  SPIN.  SPIN. - - - - - - DERATED - - - - - -
                         RES   RES  TOTAL  BASE  PEAK  SPINNING
            %    MW   MW    %    MW  CAP(MW) CAP(MW) CAP(MW) RES(MW)

       1   3 100.0  1650.0   0.0   0    0.0 1175.0  210.0  965.0   0.0
       2   2 100.0  206.4   0.0   0    0.0  187.0   0.0  187.0   0.0
       3   4  90.0  270.0  150.0   10   27.0  972.0  540.0  432.0  97.2
       4   9  91.1  276.0  150.0   10   27.6 2262.9 1229.8 1033.1  226.3
       5   1  92.0  274.0  189.0   10   27.4  252.1  173.8  78.2  25.2
       6   7  92.7   85.0  46.9   10   8.5  551.6  304.3  247.3  55.2
       7   4  94.0   50.0  50.0   0   0.0  188.0  188.0   0.0   0.0
       8   1  85.0  120.0  60.0   0   0.0  102.0  51.0  51.0   0.0

PLANT UNIT CUMULATIVE CUMULATIVE  SYSTEM
           DERATED  DERATED  REQUIRED
          SPIN. RES. CAPACITY  SPIN. RES.

       2   2    0.0    0.0 *********
       1   3    0.0   210.0 *********
       7   4    0.0   398.0    50.0
       4   9   226.3   1627.9   150.0
       6   7   281.4   1932.2   150.0
       3   4   378.6   2472.2   150.0
       5   1   403.9   2646.1   400.0
      1004   9   177.6   3679.1   400.0
      1006   7   122.4   3926.4   400.0
      1003   4    25.2   4358.4   400.0
      1005   1    0.0   4436.6   580.0
       8   1    0.0   4487.6   580.0
      1008   1    0.0   4538.6   580.0
       2   2    0.0   4725.6    0.0
       1   3    0.0   5690.6    0.0

  PERIOD  1 OF YEAR 1998  CONFIGURATION SIMULATED  0  0  0  0  0  0  0
   HYDROCONDITION   1    PROBABILITY  45.0 %

   **************************************** HYDROPLANTS OPERATIONAL SUMMARY ****************************************
    HYDRO NO. LORD.  BASE   PEAK  TOTAL   BASE   PEAK  TOTAL   PEAK  ENERGY  ENERGY  O&M  CAPAC.
    PLANT OF  POS.  CAPAC.  CAPAC.  CAPAC.  ENERGY  ENERGY  ENERGY  MINENG. SPILLED SHORTAGE (LOCAL) FACTOR
    NAME PROJ. PL U  (MW)   (MW)   (MW)  (GW·H)  (GW·H)  (GW·H)   (GW·H)  (GW·H)  (GW·H)  (K$)   (%)

   1 HYD1  3  0 0  210.0  965.0  1175.0  460.0  875.0  1335.0   0.0   0.0   37.2  2722.5  36.9
   2 HYD2  2  0 0   0.0  187.0  187.0   0.0  102.1  102.1   0.0   0.0   22.9  340.6  22.6

   TOTALS  5      210.0  1152.0  1362.0  460.0  977.1  1437.1   0.0   0.0   60.1  3063.1  35.3

   ************************************* THERMAL PLANTS OPERATIONAL SUMMARY ****************************************
   THERMAL NO. UNIT CAPAC. PLANT  BASE  PEAK  TOTAL   FUEL   FUEL   FUEL   O&M  MAINT   CAPAC.
    PLANT OF  BASE  TOTAL CAPAC. ENERGY ENERGY  ENERGY  DOMESTIC FOREIGN  TOTAL  (DMSTC) PROB. FOR FACTOR
    NAME UNTS (MW)  (MW)  (MW)  (GW·H)  (GW·H)  (GW·H)   (K$)   (K$)   (K$)   (K$)  (%)  (%)  (%)

   3 FLG1  4  150.0 270.0 1080.0  919.2   5.5  924.7  18294.1    0.0  18294.1 17685.4  0.0 10.0 39.1
   4 FLG2  9  150.0 276.0 2484.0 2346.5  283.2  2629.7  37258.3    0.0  37258.3 19492.7  0.0  8.9 48.3
   5 FCOA  1  400.0 580.0  580.0  230.2   0.3  230.6  5163.6    0.0  5163.6  6233.7 52.8  8.0 18.2
   6 FOIL  7  80.0 145.0 1015.0  580.8   9.9  590.7    0.0  12030.3  12030.3 14860.7 41.4  7.3 26.6
   7 F-GT  4  50.0  50.0  200.0  358.7   0.0  358.7  4971.4    0.0  4971.4  5583.9  0.0  6.0 81.9
   8 F-CC  1  87.0 174.0  174.0  97.3  97.3  194.6    0.0  5045.6  5045.6  2069.2 31.0 15.0 51.1
   9 V-CC  0  300.0 600.0   0.0   0.0   0.0   0.0    0.0    0.0    0.0   0.0  0.0 10.0  0.0
   10 VLG1  0  150.0 280.0   0.0   0.0   0.0   0.0    0.0    0.0    0.0   0.0  0.0 10.0  0.0
   11 VLG2  0  150.0 280.0   0.0   0.0   0.0   0.0    0.0    0.0    0.0   0.0  0.0 10.0  0.0
   12 VCOA  0  400.0 580.0   0.0   0.0   0.0   0.0    0.0    0.0    0.0   0.0  0.0  8.0  0.0
   13 NUCL  0  300.0 600.0   0.0   0.0   0.0   0.0    0.0    0.0    0.0   0.0  0.0 10.0  0.0

   TOTALS 26         5533.0 4532.7  396.2  4928.9  65687.4  17075.9  82763.4 65925.6       40.7

   ******************************************* SYSTEM OPERATIONAL SUMMARY ******************************************
   THERMAL CAPACITY    (MW)      5533.0           THERMAL GENERATION   (GW·H)      4928.9
    PLANT TYPE  0    0.0                     PLANT TYPE  0    0.0
    PLANT TYPE  1   1080.0                     PLANT TYPE  1   924.7
    PLANT TYPE  2   2484.0                     PLANT TYPE  2   2629.7
    PLANT TYPE  3   580.0                     PLANT TYPE  3   230.6
    PLANT TYPE  4   1015.0                     PLANT TYPE  4   590.7
    PLANT TYPE  5   200.0                     PLANT TYPE  5   358.7
    PLANT TYPE  6   174.0                     PLANT TYPE  6   194.6
    PLANT TYPE  7    0.0                     PLANT TYPE  7    0.0
    PLANT TYPE  8    0.0                     PLANT TYPE  8    0.0
    PLANT TYPE  9    0.0                     PLANT TYPE  9    0.0
   HYDRO CAPAC. AVAILABLE (MW)      1362.0           HYDRO GENERATION    (GW·H)      1437.1
    HYDRO TYPE HYD1  1175.0                     HYDRO TYPE HYD1  1335.0
    HYDRO TYPE HYD2   187.0                     HYDRO TYPE HYD2   102.1

   TOTAL CAPACITY        (MW)   6895.0           TOTAL GENERATION       (GW·H)   6366.0
   PEAK LOAD           (MW)   5400.0           ENERGY DEMAND        (GW·H)   7095.6
   MINIMUM LOAD         (MW)   2160.0           UNSERVED ENERGY        (GW·H)    729.6
   MAINTENANCE SPACE       (MW)   1495.0           ENERGY BALANCE        (GW·H)     0.0
   RESERVE CAPACITY       (MW)    715.0           LOSS-OF-LOAD PROBABILITY   (%)   13.1140
```

Figure 7.2. (page 2) MERSIM printout for a fixed expansion run of the sample problem. MERSIM Run-1. Loading order and detailed Operational Summary for Period 1, Hydro-condition 1 in 1998 (MERSIM1.REP file).

```
STATE  COST K$ LOLP % - DAYS/YEAR  1998  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 1  697248. 4.2806  15.624 <- WITH MAINT  0  0  0  0  0  0  0
                 ENS GW·H ->   747.3  1099.1   551.9

                       -1

STATE  COST K$ LOLP % - DAYS/YEAR  1999  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 2  766562. 4.3038  15.709 <- WITH MAINT  0  0  0  0  0  0  0
                 ENS GW·H ->   898.6  1254.6   614.0

                       -1

STATE  COST K$ LOLP % - DAYS/YEAR  2000  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 3  831432. 0.4583  1.673 <- WITH MAINT  0  0  0  0  0  0  0
                 ENS GW·H ->    5.8   14.7    2.2

                       -1

STATE  COST K$ LOLP % - DAYS/YEAR  2001  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 4  904086. 0.1983  0.724 <- WITH MAINT  1  0  0  0  0  0  0
                 ENS GW·H ->    2.3    5.9    0.8

                       -1

STATE  COST K$ LOLP % - DAYS/YEAR  2002  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 5  1057350. 6.1679  22.513 <- WITH MAINT  1  1  0  1  0  0  1
                 ENS GW·H ->  2099.9  2221.9  1793.9

                       -1

STATE  COST K$ LOLP % - DAYS/YEAR  2003  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 6  1135520. 2.5854  9.437 <- WITH MAINT  2  1  0  1  0  1  1
                 ENS GW·H ->   773.2  1008.4   511.4

                       -1
```

```
............................................
............................................
............................................
```

```
STATE  COST K$ LOLP % - DAYS/YEAR  2015  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 18  1868528. 0.1755  0.640 <- WITH MAINT  3  3  5  8  3  2  2
                 ENS GW·H ->    3.6    5.2    2.1

                       -1

STATE  COST K$ LOLP % - DAYS/YEAR  2016  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 19  1980731. 0.1452  0.530 <- WITH MAINT  3  4  5  9  3  2  2
                 ENS GW·H ->    2.9    4.2    1.6

                       -1

STATE  COST K$ LOLP % - DAYS/YEAR  2017  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 20  2005822. 0.1253  0.457 <- WITH MAINT  3  4  6  9  4  2  2
                 ENS GW·H ->    2.4    3.5    1.4

                       -1

                       -1
```

Figure 7.2. (page 3) MERSIM printout for a fixed expansion run of the sample problem. MERSIM Run-1. List of configuration simulated (MERSIM2.REP file).

```
 YEAR  1998

  SUMMARY OF RESULTS FOR   CONFIGURATION SIMULATED  0  0  0  0  0  0  0

               ***** EXPECTED GENERATION COSTS  (K$) *****
          CAPACITY  TOTAL    O&M  **** F U E L  C O S T S ****
            (MW)    COSTS   COSTS  TOTAL  DOMESTIC  FOREIGN
  THERMAL PLANTS
     TYPE  0      0.0     0.0     0.0     0.0     0.0     0.0
     TYPE  1   1080.0 118197.1  65649.7  52547.4  52547.4     0.0
     TYPE  2   2484.0 210568.9  75970.7 134598.2 134598.2     0.0
     TYPE  3    580.0 107219.4  36693.3  70526.1  70526.1     0.0
     TYPE  4   1015.0 177499.0  64849.2 112649.7     0.0 112649.7
     TYPE  5    200.0  41775.1  22289.4  19485.7  19485.7     0.0
     TYPE  6    174.0  29736.5  8483.3  21253.1     0.0  21253.1
     TYPE  7      0.0     0.0     0.0     0.0     0.0     0.0
     TYPE  8      0.0     0.0     0.0     0.0     0.0     0.0
     TYPE  9      0.0     0.0     0.0     0.0     0.0     0.0
   TOTAL THERMAL   5533.0 684996.0 273935.8 411060.3 277157.4 133902.9

  HYDRO PLANTS
     TYPE HYD1   1650.0       10890.0
     TYPE HYD2    206.4        1362.2
   TOTAL HYDRO    1856.4       12252.2

   TOTAL SYSTEM   7389.4 697248.3 286188.0 411060.3 277157.4 133902.9


        HYDROCONDITION     1     2     3
        PROBABILITY (%)   45.0   30.0   25.0

  UNSERVED ENERGY  (GW·H)      747.3  1099.1   551.9

  LOSS-OF-LOAD PROBABILITY (%)  4.0354  5.8096  2.8872

  EXPECTED LOLP (WEIGHED) (%)  4.2806


 ENERGY OUTPUT (GW·H) BY PLANT FOR YEAR 1998

 PLANT   PERIODS:
     1     2     3     4   TOTAL


 HYD1  1325.3  1375.3  1475.3  1552.8  5728.6
 HYD2  100.4  100.4  100.4  100.4  401.8
 FLG1  922.4  856.1  375.2  505.8  2659.6
 FLG2  2639.8  2350.8  2444.3  2083.8  9518.7
 FCOA  207.5  913.7  1066.5  1086.4  3274.0
 FOIL  609.8  1431.0  1828.8  1872.1  5741.6
 F-GT  312.8  269.7  411.7  411.7  1405.9
 F-CC  192.7  133.6  239.8  253.5  819.7
 V-CC   0.0   0.0   0.0   0.0   0.0
 VLG1   0.0   0.0   0.0   0.0   0.0
 VLG2   0.0   0.0   0.0   0.0   0.0
 VCOA   0.0   0.0   0.0   0.0   0.0
 NUCL   0.0   0.0   0.0   0.0   0.0
```

Figure 7.2. (page 4) MERSIM printout for a fixed expansion run of the sample problem. MERSIM Run-1. Yearly summaries of results of simulation for 1998 (MERSIM3.REP file).

```
Plants concerned in group-limitation:
 Group-limitation= 1  Measure index= 1  Plants= F-CC VLG2
 Group-limitation= 2  Measure index= 2  Plants= FLG1 FLG2 FCOA FOIL F-GT
                        VLG1 VLG2 VCOA
 Group-limitation= 3  Measure index= 3  Plants= FLG1 FLG2 FCOA FOIL F-GT
                        F-CC V-CC VLG1 VLG2 VCOA
 Group-limitation= 4  Measure index= 1  Plants= FLG1 FLG2
 ------------------------------------------------
 configuration simulated:  0  0  0  0  0  0  0
 year   period   hydro-   No. of strategies   No. of strategies
          condition    generated        used
 1998    1     1        23           2
 1998    1     2        23           2
 1998    1     3        23           2
 1998    2     1        43           2
 1998    2     2        43           2
 1998    2     3        43           2
 1998    3     1        43           2
 1998    3     2        43           2
 1998    3     3        43           2
 1998    4     1        43           2
 1998    4     2        43           2
 1998    4     3        43           2
```

Figure 7.2. (page 5) MERSIM printout for a fixed expansion run of the sample problem. MERSIM Run-1. Report of strategies generated and used by Group Limitations (GROUPLIM.REP file).

```
DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL    0  0  0  0
  2
 1.0       -1
  4
  0
  5
 25
  8
  2
  3  0  0 30 26
  4  0 20 10 26
  1      (END OF YEAR 1998)
  1      (END OF YEAR 1999)
  8
  2
  3  0 30 26  0
  4 -1
  1      (END OF YEAR 2000)
  1      (END OF YEAR 2001)
  1      (END OF YEAR 2002)
  1      (END OF YEAR 2003)
  1      (END OF YEAR 2004)
  1      (END OF YEAR 2005)
  1      (END OF YEAR 2006)
  1      (END OF YEAR 2007)
  1      (END OF YEAR 2008)
  1      (END OF YEAR 2009)
  1      (END OF YEAR 2010)
  1      (END OF YEAR 2011)
  1      (END OF YEAR 2012)
  1      (END OF YEAR 2013)
  1      (END OF YEAR 2014)
  1      (END OF YEAR 2015)
  1      (END OF YEAR 2016)
  1      (END OF YEAR 2017)
```

Figure 7.3. MERSIM input data for variable expansion runs of the sample problem (DEMOCASE).

7.3.3. Input data for dynamic expansion plans

Before executing the series of MERSIM runs considering dynamic (or variable) expansion plans, it is important to understand how the intermediate file containing results of simulations is used in the program. With each iteration of variable expansion plan, CONGEN (which is executed by VCON.BAT file) will copy the results of configuration simulated in the previous MERSIM run stored in SIMULNEW.BIN file to SIMULOLD.BIN file. In the MERSIM run for present iteration, the program will read the information on SIMULOLD.BIN file before proceeding to simulate the configurations submitted and will check if the configuration was simulated in the previous runs. In case, it is present in the SIMULOLD.BIN file, the results will be copied to SIMULNEW.BIN file. If the configuration is new (i.e. not present in SIMULOLD.BIN file) then the program will simulate it and store the results in SIMULNEW.BIN file. This procedure saves computer time and is handled by the batch files provided for execution of WASP-IV (see chapter 2 and 10).

After executing the corresponding CONGEN run as discussed in Section 6.3.3, the MERSIM run was carried out. A number of CONGEN-MERSIM-DYNPRO iterations were required to reach the optimal solution. The MERSIM runs for each iteration were executed using the same input data shown in Figure 7.3. The MERSIM printouts for two of these runs are shown in Figures 7.4 and 7.5.

Comparing the data records of Figure 7.3 with the ones used for the fixed expansion plan run (MERSIM Run-1, Fig. 7.1), it can be seen that they are essentially the same except for a few minor changes introduced for dynamic expansion plans which do not affect the numerical calculations carried out by the program. For example, the first line on Fig. 7.3 specifies a "0" for the file printing option (IOFILE). Also, and in order to reduce the printout which would be associated with a variable expansion plan run of MERSIM, the printout option (type-4 record) has been set to "0" requesting only minimum output for all years.

It may be emphasised that no change should be made in the input of MERSIM for all runs of the variable expansion plan, except for change in output options. The reason being that the MERSIM runs of successive iterations will use the results of previous runs and if any change is made in spinning reserves requirements, loading order instructions, maintenance schedule or group limitations, the results of simulations from previous iterations will not be compatible with those for present run.

7.3.4. Printouts for dynamic (variable) expansion plans

The MERSIM printout for variable expansion runs is essentially the same as for the fixed expansion plan described in Section 7.3.2 with the difference that both, the file printing option and the print output option have been set to "0" for variable expansion runs. Thus, the printout for these runs includes only: the cover page identifying the run (equal to page 1 of Fig. 7.2), followed by input data read by records (similar to middle part of page 1 of Fig. 7.2) in the MERSIM1.REP file, and the listing of the configurations which were simulated in the present run (similar to page 3 of Fig. 7.2) in the MERSIM2.REP file, i.e. those configurations simulated in previous runs and contained in the current SIMULOLD.BIN file are not repeated in the printout.

Figures 7.4 and 7.5 illustrate a sample of the MERSIM printout for two different dynamic expansion plans. Fig. 7.4 corresponds to the first of such runs (called MERSIM Run-2), using the EXPANALT.BIN file created by CONGEN Run-2 presented in Section 6.3.3.1 and Fig. 7.5 to the last run (MERSIM Run-3) of the series made while searching for the optimum solution of the sample problem and using the EXPANALT.BIN file created by CONGEN Run-3 (Section 6.3.3.2).

For the first variable expansion MERSIM run, only the configurations simulated in this run for the first five years of study are shown in Fig. 7.4. Each configuration is reported in a similar way as discussed for the fixed expansion MERSIM run. The number of the configuration (STATE) corresponds to the same number on the SIMULNEW.BIN file, taking into account the list of configurations contained in the current EXPANALT.BIN and SIMULOLD.BIN files. Thus, for the first three years no configuration is shown as there was only one configuration generated for these years by the corresponding CONGEN run and each of these configurations has already been simulated in the previous run of the MERSIM and copied to SIMULOLD.BIN file. In the 4th year, there were two configurations for the present run but one of them was same as in the previous run for this year and only one new configuration was to be simulated which is reported in the listing as state number 5. Similarly, state 20 does not appear in the listing for year 2002 since this corresponds to the configuration already simulated in MERSIM Run-1.

After a series of variable expansion MERSIM runs, the SIMULNEW.BIN file keeps increasing as new configurations are being simulated and added to the listing for each year. The advantage of printing only the configurations simulated in each run stems from the fact that relatively short printout is produced for each year, permitting quick revision of the results. This is illustrated by Figure 7.5 which shows the listing of configurations simulated in MERSIM Run-3 (in fact, no new configuration was added to the SIMULNEW file in this run).

```
STATE  COST K$ LOLP % - DAYS/YEAR  1998  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * *

                        -1

STATE  COST K$ LOLP % - DAYS/YEAR  1999  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * *

                        -1

STATE  COST K$ LOLP % - DAYS/YEAR  2000  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * *

                        -1

STATE  COST K$ LOLP % - DAYS/YEAR  2001  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 5  921447. 0.0383  0.140 <- WITH MAINT  2  0  0  0  0  0  0
                 ENS GW·H ->    0.3    0.9    0.1

                        -1

STATE  COST K$ LOLP % - DAYS/YEAR  2002  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 6  1102515. 5.1791  18.904 <- WITH MAINT  2  2  0  0  0  0  0
                 ENS GW·H ->  1527.9  1098.4  1268.1
 7  1110853. 0.5371  1.960 <- WITH MAINT  2  0  0  1  0  0  0
                 ENS GW·H ->   10.9   13.9    9.0
 8  1114865. 2.1520  7.855 <- WITH MAINT  2  1  0  1  0  0  0
                 ENS GW·H ->   776.4   900.7   396.9
 9  1045172. 10.4083  37.990 <- WITH MAINT  1  2  0  1  0  0  0
                 ENS GW·H ->  3629.0  3822.6  3347.9
 10  1128199. 2.4126  8.806 <- WITH MAINT  2  2  0  1  0  0  0
                 ENS GW·H ->   878.6  1006.4   682.7
 11  1080401. 4.7591  17.371 <- WITH MAINT  1  0  0  2  0  0  0
                 ENS GW·H ->  1622.9  1729.7  1478.2
 12  1131100. 0.1407  0.514 <- WITH MAINT  2  0  0  2  0  0  0
                 ENS GW·H ->    2.2    3.0    1.8
 13  1093691. 4.5822  16.725 <- WITH MAINT  1  1  0  2  0  0  0
                 ENS GW·H ->  1683.7  1790.1  1388.8
 14  1147558. 1.2146  4.433 <- WITH MAINT  2  1  0  2  0  0  0
                 ENS GW·H ->   311.6   457.7   275.4
 15  1091809. 7.2985  26.639 <- WITH MAINT  1  2  0  2  0  0  0
                 ENS GW·H ->  2620.5  2904.8  2329.3
 16  1161606. 0.7087  2.587 <- WITH MAINT  2  2  0  2  0  0  0
                 ENS GW·H ->   202.3   349.0   145.3
 17  1082475. 3.4449  12.574 <- WITH MAINT  2  1  0  0  0  0  1
                 ENS GW·H ->  1040.8  1188.6   851.2
 18  1098357. 4.5483  16.601 <- WITH MAINT  2  2  0  0  0  0  1
                 ENS GW·H ->  1337.6  1034.7  1353.8
 19  1104596. 0.4046  1.477 <- WITH MAINT  2  0  0  1  0  0  1
                 ENS GW·H ->    7.7   10.6    5.7
 21  1112805. 1.6806  6.134 <- WITH MAINT  2  1  0  1  0  0  1
                 ENS GW·H ->   456.1   808.5   455.5
 22  1044540. 9.8054  35.790 <- WITH MAINT  1  2  0  1  0  0  1
                 ENS GW·H ->  3419.0  3680.1  3109.2
 23  1125116. 2.0446  7.463 <- WITH MAINT  2  2  0  1  0  0  1
                 ENS GW·H ->   738.1   914.1   524.1
 24  1077058. 4.3867  16.011 <- WITH MAINT  1  0  0  2  0  0  1
                 ENS GW·H ->  1517.2  1650.9  1344.2
 25  1125201. 0.1014  0.370 <- WITH MAINT  2  0  0  2  0  0  1
                 ENS GW·H ->    1.5    2.1    1.1
 26  1092748. 4.0785  14.887 <- WITH MAINT  1  1  0  2  0  0  1
                 ENS GW·H ->  1427.2  1711.4  1247.6
 27  1140395. 0.9519  3.474 <- WITH MAINT  2  1  0  2  0  0  1
                 ENS GW·H ->   270.9   400.2   231.8
 28  1092388. 6.6416  24.242 <- WITH MAINT  1  2  0  2  0  0  1
                 ENS GW·H ->  2406.5  2675.8  2027.0
 29  1156462. 0.6493  2.370 <- WITH MAINT  2  2  0  2  0  0  1
                 ENS GW·H ->   131.4   240.6   283.5

                        -1
```

Figure 7.4. MERSIM printout (partial) for the first variable expansion run of the sample problem (MERSIM Run-2). Listing of the configurations simulated in the run

```
STATE  COST K$ LOLP % - DAYS/YEAR  1998  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * *

                        -1
STATE  COST K$ LOLP % - DAYS/YEAR  1999  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * *

                        -1
STATE  COST K$ LOLP % - DAYS/YEAR  2000  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * *

                        -1
STATE  COST K$ LOLP % - DAYS/YEAR  2001  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * *

                        -1
STATE  COST K$ LOLP % - DAYS/YEAR  2002  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * *

                        -1
STATE  COST K$ LOLP % - DAYS/YEAR  2003  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * *

                        -1
STATE  COST K$ LOLP % - DAYS/YEAR  2004  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * *

                        -1
STATE  COST K$ LOLP % - DAYS/YEAR  2005  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * *

                        -1
```

....
....
....

```
STATE  COST K$ LOLP % - DAYS/YEAR  2015  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * *

                        -1
STATE  COST K$ LOLP % - DAYS/YEAR  2016  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * *
                        -1
STATE  COST K$ LOLP % - DAYS/YEAR  2017  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * *

                        -1
                        -1
```

Figure 7.5. MERSIM printout (partial) for the last variable expansion run of the sample problem (MERSIM Run-3). Listing of the configurations simulated in the run

7.3.5. Re-simulation of the optimum solution

In carrying out MERSIM with a variable expansion schedule involving hundreds of configurations, the minimum print output option (IOPT = 0) was specified in order to avoid printing a large amount of unnecessary information. Some of this information, however, is useful for the analysis of the final results. Moreover, at the end of the dynamic optimization process, if Module 7 (REPROBAT) is to be run to obtain a full report of the optimal solution, it is necessary to execute first a resimulation of this optimal solution in order to create the appropriate SIMULRSM.BIN file needed by REPROBAT. Thus, there is a provision in WASP-IV to reproduce this information for the optimum schedule of additions, by executing a run of REMERSIM (it stands for *RE*simulate *MERSIM*). The REMERSIM run uses the same program as MERSIM except for the input and output files used.

The batch file REMER.BAT provided to execute a REMERSIM run handles the necessary file assignments. This batch file copies the EXPANREP.BIN file which was created by the latest DYNPRO run to EXPANALT.BIN file and clears the SIMULOLD.BIN file so that the configurations (one for each year) selected in the optimal solution are re-simulated.

The data records for execution of the resimulation run are the same as the ones used in the MERSIM runs for variable expansion plans, except that detailed results of group limitations (if such limits are imposed on the system) should be requested by setting IOUTGR=1 on the type-X record and that maximum output (IOPT =2) should be specified for all years of the study in order to get a detailed listing with the results of the simulations for each configuration per period and hydro-condition described in the study. Alternatively, the intermediate output (IOPT=1) or the minimum output (IOPT=0) may be specified by the user for some of the years in the REMERSIM run of the case study, particularly if the results of the simulations for the configurations included in the optimal solution have already been analyzed in previous runs. Figure 7.6 lists the input data used for the REMERSIM run of the sample problem. (*Important note: In each year IOPT must be greater than, or equal to 1 if the REMERSIM run is to be followed by a REPROBAT run requesting full report of the current DYNPRO solution or the optimal solution).*

Additionally, type-7 records are used in the re-simulation run to provide information on specific fuel consumption and fuel stock by unit of each of the thermal plants. This information will be used by REMERSIM to calculate total fuel consumption and stock by plant which will be passed to REPROBAT.

In the sample problem, the type-7 records (after the type-1 INDEX=7 record) are as follows. The first two (type-7a) records specify the domestic fuel consumption by unit (ton/GW·h) for the FIXSYS+VARSYS thermal plants. The next two (type-7b) records provide similar information but for the foreign fuel. These are followed by the records specifying the domestic fuel stock by unit (next two records of type-7c) and foreign fuel stock by unit (last two records of type-7d). Both values are specified in ton. Note that two records for each set are required since 11 thermal plants are included in the combined list of FIXSYS plus VARSYS thermal plants. It should be noted that these records must follow the sequence above described and include as many entries as the number of FIXSYS+VARSYS thermal plants (see Table 7.1).

For the REMERSIM run, the EXPANREP.BIN file contains the configurations (one per year) included in the optimal solution. Each configuration is taken by MERSIM for re-simulating the system operation so as to report the same kind of information already described for a fixed expansion MERSIM run (see Section 7.3.2).

Figure 7.7 corresponds to a sample of the printout of the REMERSIM run for re-simulation of the optimal solution for the sample problem. The printout is similar as for other MERSIM runs (see page 3 of Fig. 7.2, and Figures 7.4 and 7.5) with the only difference that in this case, the listing of the yearly configurations bears a title "THIS IS A RESIMULATION OF THE FINAL SOLUTION FOUND BY THE DYNAMIC PROGRAM". Normally, REMERSIM is run using IOFILE = 0 (no printing of FIXSYS or VARSYS files). Thus, the printout begins with the cover page and the list of input data for the first year of study. Since maximum output is normally requested for re-simulation runs, a detailed output is reported by the program with the operational results of the simulation for each period, each hydro condition and each year of the study (similar to page 2 of Fig. 7.2). The input data for each year is also printed by the program. (These printouts are not shown in figure 7.7, since they are similar to those described for fixed expansion run). If pumped storage plants are present in the system, the results of P-S operation will also be reported with details of off-loading, pumping capabilities of thermal plants, generation by P-S plants, off-loaded thermal plants, etc.

Again, since maximum (or intermediate) output is normally requested for resimulation runs, the printout includes the operational summaries for each year of study (lower part of Fig. 7.7 page 3) as described for the output of the fixed expansion run of MERSIM (see page 4 of Fig. 7.2). However, the REMERSIM printout includes additional summary tables for each year when IOPT>0. These are printed for each configuration and each hydro-condition (adding the values for the same hydro-condition for all periods). Page 2 of Fig. 7.7 illustrates this part of the output for hydro-condition 1 and the annual expected values for year 1998. These are followed by a summary of the annual expected values (weighting the values for each hydro-condition by the hydro-condition probabilities). Note that these tables also report the fuel consumption by each thermal plant. These summary tables are very convenient to review the results of the simulation of the DYNPRO solution under examination.

Another output of the REMERSIM run are the detailed results of group limitations (if imposed on the system) in the GROUPLIM.REP file. These are shown on pages 4 and 5 of figure 7.7 for the Sample problem. Page 4 of figure 7.7 first reports thermal plants involved in various group limitations, then configuration simulated and year, period and hydro-condition. Then this part of printout includes initial loading order (strategy 1), names of thermal plants (capacity blocks), number of units, availability and capacity. The next line is the resultant LOLP, ENS, Cost and weight of this strategy. After that, generation by each thermal plant is reported for this strategy and at the end, a list of the actual contributions and the imposed limits for all group limitations. In this sample problem, it may be noted that group limits 2 and 4 are violated by this strategy and hence new strategies have to be generated and evaluated.

Page 5 of figure 7.7 shows similar results of other strategies with one difference that along with the generation by thermal plant for the present strategy, the generation for the initial strategy are also reported together with the difference between the two strategies. In the sample problem, 23 strategies were generated for period 1, hydro condition 1 in year 1998, but only strategies, viz. number 2 and 23, were used (by mixing them with optimal weights) to obtain the least cost dispatch strategy which satisfies all the group limitations imposed. The results of this optimal (mixed) strategy are shown at the bottom of the page 5 of figure 7.7.

Another output of the REMERSIM run are the results written on the SIMGRAPH.BIN file that can be used for preparing graphical presentation of results.

The REMERSIM printout for the optimal solution of the case study should be revised very carefully by the user in order to make sure that the results are not obviously wrong, particularly concerning plant capacity factors, number of units in each plant, the amount of energy not served and the energy balance as it is explained at the end of Section 7.4. In addition, the REMERSIM printout should be checked by the user to determine whether the results of the simulations are reasonable. This revision should concentrate in such aspects as:

- the loading order calculated by the program (if applicable);
- the capacity factors resulting from the simulation for thermal plants which are supposed to be operating in a certain region of the load curve (base, intermediate or peak load);
- the amount of hydro energy shortage and/or energy spillage (if applicable); etc.

As a result of this analysis, it may be necessary to proceed to new optimization runs involving iterations of CONGEN-MERSIM-DYNPRO in order to correct some of the results that are judged unacceptable. In some extreme cases, it may be necessary to initiate a new WASP study if the data to be corrected affect one of the three first modules of WASP or the data specified for the simulation runs. In view of the above, it is strongly recommended to run REMERSIM at certain stages of the optimization procedure in order to guarantee that the intermediate solution reported by DYNPRO satisfies all conditions described above.

```
DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL    0  0  1  0
  2
 1.0       -1
  4
  2
  5
 25
  7
 1722.22 1522.34 440.81  00.00 330.00  00.00  00.00 1619.05 1563.49
  00.00  00.00
  00.00  00.00  00.00 231.55  00.00 186.18 177.27  00.0  00.00
 412.64  00.00
1000000.1000000.1000000.  0.0 1000000.  0.0   0.0 1000000.1000000.
  0.0   0.0
  0.0   0.0   0.0 1000000.  0.0 1000000.1000000.  0.0   0.0
1000000.  1000.
  8
  2
  3  0  0 30 26
  4  0 20 10 26
  1      (END OF YEAR 1998)
  1      (END OF YEAR 1999)
  8
  2
  3  0 30 26  0
  4 -1
  1      (END OF YEAR 2000)
  1      (END OF YEAR 2001)
  1      (END OF YEAR 2002)
  1      (END OF YEAR 2003)
  1      (END OF YEAR 2004)
  1      (END OF YEAR 2005)
  1      (END OF YEAR 2006)
  1      (END OF YEAR 2007)
  1      (END OF YEAR 2008)
  1      (END OF YEAR 2009)
  1      (END OF YEAR 2010)
  1      (END OF YEAR 2011)
  1      (END OF YEAR 2012)
  1      (END OF YEAR 2013)
  1      (END OF YEAR 2014)
  1      (END OF YEAR 2015)
  1      (END OF YEAR 2016)
  1      (END OF YEAR 2017)
```

Figure 7.6. Input data of the REMERSIM run for the sample problem (DEMOCASE).

```
THIS IS A SIMULATION OF THE FINAL SOLUTION FOUND BY THE DYNAMIC PROGRAM
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

  STATE  COST K$ LOLP % - DAYS/YEAR  1998  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

   1  697248. 4.2806  15.624 <- WITH MAINT  0  0  0  0  0  0  0
                  ENS GW·H ->   747.3  1099.1   551.9

                        -1

  STATE  COST K$ LOLP % - DAYS/YEAR  1999  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

   2  766562. 4.3038  15.709 <- WITH MAINT  0  0  0  0  0  0  0
                  ENS GW·H ->   898.6  1254.6   614.0

                        -1

  STATE  COST K$ LOLP % - DAYS/YEAR  2000  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

   3  831432. 0.4583  1.673 <- WITH MAINT  0  0  0  0  0  0  0
                  ENS GW·H ->    5.8   14.7    2.2

                        -1

  STATE  COST K$ LOLP % - DAYS/YEAR  2001  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

   4  904086. 0.1983  0.724 <- WITH MAINT  1  0  0  0  0  0  0
                  ENS GW·H ->    2.3    5.9    0.8

                        -1

  STATE  COST K$ LOLP % - DAYS/YEAR  2002  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

   5  1103057. 0.3800  1.387 <- WITH MAINT  3  0  0  0  0  0  1
                  ENS GW·H ->    7.2   10.0    5.6

                        -1



.................................................................
.................................................................
.................................................................



  STATE  COST K$ LOLP % - DAYS/YEAR  2013  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

   16  1732685. 0.1719  0.628 <- WITH MAINT  4  1  2  7  2  2  2
                  ENS GW·H ->    3.6    5.2    2.0

                        -1

  STATE  COST K$ LOLP % - DAYS/YEAR  2014  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

   17  1822701. 0.2038  0.744 <- WITH MAINT  4  1  4  8  2  2  2
                  ENS GW·H ->    4.5    6.4    2.5

                        -1

  STATE  COST K$ LOLP % - DAYS/YEAR  2015  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

   18  1844431. 0.1566  0.572 <- WITH MAINT  4  1  5  8  3  2  2
                  ENS GW·H ->    3.3    4.7    1.8

                        -1

  STATE  COST K$ LOLP % - DAYS/YEAR  2016  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

   19  1948630. 0.2020  0.737 <- WITH MAINT  4  1  5  9  3  2  2
                  ENS GW·H ->    4.5    6.4    2.6

                        -1

  STATE  COST K$ LOLP % - DAYS/YEAR  2017  CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

   20  1974395. 0.1740  0.635 <- WITH MAINT  4  1  6  9  4  2  2
                  ENS GW·H ->    3.8    5.4    2.2

                        -1

                        -1
```

Figure 7.7. (Page 1) REMERSIM printout for the optimum solution of DEMOCASE. Summary output of the list of configurations simulated in the run (MERSIM2.REP file).

** SUMMARY OF YEAR 1998 **

CONFIGURATION SIMULATED 0 0 0 0 0 0 0

*** HYDROCONDITION 1 ***

	PLANT NAME	PLANT TYPE	UNIT CAPACITY (MW)	NO.OF UNITS	CAPACITY FACTOR (%)	ENERGY (GW·H)	FUEL CONSUMPTION DOMESTIC (TON)	FOREIGN (TON)	GENERATION COSTS (K$)
1	HYD1	10	0.0	1	39.71	5740.00	0.00	0.00	10890.000
2	HYD2	11	0.0	1	22.59	408.40	0.00	0.00	1362.240
3	FLG1	1	0.0	4	27.03	2557.46	4404507.50	0.00	115677.961
4	FLG2	2	0.0	9	44.29	9637.73	14671907.00	0.00	212423.422
5	FCOA	3	0.0	1	64.85	3294.78	1452373.63	0.00	107804.203
6	FOIL	4	0.0	7	64.62	5745.87	0.00	1330455.13	177601.766
7	F-GT	5	0.0	4	80.16	1404.46	463471.03	0.00	41752.914
8	F-CC	6	0.0	1	53.66	817.94	0.00	152283.34	29681.668
9	V-CC	6	0.0	0	0.00	0.00	0.00	0.00	0.000
10	VLG1	1	0.0	0	0.00	0.00	0.00	0.00	0.000
11	VLG2	2	0.0	0	0.00	0.00	0.00	0.00	0.000
12	VCOA	3	0.0	0	0.00	0.00	0.00	0.00	0.000
13	NUCL	0	0.0	0	0.00	0.00	0.00	0.00	0.000
TOTALS						29606.64			697194.313

************************************ THERMAL PLANTS AGGREGATED BY PLANT TYPE ************************************

PLANT TYPE	TOTAL CAPACITY (MW)	CAPACITY FACTOR (%)	TOTAL ENERGY (GW·H)	TOTAL FUEL CONSUMPTION DOMESTIC (TON)	FOREIGN (TON)	GENERATION COSTS (K$)
0	0	0.00	0.00	0.00	0.00	0.00
1	1080	27.03	2557.46	4404507.50	0.00	115677.96
2	2484	44.29	9637.73	14671907.00	0.00	212423.42
3	580	64.85	3294.78	1452373.63	0.00	107804.20
4	1015	64.62	5745.87	0.00	1330455.13	177601.78
5	200	80.16	1404.46	463471.03	0.00	41752.91
6	174	53.66	817.94	0.00	152283.34	29681.67
7	0	0.00	0.00	0.00	0.00	0.00
8	0	0.00	0.00	0.00	0.00	0.00
9	0	0.00	0.00	0.00	0.00	0.00

Figure 7.7. (Page 2) REMERSIM printout for the optimum solution of DEMOCASE. Operational summary for hydro condition 1 for Year 1998 (MERSIM3.REP file).

```
*********************************************** SUMMARY OF YEAR 1998 ************************************************

   CONFIGURATION SIMULATED  0  0  0  0  0  0  0

   HYDROCONDITION:    1    2    3
   PROBABILITY:    0.450  0.300  0.250

 ************************* SIMULATION RESULTS WEIGHTED BY PROBABILITY OF EACH HYDROCONDITION ***************************

        PLANT  PLANT   UNIT   NO.OF   CAPACITY            FUEL CONSUMPTION     GENERATION
        NAME  TYPE  CAPACITY  UNITS   FACTOR    ENERGY    DOMESTIC      FOREIGN     COSTS
               (MW)           (%)      (GW·H)       (TON)       (TON)       (K$)

      1  HYD1  10    0.0     1    39.63    5728.60      0.00      0.00    10890.000
      2  HYD2  11    0.0     1    22.22     401.76      0.00      0.00    1362.240
      3  FLG1   1    0.0     4    28.11    2659.61   4580435.50      0.00   118197.125
      4  FLG2   2    0.0     9    43.74    9518.71   14490712.00      0.00   210568.906
      5  FCOA   3    0.0     1    64.44    3274.03   1443224.38      0.00   107219.438
      6  FOIL   4    0.0     7    64.58    5741.65      0.00   1329478.75   177498.969
      7  F-GT   5    0.0     4    80.24    1405.89    463944.25      0.00    41775.086
      8  F-CC   6    0.0     1    53.78     819.71      0.00    152613.22    29736.465
      9  V-CC   6    0.0     0    0.00      0.00      0.00      0.00      0.000
     10  VLG1   1    0.0     0    0.00      0.00      0.00      0.00      0.000
     11  VLG2   2    0.0     0    0.00      0.00      0.00      0.00      0.000
     12  VCOA   3    0.0     0    0.00      0.00      0.00      0.00      0.000
     13  NUCL   0    0.0     0    0.00      0.00      0.00      0.00      0.000
   TOTALS                          29549.96                   697248.313
 ************************************ THERMAL PLANTS AGGREGATED BY PLANT TYPE **************************************

        PLANT    TOTAL   CAPACITY    TOTAL     TOTAL FUEL CONSUMPTION   GENERATION
        TYPE   CAPACITY   FACTOR    ENERGY     DOMESTIC     FOREIGN     COSTS
               (MW)      (%)      (GW·H)       (TON)       (TON)      (K$)

         0       0    0.00      0.00       0.00      0.00      0.00
         1     1079    28.11     2659.61    4580435.50      0.00   118197.13
         2     2483    43.74     9518.71   14490712.00      0.00   210568.91
         3      579    64.44     3274.03    1443224.38      0.00   107219.44
         4     1013    64.58     5741.65       0.00   1329478.75   177498.98
         5      199    80.24     1405.89    463944.25      0.00    41775.09
         6      173    53.78      819.71       0.00    152613.22    29736.46
         7       0    0.00      0.00       0.00      0.00      0.00
         8       0    0.00      0.00       0.00      0.00      0.00
         9       0    0.00      0.00       0.00      0.00      0.00

  YEAR  1998

   SUMMARY OF RESULTS FOR   CONFIGURATION SIMULATED  0  0  0  0  0  0  0

                  ***** EXPECTED GENERATION COSTS  (K$) *****
             CAPACITY  TOTAL    O&M  **** F U E L  C O S T S ****
               (MW)   COSTS   COSTS  TOTAL  DOMESTIC  FOREIGN
   THERMAL PLANTS
      TYPE  0     0.0    0.0    0.0    0.0    0.0    0.0
      TYPE  1   1080.0 118197.1  65649.7  52547.4  52547.4    0.0
      TYPE  2   2484.0 210568.9  75970.7 134598.2 134598.2    0.0
      TYPE  3    580.0 107219.4  36693.3  70526.1  70526.1    0.0
      TYPE  4   1015.0 177499.0  64849.2 112649.7    0.0 112649.7
      TYPE  5    200.0  41775.1  22289.4  19485.7  19485.7    0.0
      TYPE  6    174.0  29736.5   8483.3  21253.1    0.0  21253.1
      TYPE  7     0.0    0.0    0.0    0.0    0.0    0.0
      TYPE  8     0.0    0.0    0.0    0.0    0.0    0.0
      TYPE  9     0.0    0.0    0.0    0.0    0.0    0.0
    TOTAL THERMAL   5533.0 684996.0 273935.8 411060.3 277157.4 133902.9

   HYDRO PLANTS
      TYPE HYD1   1650.0       10890.0
      TYPE HYD2    206.4       1362.2
    TOTAL HYDRO    1856.4       12252.2

    TOTAL SYSTEM   7389.4 697248.3 286188.0 411060.3 277157.4 133902.9


         HYDROCONDITION     1     2     3
         PROBABILITY (%)   45.0   30.0   25.0

   UNSERVED ENERGY  (GW·H)     747.3  1099.1   551.9

   LOSS-OF-LOAD PROBABILITY (%)  4.0354  5.8096  2.8872

   EXPECTED LOLP (WEIGHED) (%)  4.2806

 ENERGY OUTPUT (GW·H) BY PLANT FOR YEAR 1998

 PLANT   PERIODS:
     1    2    3    4   TOTAL


 HYD1  1325.3  1375.3  1475.3  1552.8  5728.6
 HYD2  100.4  100.4  100.4  100.4  401.8
 FLG1  922.4  856.1  375.2  505.8  2659.6
 FLG2  2639.8  2350.8  2444.3  2083.8  9518.7
 FCOA  207.5  913.7  1066.5  1086.4  3274.0
 FOIL  609.8  1431.0  1828.8  1872.1  5741.6
 F-GT  312.8  269.7  411.7  411.7  1405.9
 F-CC  192.7  133.6  239.8  253.5  819.7
 V-CC   0.0   0.0   0.0   0.0   0.0
 VLG1   0.0   0.0   0.0   0.0   0.0
 VLG2   0.0   0.0   0.0   0.0   0.0
 VCOA   0.0   0.0   0.0   0.0   0.0
 NUCL   0.0   0.0   0.0   0.0   0.0
```

Figure 7.7. (Page 3) REMERSIM printout for the optimum solution of DEMOCASE. Operational summary for yearly averages for the year 1998 (MERSIM3.REP file).

```
Plants concerned in group-limitation:
 Group-limitation= 1  Measure index= 1  Plants= F-CC VLG2
 Group-limitation= 2  Measure index= 2  Plants= FLG1 FLG2 FCOA FOIL F-GT
                        VLG1 VLG2 VCOA
 Group-limitation= 3  Measure index= 3  Plants= FLG1 FLG2 FCOA FOIL F-GT
                        F-CC V-CC VLG1 VLG2 VCOA
 Group-limitation= 4  Measure index= 1  Plants= FLG1 FLG2
 ==============================================================================
 configuration simulated:  0  0  0  0  0  0  0
 year=1998  period= 1  hydro condition= 1

 Initial loading order (strategy 1)

  Plant    Units  Availability  Capacity (MW)
 F-GT(base)   4     0.94      50.00
 FLG2(base)   9     0.91     150.00
 FOIL(base)   7     0.93      46.90
 FLG1(base)   4     0.90     150.00
 FCOA(base)   1     0.92     188.97
 FLG2(peak)   9     0.91     126.00
 FOIL(peak)   7     0.93      38.10
 FLG1(peak)   4     0.90     120.00
 FCOA(peak)   1     0.92      85.03
 F-CC(base)   1     0.85      60.00
 F-CC(peak)   1     0.85      60.00

 lolp:  0.268 %  ens:   0.82623 GW·h  cost:  41686.980  weight:0.0000

     Plant   Generation (GW·h)
     FLG1   1117.01685
     FLG2   3162.55786
     FCOA    284.54431
     FOIL    681.20856
     F-GT    411.72003
     F-CC      0.56584
     V-CC      0.00000
     VLG1      0.00000
     VLG2      0.00000
     VCOA      0.00000
     NUCL      0.00000

 Limitation    Contribution     Limit
   1       0.10535  <   2459.69116
   2      179.91039  >   150.00000
   3       78.82391  <   250.00000
   4      7049.56494  >   5909.09082

 ------------------------------------------------------------
```

Figure 7.7. (Page 4) REMERSIM printout for the optimum solution of DEMOCASE. Output of the Group Limitation results. (GROUPLIM.REP file).

```
Strategy 2
The strategy was generated by moving the plants concerned in
group-limitation 2 to the end of the initial loading order.

lolp:  0.268 %  ens:   0.82623 GW·h  cost:  42750.719  weight:0.8712

Plant   New Generation   Original Generation   Difference
        (GW·h)          (GW·h)        (GW·h)
FLG1     1061.39905      1117.01685      -55.61774
FLG2     3018.46460      3162.55786      -144.09320
FCOA     264.66489       284.54431      -19.87942
FOIL     678.01678       681.20856       -3.19175
F-GT     411.72006       411.72003       0.00003
F-CC     223.38004        0.56584      222.81421
V-CC      0.00000        0.00000       0.00000
VLG1      0.00000        0.00000       0.00000
VLG2      0.00000        0.00000       0.00000
VCOA      0.00000        0.00000       0.00000
NUCL      0.00000        0.00000       0.00000

Limitation    Contribution     Limit
  1       41.58931  <   2459.69116
  2      172.17694  >   150.00000
  3       75.77210  <   250.00000
  4      6744.20215  >   5909.09082

-----------------------------------------------------------
Strategy 23
The strategy was generated by moving the plants concerned in
any group limitation to the end of the initial loading order.
and leaving the last 11 plants out from the loading order.

lolp: 100.000 %  ens: 5658.43994 GW·h  cost:  5658.433  weight:0.1288

Plant   New Generation   Original Generation   Difference
        (GW·h)          (GW·h)        (GW·h)
FLG1      0.00000      1117.01685     -1117.01685
FLG2      0.00000      3162.55786     -3162.55786
FCOA      0.00000       284.54431      -284.54431
FOIL      0.00000       681.20856      -681.20856
F-GT      0.00000       411.72003      -411.72003
F-CC      0.00000        0.56584       -0.56584
V-CC      0.00000        0.00000       0.00000
VLG1      0.00000        0.00000       0.00000
VLG2      0.00000        0.00000       0.00000
VCOA      0.00000        0.00000       0.00000
NUCL      0.00000        0.00000       0.00000

Limitation    Contribution     Limit
  1       0.00000  <   2459.69116
  2       0.00000  <   150.00000
  3       0.00000  <   250.00000
  4       0.00017  <   5909.09082

-----------------------------------------------------------
Mixed strategy

lolp: 13.114 %  ens:  729.55042 GW·h  cost:  37973.055

    Plant  Weighted Generation (GW·h)
    FLG1      924.68774
    FLG2     2629.67725
    FCOA      230.57541
    FOIL      590.68549
    F-GT      358.68881
    F-CC      194.60278
    V-CC        0.00000
    VLG1        0.00000
    VLG2        0.00000
    VCOA        0.00000
    NUCL        0.00000

Limitation    Contribution     Limit
  1       36.23150  <   2459.69116
  2      150.00000  =   150.00000
  3       66.01241  <   250.00000
  4      5875.52783  <   5909.09082
==============================================================================
```

Figure 7.7. (Page 5) REMERSIM printout for the optimum solution of DEMOCASE. Output of the Group Limitation results (GROUPLIM.REP file).

Chapter 8

EXECUTION OF DYNPRO

8.1. INPUT/OUTPUT FILES

DYNPRO uses 9 input/output files. The user supplied inputs specific to current run of DYNPRO are provided in input file called "DYNPRO.DAT". This file should be prepared by the user according to instructions given in the next section. The other input files for this module are: "VARPLANT.BIN" produced by VARSYS; "EXPANALT.BIN" produced by CONGEN; "SIMULNEW.BIN" produced by MERSIM. It generates two intermediate output files, "OSDYNDAT.BIN" for use by REPROBAT and "EXPANREP.BIN" to be used by MERSIM for re-simulation of the final optimum solution. This, is used by the program to carry out the economic evaluation of all alternative expansion schedules or plans permitted by the current EXPANALT.BIN file and to select among them, the one having the least total costs. The results of DYNPRO are reported in three output files called "DYNPRO1.REP", "DYNPRO2.REP" and "DYNPRO3.DBG". The two report files must be reviewed carefully by the user to confirm successful execution of the current run.

As discussed in Chapter 1, the total costs of an expansion plan are expressed by the objective function which in turn is defined as the sum of capital investment costs (corrected by salvage value) of the VARSYS plants added by the plan plus the total operating costs (including energy not served costs) of the system for each year; all costs discounted to a reference year. For each year of the study, DYNPRO evaluated the objective function for each configuration included in the EXPANALT.BIN file. In doing so, the program also chooses the optimum path to reach this configuration using a dynamic programming algorithm. Thus, at each stage (year) the program calculates the optimal way of reaching a given configuration in the preceding year connected to the optimum path. Obviously, the configuration in the last year which has the least value of objective function must be included in the optimum (best) expansion plan.

The configuration in the precedent years contained in this optimum plan are retrieved by the program simply tracing back through the stage-by stage optimal decisions. During the traceback process, DYNPRO also examines the restrictions that were defined in CONGEN and identified on the printout the states on the optimal trajectory for which these restrictions acted as a constraint to the solution. Interpreting the DYNPRO printout, the user can proceed to a new dynamic iteration involving sequential runs of CONGEN-MERSIM-DYNPRO; with the restrictions in the CONGEN run modified accordingly. The process is repeated until the best solution reported by DYNPRO, not "constrained" by the CONGEN restrictions, is obtained. This will be the optimum solution for the case under study.

The DYNPRO module can also be used to evaluate any specific expansion schedule, such as the predetermined expansion plan of DEMOCASE described in Section 6.3.1 for which the user explicitly defines the number of units or projects of each expansion candidate that are to be added to the system in each year of the study. In this case, DYNPRO simply performs as a cash flow program. This procedure can be used to evaluate a number of expansion patterns of system expansion to select a favorable area to be used as starting point in full-scale dynamic optimization runs. Also the fixed expansion mode for execution of DYNPRO is recommended during the debugging phase of the input data records of the WASP modules. Section 8.3.1 describes how to run DYNPRO in the "fixed expansion" mode and Section 8.3.3 for dynamic expansion plans.

8.2. INPUT DATA PREPARATION

Table 8.1 lists 17 types of data records used by the DYNPRO module of WASP-IV. As for all other WASP modules, the first record is the usual type-X record specifying the title of the study and the printing options for the VARSYS file (IOFILE) and the listing of states considered in the run and/or debug information (IOPT).

Record type-A gives the information required for economic calculations of present worth discounting values of costs and cost escalation first year of study and length of study. Record type-B provides values of discount rate to be applied to all domestic and foreign costs.

Records type-1 with INDEX = 1 (2, 3, 4, 6, 7, 9, 11, 12, 13, 16 or 17) indicate that the next record (or records) are of a type equal to the INDEX number (index numbers 5, 8, 10, 14, and 15 are not used). Records type-1 INDEX=1 are the usual end of year record and the remaining record types are used to give instructions for the economic calculations to be carried out by DYNPRO or to control the printout of the run.

Records type-1 with INDEX=2 and type-2 are used to specify the economic data on capital costs, plant life and construction time of each VARSYS expansion candidate. For hydro and pumped storage candidates the corresponding type-2 record contains only information on plant life (leaving blank the rest of the record). This tells the computer that capital cost information for each hydro and pumped storage project in VARSYS follows on type-2a records and type-2b records respectively.

Record type-3 is used if a multiplying factor (> 1.0, default = 1.0) is to be applied to all foreign costs. Records type-4 to give the annual escalation ratios (default =1.0) applicable to domestic and foreign capital costs of each expansion candidate. Records type-6 and type-7 are used to impose additional constraints on maximum and minimum number of units of each expansion candidate to be considered in a year for determining optimum schedule for system expansion. Record type-9 gives the annual escalation ratios on local and foreign operating costs of each "fuel" type (including two hydro types or one composed hydro type and one P-5 type) and energy not served cost. A type-11 record will give the information required to evaluate the cost of the energy not served resulting from the simulation, and record type-12 on the reliability of the configurations (limit of the system's LOLP to be respected by the yearly configurations). A type-13 record specifies the number of best solutions to be included in the printout, and a type-16 record can be used to change (from default) the option for calculating salvage value of the plants added by the expansion plan. Finally, type-17 records define escalation ratios, by "fuel" type, for domestic (local) and foreign fuel costs.

It should be noted here that the use of the above mentioned data records for different years of the study should be done with great care, since the program will carry out the optimization based on the instructions given in these records. The user should be aware that by altering some of the economic parameters through the years of the study, the comparison between alternative expansion schedules is also altered. This is particularly valid for the various escalation rates described in the DYNPRO data records, which should be kept constant while searching for the optimal solution of the case study. All DYNPRO capabilities for handling various input data are particularly advantageous for carrying out sensitivity studies as it is described in Chapter 11.

Similar to the other WASP modules, it is important to use the proper sequence of data records for the program to run. For the convenience of the user most of the variables required by DYNPRO are set automatically to default values by the program before reading any input data; thus permitting its execution with a relatively small number of input records. Finally, there is no special order in which type-2 through type-17 records must appear in the input data (except that they should be preceded by a type-1 record of the same INDEX number).

The input data for a run of DYNPRO are arranged in the following sequence:

(a) For the first year:

First record: A type-X record (title of study and printing options).

Second record: A type-A record (JHRPWB, JHRFUL, JAHR, and NJHRS).

Third record: A type-B record with values for discount rates on domestic and foreign costs.

Next records: One type-1 INDEX=2 record followed by as many type-2 records as thermal candidates are described in VARSYS.

Next records: Groups of type-2 and type-2a records for each hydro plant type described in VARSYS; each group must be composed of one type-2 record with the economic plant life of the hydro type and as many type-2a records as the number of projects of this type are described in VARSYS.

Next records: One type-2 record for pumped storage projects followed by as many type-2b records as the pumped storage projects specified in VARSYS.

Following records: Groups of one record type-1 INDEX=3, =4, =6, =7, =9, =11, =12, =13, =16 or =17, and one or more records of type equal to the INDEX number, if it is required to change the default values of the corresponding variable(s) (see Table 8.1). The information given on type-3, -6, -7, -11, -12, -13 or -16 records requires only one record of the respective type, that of type-4 record requires one record per expansion candidate, and that of type-9 and -17 requires two records of the type.

Last record: One type- INDEX=1 record (end of the year).

Table 8.1. (page 1) Types of data records used in DYNPRO

Record type	Columns	Format[1]	Fortran name	Information
	1–60	A	IDENT	Title of study (centered to columns 30–31).
X	61–64	I	IOFILE	File printing option; equals 1 to print the VARSYS file (default value = 0, i.e., no file printing).
	65–68	I	IOPT	Special printing option; equals 1 to print all states considered in the run; equal 2 to print debug information. (The default value = 0, prints neither information.)
	1–5	I	JHRPWB	Base year for cost discounting calculation.
	6–10	I	JHRFUL	Base year for cost escalation calculation (normally the same value as JHRPWB).
A	11–15	I	JAHR	First year of study.
	16–20	I	NJHRS	Number of years to be considered for the economic comparison carried out by DYNPRO. Note: See Section 8.7 for details on the definition of JHRPWB and JHRFUL.
B	1–10	F	TEMPL	Single domestic discount rate (%/year).
	11–20	F	TEMPF	Single foreign discount rate (%/year).
1	1–4	I	INDEX	Index number: 1 indicates that all data for current year have been completed; 2 through 17 indicate that one or more records follow of type equal to the INDEX number, except that INDEX=5, 8, 10, 14 and 15 are not used in the DYNPRO Module of WASP-IV.
	1–8	F	COSTL(IP)	Depreciable domestic capital cost ($/kW) of expansion canditate plant IP (IP is the number of the plant in VARSYS). (leave blank for hydro or P-S.)
	9–16	F	COSTF(IP)	Depreciable foreign capital cost ($/kW). (leave blank for hydro or P-S.)
2[2]	17–24	F	PLIFE(IP)	Plant life (in years and fractions of years) to be used for salvage value calculation.
	25–32	F	COST2L(IP)	Non-depreciable domestic capital cost ($/kW). (leave blank for hydro or P-S.)
	33–40	F	COST2F(IP)	Non-depreciable foreign capital cost ($/kW). (leave blank for hydro or P-S.)
	41–48	F	ORC(IP)	Interest during construction included in COSTL and COSTF (in %). (leave blank for hydro or P-S.)
	49–56	F	TCON(IP)	Construction time (in years and fraction of years). (leave blank for hydro or P-S.)

Table 8.1. (page 2) Types of data records used in DYNPRO

Record type	Columns	Format[1]	Fortran name	Information
	1–8	F	HCOSTL(J)	Depreciable domestic capital cost ($/kW) of hydro project J, where J is the project number of this type in VARSYS.
2a[3]	9–16	F	HCOSTF(J)	Depreciable foreign capital cost ($/kW) of hydro project J.
	41–48	F	ORC(J)	Same as ORC(IP) but for hydro project J.
	49–56	F	TCON(J)	Same as TCON(IP) but for hydro project J.
	73–76	A	NOMHY(J)	Name of hydro project J (must be equal to PNAME in record 2a of VARSYS).
	1–8	F	PCOSTL(J)	Depreciable domestic capital cost ($/kW) of P-S Project J, where J is the project number in VARSYS.
2b[6]	9–16	F	PCOSTF(J)	Depreciable foreign capital cost ($/kW) of P-S project J.
	41–48	F	ORC(J)	Same as ORC(IP) but for P-S project J.
	49–56	F	TCON(J)	Same as TCON(IP) but for P-S project J.
	73–76	A	NOMPS(J)	Name of P-S project J (must be equal to NAMPS in record 4a of VARSYS).
3	1–8	F	FF	Factor by which all foreign costs will be multiplied (generally speaking FF should have values greater than 1.0) (default value 1.0)
	1–8	F	ESCLC(IP)	Annual escalation ratio of domestic capital cost of VARSYS plant IP (default value 1.0)
4[4]	9–16	F	ESCFC(IP)	Same as ESCLC(IP) except that it applies to foreign capital costs.
6	1–4, 5–8, etc.	I I I	NLIMIT(IP)	Maximum number of units (sets) of the expansion candidate IP (plant number in the VARSYS list) which can be added per year (default value 50). One value per candidate. One record suffices since the maximum number of candidates is 14 (there should be NALTS numbers in the record).
7	1–4, 5–8, etc.	I I	NLOWLT(IP)	Like NLIMIT(IP) except that it defines the minimum number of units (sets) of each expansion candidate which must be added per year (default value is 0) (there should be NALTS numbers in the record).
9	1–6, 7–12, etc.	F F	RTESLO(I) RTESFO(I)	(1st record) On each record the 13 numbers[5] are the (2nd record) annual escalation **ratios** of plants of "fuel" type (I) to be applied to the domestic (1st record) and foreign (2nd record) operating costs (default values 1.0)
11	1–8, 9–16, 17–24	F F F	CF1, CF2, CF3	Coefficients of the 2nd order polynomial of the incremental cost of unserved energy ($/kWh) as a function of the unserved energy (expressed as a fraction of total annual energy) (default values 0.0).

Table 8.1. (page3) Types of data records used in DYNPRO

Record type	Columns	Format[1]	Fortran name	Information
12	1–8	F	CLOLP	Critical value of annual loss-of-load probability (in %) (default value 100).
13	3–4	I	NBEST	Number of best solutions to be reported; values from 1 to 10 (default value 1).
16	1–4	I	ISAL	Salvage value option; 0 (default value) calls for linear depreciation; 1 calls for sinking fund depreciation.
17	1–6, 7–12, 13–18, etc.	F F F	EOPL(I) EOPF(I)	(1st record) Escalation ratios by type of ("fuel") plant (2nd record) for domestic (1st record) and foreign (2nd record) fuel costs. (This allows sensitivity studies on fuel costs) (default values = 1.0) (thirteen numbers per record).[5]

Notes to Table 8.1

(1) See Section 2.5 for Format description.

(2) One record for each expansion candidate in the sequence listed in VARSYS, first all thermal candidates, then hydro type A (if any) followed by hydro type B (if any); each hydro type is followed by a set of records type-2a (see [3] below); then P-S (if any) followed by a set of records type-2b (see [6] below).

(3) One record for each hydro project in the sequence listed in VARSYS, first all projects type A (if any) preceded by the respective type-2 record, and then all projects of type B (if any) also preceded by a record type-2.

(4) Same order and number of records as explained in [2] above; one record for each thermal, hydro- type and/or P-S existing in VARSYS.

(5) Plant ("fuel") types in DYNPRO of WASP-IV go from 0 to 12 (total equal 13). Types 0, 1, 2,..., 9 are used for thermal plants; 10 and 11 for hydro type A and B respectively or for HYDR and PUMP respectively; and 12 is used for energy not served cost.

(6) One record for each P-S project in the sequence listed in VARSYS, preceded by a record type-2.

(b) For the second and subsequent years:

Groups of a record type-1 with INDEX equal to the type of record (or records) which follow for each change of the respective variables. For example, the constraints on plant expansion schedule (record type-6 and type-7), the coefficients for evaluating the cost of unserved energy (type-11 record), and the reliability constraint (type-12) may be changed from year to year.

As explained before, it is recommended not to use records type-3, -4, -9, or -14 through -17 for the remaining years of the study, while searching for the optimal solution which will serve as reference solution for the case under study. These may be used to perform sensitivity studies.

Last record: One record type-1 INDEX=1 (end of the year).

8.3. SAMPLE PROBLEM

8.3.1. Input data for a fixed expansion plan (DYNPRO Run-1)

Figure 8.1 represents the input data prepared for a fixed expansion plan for which DYNPRO is used only to evaluate the costs of a predetermined expansion schedule. This corresponds to the first DYNPRO run (identified as DYNPRO Run-1) for the sample problem, using the EXPANALT and SIMULNEW files created by CONGEN Run-1 and MERSIM Run-1 described in the Sections 6.3 and 7.3, respectively.

The first line in Fig. 8.1 is the usual type-X record with the title of study and the printout options for the run. The same remarks made in Section 6.3 for the title of study to be used in type-X record of CONGEN are also valid for DYNPRO. The "0" in column 64 of this record suppresses printing of the information of the VARSYS file, while the "1" in col. 68 calls for printing the list of configurations considered in the run.

The second line of Fig. 8.1 is a type-A record which specifies in the first two (5-columns) fields the base years for present worth discounting of costs and cost escalation calculations (1998); in the 3rd field the first year of the study (1998); and in the last field the number of years (20) in the study.

The next line is a type-B record with values for respective single discount rates (in % per year) on local and foreign components of costs (all types of expenditures); both values are 10% per year for the sample problem.

Input line number 4 is a type-1 INDEX=2 record informing the program that capital cost data, plant life and construction times follow on type-2 records. As explained earlier, this record must be followed by one type-2 record for each expansion candidate. For hydro and pumped storage plants, the type-2 records will contain only plant life (in columns 17–24) and will be followed by as many type-2a (for hydro) or type-2b (for pumped storage) records as the number of hydro or pumped storage projects listed in VARSYS. Consequently, input lines number 5 to 9 of Fig. 8.1 give the data for the thermal expansion candidates for records type-2 in the same order of the listing in Figure 5.1. In the sample problem, each record has been identified by the plant number and code name in cols. 71–76. This is for the convenience of the user and is not needed nor read by the program.

The input line number 10 corresponds to the type-2 record for hydro plant A (HYD1), which contains the plant life (50. years) of the hydro projects of this type (note that the plant number and code name have also been added in cols. 71–76 for the convenience of the user). This is followed by two type-2a records to specify the cost information for these projects. Each type-2a record shows in cols. 73–76 the name of the project (NOMHY equal to NAMEP on record type-2a of VARSYS), information required by DYNPRO and REPROBAT for printing purposes. A similar sequence is used in the next three input lines: one type-2 record for hydro plant B (HYD2) and two type-2a records with the cost data for hydro projects of this plant type. If pumped storage plants are present in the system, as pointed out above, a type-2 record followed by type-2b records will be used. Each type-2b record will, in this case, contain in cols. 73–76 the name of pumped storage project (NOMPS equal to NAMPS on record type-2b of VARSYS).

```
DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL  0 1
1998 1998 1998 20
 10.  10.
2
318. 477.  25.  0.  0. 11.92  3.    1 V-CC
594. 891.  25.  0.  0. 19.2  5.    2 VLG1
544. 817.  25.  0.  0. 19.2  5.    3 VLG2
495. 743.  25.  0.  0. 19.2  5.    4 VCOA
730. 1703.  30.  0.  0. 26.0  7.    5 NUCL
     50.           6 HYD1
841. 841.       22.67  6.     VHY2
970. 970.       22.67  6.     VHY3
     50.           7 HYD2
742. 742.       19.2  5.     VHY1
866. 866.       19.2  5.     VHY4
6
50 50 50 50 50 50 50
7
0 0 0 0 0 0 0
11
 1.  0.  0.
12
100.
13
1
16
1
1   (END OF YEAR 1998)
1   (END OF YEAR 1999)
1   (END OF YEAR 2000)
1   (END OF YEAR 2001)
1   (END OF YEAR 2002)
1   (END OF YEAR 2003)
1   (END OF YEAR 2004)
1   (END OF YEAR 2005)
1   (END OF YEAR 2006)
1   (END OF YEAR 2007)
1   (END OF YEAR 2008)
1   (END OF YEAR 2009)
1   (END OF YEAR 2010)
1   (END OF YEAR 2011)
1   (END OF YEAR 2012)
1   (END OF YEAR 2013)
1   (END OF YEAR 2014)
1   (END OF YEAR 2015)
1   (END OF YEAR 2016)
1   (END OF YEAR 2017)
```

Figure 8.1. (page 1) DYNPRO input data for a fixed expansion plan of the sample problem (DEMOCASE). DYNPRO Run-1.

The next line is a type-1 INDEX=6 record, followed by a type-6 record which specifies the maximum number of units or projects of each expansion candidate that can be added in the year[1]. Similarly, the type-1 INDEX=7 and type-7 records that follow are used to specify the minimum number of units or projects of each expansion candidate that must be added in the year[1]. These records allow the user to impose additional constraints on the optimization by controlling the pace of additions of each candidate. These are not recommended to be used while searching for the reference optimal solution for a WASP case study since they may distort the optimization procedure and re-route the area of optimality. Nevertheless, the type-6 and type-7 records could be used to make adjustment to the reference optimal solution in order to determine a more practical and viable schedule of additions for the power system.

[1] Note that the specified value (s) is (are) equal to the default value(s) contained in the program (see Table 8.1). Therefore, these groups of records may have been omitted altogether, but they have been included here for demonstration purposes.

The next line in Fig. 8.1 is a type-1 INDEX=11 record and is followed by a type-11 record. This specifies the coefficients of the second order polynomial describing the incremental cost of unserved energy as a function of the amount of unserved energy. In the sample problem, the constant coefficient is 1.0; the coefficient of first order and the 2nd order coefficient are 0.0. Thus, DYNPRO will evaluate the cost of the unserved energy (in thousand $) as:

$$\text{Unserved Energy Cost} = [\ 1.0 + 1/2 \times 0.0 \times ENS/EA + 1/3 \times 0.0\ (ENS/EA)^2\ ] \times ENS \times 10^3$$

where ENS represents the amount of unserved energy calculated by MERSIM and EA the annual demand for the corresponding year, with ENS and EA expressed in GWh and the coefficients in $/kWh. The above expression is calculated for each hydro-condition and the results weighted by the respective hydro-condition probability to give the expected cost of the energy not served.

The next input line is a type-1 INDEX-12 record, followed by a type-12 record giving the critical LOLP. For a predetermined expansion schedule, this is normally taken as 100% in order not to reject any configuration[1]. The subsequent lines are a type-1 INDEX=13 record followed by a type-13 record which tells the computer the number of *best*, *next best* and so on (up to 10) solutions to be reported on. In this case only one solution can be reported (for a fixed expansion plan there is only one state per year and only one solution).

Next lines are a type-1 INDEX=16 record calling for a type-16 record to indicate the salvage value option; the "1" shown in this record calls for sinking fund depreciation.

The remaining records are all type-1 INDEX=1 (all identified with the year for convenience of the user) informing the computer that all data have been read and that calculations should be carried out for each year of the study.

Concerning other data record types allowed by DYNPRO, records type-1 INDEX=3, 4, 9, 17 were not used in order not to alter the optimization process to be carried by DYNPRO. In fact, it is recommended to leave the respective variables controlled by these records to the default values while searching for the reference optimal solution and concentrate on changes of these values while conducting sensitivity analyses.

Finally, records type-1 INDEX=5, 8, 10, 14 and 15 are not permitted in DYNPRO; if used, they would lead to interruption of program execution and printing of an error message as explained in Chapter 13, Section 7, which describes the DYNPRO error messages.

8.3.2. Printout for a fixed expansion plan (DYNPRO Run-1)

Figure 8.2 shows the (partial) DYNPRO printout for the fixed expansion plan of DEMOCASE using the input data of Figure 8.1 and the EXPANALT.BIN and SIMULNEW.BIN files created by CONGEN Run-1 and MERSIM Run-1 respectively. Since the file printing option (IOFILE) on record type-X of this run is "0", the program does not print first the variable system description read from the VARPLANT.BIN file. This information, would be similar to the one on page 1 of Fig. 6.2.

Page 1 of Fig 8.2 shows, on the top part, the cover page of the printout, which except for the module name, shows the same information as for the CONGEN runs (see Fig. 6.2). The rest of page 1 of figure 8.2 summarises the economic parameters and the capital costs given as input data; all type-1 INDEX records are printed along with the data on the respective records (or record) which follow. After printing of an INDEX=1, the program reports the value of the objective function for each configuration (or state) in the year (in this case only one state) and the state in the preceding year included in the sub-optimum path to reach this year state. Page 2 shows this information for the first and last few years of the study.

Since only type-1 INDEX=1 records were used for the second and subsequent years, the printout for all these years includes an INDEX=1 followed by the respective value of the objective function of the states and number of the previous year state included in the sub-optimum path[2].

Page 3 illustrates the results of the calculations carried out by DYNPRO for the sample problem. These are presented in a table that summarizes the most important results for the yearly configurations contained in the solution.

First the program reports the number of the solution (in this case only one) followed by a summary of each year's construction cost (*CONCST*), salvage value (*SALVAL*), operating cost (*OPCOST*) and cost of unserved energy (*ENSCST*). The objective function for each year is shown under *TOTAL* together with the cumulative value (*CUMM.*) of the objective function up to the corresponding year[3]. Note that the table lists the years of study in descending order starting with the last year. All values expressed in present worth and thousands of dollars (K$). The reliability of the configuration (LOLP) is also shown (in %). Finally, each yearly configuration is identified by the plant name and the number of units or projects of each candidate plant.

Since no VARSYS plant was added in first three years (1998, 1999 and 2000), the configurations for this year (at the bottom of page 3) are identified by zero sets or projects for all expansion candidates, and zero construction cost and salvage value. The total costs for these years are simply the sum of the corresponding operation costs and costs of unserved energy. For the remaining years, since there are new capacity additions, all values of the above mentioned cost items are reported.

The above described summary table with the DYNPRO results is very useful for having a glance at the best solutions reported by DYNPRO. Its usefulness for the process of finding the optimal solution is explained in Section 8.3.4.

Since for the present run of DYNPRO the print option IOPT is "1", after reporting the solution for the run the program prints the list of the states considered in the run. This list is shown on page 4 of Fig. 8.2. It should be noted that for variable expansion runs, with hundreds of configurations, this list can add several pages to the DYNPRO printout. Thus the convenience of setting IOPT to "0" for variable expansion runs.

---

[2] For a fixed expansion plan there is only one state per year and only one solution. The use of the information on the optimization pattern will be explained in Section 8.3.4.

[3] For each state, the total cumulative value of the objective function is identical to the one reported on page 2 of Fig. 8.2.

```
 WASP COMPUTER PROGRAM PACKAGE

    DYNPRO MODULE

     CASE STUDY

DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL

 **************************************
 *         *
 * LIST OF VAR. EXPAN. CANDIDATES *
 *         *
 **************************************
 *   THERMAL PLANTS   *
 *         *
 *  SEQU.NUMBER  NAME  *
 *   1   V-CC  *
 *   2   VLG1  *
 *   3   VLG2  *
 *   4   VCOA  *
 *   5   NUCL  *
 *         *
 **************************************
 *  HYDROELECTRIC PLANTS  *
 *         *
 *  SEQU.NUMBER  NAME  *
 *   6   HYD1  *
 *   7   HYD2  *
 *         *
 **************************************

ALL COSTS WILL BE DISCOUNTED TO THE YEAR 1998
BASE YEAR FOR COST ESCALATION CALCULATION 1998
FIRST YEAR OF STUDY = 1998
DURATION OF STUDY = 20 YEARS
DISCOUNT RATE APPLIED TO ALL DOMESTIC COSTS - %/YR = 10.00
DISCOUNT RATE APPLIED TO ALL FOREIGN COSTS - %/YR = 10.00

          ***** INPUT OF YEAR 1998 *****
INDEX = 2
  -- C A P I T A L C O S T S ($/KW) --  PLANT    CONSTR.
  (DEPRECIABLE PART) (NON-DEPREC. PART)  LIFE  I.D.C.  TIME
PLANT DOMESTIC FOREIGN  DOMESTIC FOREIGN  (YEARS)  (%)  (YEARS)
V-CC  318.0  477.0  0.0  0.0  25.  11.92  3.0
VLG1  594.0  891.0  0.0  0.0  25.  19.20  5.0
VLG2  544.0  817.0  0.0  0.0  25.  19.20  5.0
VCOA  495.0  743.0  0.0  0.0  25.  19.20  5.0
NUCL  730.0 1703.0  0.0  0.0  30.  26.00  7.0

HYD1 HYDRO PROJECT(S) CAPITAL COSTS
VHY2  841.0  841.0       50.  22.67  6.0
VHY3  970.0  970.0       50.  22.67  6.0

HYD2 HYDRO PROJECT(S) CAPITAL COSTS
VHY1  742.0  742.0       50.  19.20  5.0
VHY4  866.0  866.0       50.  19.20  5.0

INDEX = 6
UPPER LIMIT ON NUMBER OF UNITS THAT CAN BE ADDED FOR EACH CANDIDATE IN EACH YEAR
  V-CC VLG1 VLG2 VCOA NUCL HYD1 HYD2
  50 50 50 50 50 50 50

INDEX = 7
LOWER LIMIT ON NUMBER OF UNITS THAT MUST BE ADDED FOR EACH CANDIDATE IN EACH YEAR
  V-CC VLG1 VLG2 VCOA NUCL HYD1 HYD2
  0  0  0  0  0  0  0

INDEX = 11
COEFFICIENTS FOR CALCULATION OF COST OF ENERGY NOT SERVED - IN $/KWH :
  CF1 = 1.0000 CF2 = 0.0000 CF3 = 0.0000

INDEX = 12
CRITICAL LOSS-OF-LOAD PROBABILITY - IN (%) = 100.0000

INDEX = 13
NUMBER OF BEST SOLUTIONS REQUESTED IS 1

INDEX = 16
USE SINKING FUND DEPRECIATION METHOD FOR SALVAGE VALUE CALCULATION
```

Figure 8.2. (page 1) DYNPRO printout for a fixed expansion plan of the sample problem. DYNPRO Run-1. Cover page and input information.

```
INDEX = 1
 OBJECTIVE FUNCTION STATE 1 TO 1
  1431395.
    1

           ***** INPUT OF YEAR 1999 *****

 INDEX = 1
 OBJECTIVE FUNCTION STATE 2 TO 2
  2905646.
    1

           ***** INPUT OF YEAR 2000 *****

 INDEX = 1
 OBJECTIVE FUNCTION STATE 3 TO 3
  3566760.
    2

           ***** INPUT OF YEAR 2001 *****

 INDEX = 1
 OBJECTIVE FUNCTION STATE 4 TO 4
  4533259.
    3

           ***** INPUT OF YEAR 2002 *****

 INDEX = 1
 OBJECTIVE FUNCTION STATE 5 TO 5
  7326836.
    4

           ***** INPUT OF YEAR 2003 *****

 INDEX = 1
 OBJECTIVE FUNCTION STATE 6 TO 6
  8868292.
    5

           ***** INPUT OF YEAR 2004 *****

 INDEX = 1
 OBJECTIVE FUNCTION STATE 7 TO 7
 10234274.
    6
```

………………………………………………………………….
………………………………………………………………….
…………………………………………………………………

```
           ***** INPUT OF YEAR 2014 *****

 INDEX = 1
 OBJECTIVE FUNCTION STATE 17 TO 17
 17540796.
    16

           ***** INPUT OF YEAR 2015 *****

 INDEX = 1
 OBJECTIVE FUNCTION STATE 18 TO 18
 17970164.
    17

           ***** INPUT OF YEAR 2016 *****

 INDEX = 1
 OBJECTIVE FUNCTION STATE 19 TO 19
 18349334.
    18

           ***** INPUT OF YEAR 2017 *****

 INDEX = 1
 OBJECTIVE FUNCTION STATE 20 TO 20
 18691688.
    19
```

Figure 8.2. (page 2) DYNPRO printout for a fixed expansion plan of the sample problem. DYNPRO Run-1. Values of objective function and optimal path.

```
SOLUTION # 1 VARIABLE ALTERNATIVES BY YEAR
 YEAR------ PRESENT WORTH COST OF THE YEAR ( K$ )------ OBJ.FUN. LOLP V-CC VLG2 NUCL HYD2
   CONCST SALVAL OPCOST ENSCST  TOTAL (CUMM.) %  VLG1 VCOA HYD1
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 2017 300999 271740 312705  390 342354 18691688 0.125 3 4 6 9 4 2 2
 2016 203931 164939 339673  505 379170 18349334 0.145 3 4 5 9 3 2 2
 2015 288814 212624 352475  703 429368 17970164 0.175 3 3 5 8 3 2 2
 2014 239201 155667 386946  11228 481708 17540796 0.238 3 3 5 8 2 2 2
 2013 362660 211205 403656 142269 697380 17059088 1.297 3 3 4 7 2 2 2
 2012 189082  98358 417970  17359 526053 16361708 0.263 3 2 3 6 2 2 2
 2011 533238 255656 436800  361 714743 15835655 0.081 3 2 3 5 2 2 2
 2010 350214 144380 475190  713 681736 15120912 0.130 3 2 2 5 1 2 2
 2009 251669  91995 489382  1493 650549 14439176 0.219 3 2 1 4 1 2 2
 2008   0   0 512669  732 513401 13788627 0.115 3 2 1 3 1 2 2
 2007 466134 132593 541107  164 874813 13275226 0.032 3 2 1 3 1 2 2
 2006 1015979 272306 537936  303 1281912 12400413 0.051 3 2 0 2 1 2 2
 2005 385263  95136 593171  929 884227 11118501 0.121 3 2 0 1 0 2 2
 2004 981056 233669 617731  864 1365982 10234274 0.106 3 1 0 1 0 2 1
 2003 505058  96635 672256 460777 1541456 8868292 2.585 2 1 0 1 0 1 1
 2002 896059 132584 688576 1341526 2793578 7326836 6.168 1 1 0 1 0 0 1
 2001 358377  41673 647643  2152 966499 4533259 0.198 1 0 0 0 0 0 0
 2000   0   0 655157  5957 661114 3566760 0.458 0 0 0 0 0 0 0
 1999   0   0 664444 809808 1474252 2905646 4.304 0 0 0 0 0 0 0
 1998   0   0 664800 766594 1431395 1431395 4.281 0 0 0 0 0 0 0
```

Figure 8.2. (page 3) DYNPRO printout for a fixed expansion plan of the sample problem. DYNPRO Run-1. Results of economic calculations.

```
  1 STATE   0 0 0 0 0 0 0
  2 STATE   0 0 0 0 0 0 0
  3 STATE   0 0 0 0 0 0 0
  4 STATE   1 0 0 0 0 0 0
  5 STATE   1 1 0 1 0 0 1
  6 STATE   2 1 0 1 0 1 1
  7 STATE   3 1 0 1 0 2 1
  8 STATE   3 2 0 1 0 2 2
  9 STATE   3 2 0 2 1 2 2
 10 STATE   3 2 1 3 1 2 2
 11 STATE   3 2 1 3 1 2 2
 12 STATE   3 2 1 4 1 2 2
 13 STATE   3 2 2 5 1 2 2
 14 STATE   3 2 3 5 2 2 2
 15 STATE   3 2 3 6 2 2 2
 16 STATE   3 3 4 7 2 2 2
 17 STATE   3 3 5 8 2 2 2
 18 STATE   3 3 5 8 3 2 2
 19 STATE   3 4 5 9 3 2 2
 20 STATE   3 4 6 9 4 2 2
```

Figure 8.2. (page 4) DYNPRO printout for a fixed expansion plan of the sample problem. DYNPRO Run-1. List of states considered in the run, (DYNPRO2.REP file).

8.3.3. Input data for dynamic expansion plans

The execution of DYNPRO for a dynamic (or variable) expansion plan is essentially the same as for the fixed expansion schedule except for a few changes introduced in the data records. Figure 8.3 shows the input data used for variable expansion runs of DYNPRO for the sample problem, which are very similar to those used for the fixed expansion plan (see Fig. 8.1) with a few changes. First, the type-X record in Fig. 8.3 has a zero for both printing options in order to reduce the output of the run.

Since in the dynamic optimization phase for the sample problem, one is interested in finding the optimal solution which could be used later as "reference solution" for sensitivity studies, the plant addition schedule restrictions have been left to the respective default values in DYNPRO for the minimum and maximum number of sets or projects of the expansion candidates to be added each year; i.e. records type-6 and type-7 are not used in variable expansion DYNPRO runs.

The rest of the data record types and values listed in Fig. 8.3 are the same as described for the DYNPRO run of the fixed expansion plan (see Section 8.3.1). The use of the various data record types for dynamic expansion runs of the DYNPRO module is left to the discretion of the user, according to the needs of the case study, it is however recommended to read carefully the remarks on this subject made in Section 8.4.

```
DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL  0 0
1998 1998 1998 20
 10.  10.
2
318. 477.  25.  0.  0. 11.92  3.    1 V-CC
594. 891.  25.  0.  0. 19.2  5.    2 VLG1
544. 817.  25.  0.  0. 19.2  5.    3 VLG2
495. 743.  25.  0.  0. 19.2  5.    4 VCOA
730. 1703.  30.  0.  0. 26.0  7.    5 NUCL
     50.            6 HYD1
841. 841.       22.67  6.     VHY2
970. 970.       22.67  6.     VHY3
     50.            7 HYD2
742. 742.       19.2  5.     VHY1
866. 866.       19.2  5.     VHY4
11
 1.  0.  0.
16
1
1   (END OF YEAR 1998)
1   (END OF YEAR 1999)
1   (END OF YEAR 2000)
1   (END OF YEAR 2001)
1   (END OF YEAR 2002)
1   (END OF YEAR 2003)
1   (END OF YEAR 2004)
1   (END OF YEAR 2005)
1   (END OF YEAR 2006)
1   (END OF YEAR 2007)
1   (END OF YEAR 2008)
1   (END OF YEAR 2009)
1   (END OF YEAR 2010)
1   (END OF YEAR 2011)
1   (END OF YEAR 2012)
1   (END OF YEAR 2013)
1   (END OF YEAR 2014)
1   (END OF YEAR 2015)
1   (END OF YEAR 2016)
1   (END OF YEAR 2017)
```

Figure 8.3. DYNPRO input data for variable expansion plans of the sample problem.

8.3.4. Printouts for dynamic expansion plans

The printout for variable expansion DYNPRO runs is basically the same as for the fixed expansion plan described in Section 8.3.2 but, since the printing options are both "0" for variable expansion runs, neither the data read from the VARSYS file nor the listing of states considered in the run are included in the printout for these runs. As mentioned earlier, this reduces considerably the size of the printout.

Figures 8.4 and 8.5 illustrate a sample of the DYNPRO printout for two dynamic expansion runs of the series made in the search for the reference optimal solution of the Sample problem (DEMOCASE). Figure 8.4 for the first of such runs (DYNPRO Run-2) which uses the EXPANALT.BIN and SIMULNEW.BIN files created by CONGEN Run-2 and MERSIM Run-2, respectively, and Figure 8.5 for the last run (DYNPRO Run-3) which uses the respective files created by CONGEN Run-3 and MERSIM Run-3. Only part of the printout is shown in each case.

The printout for DYNPRO Run-2 starts with the cover page identifying the run (not shown in Fig. 8.4), followed by the listing of input data for the run as shown in page 1 of Figure 8.4. Next, the program prints the so-called ***optimization pattern*** of the run, as illustrated on page 2 of Fig. 8.4 for the first few years of the study period.

The optimization pattern report produced by DYNPRO is very useful for tracing the optimal solution and the path of valid configurations (states) from any given year. In this part of the output, the objective function for each configuration considered by DYNPRO (10 per line) for each year of study is printed. The numbers below the objective function values show which state in the previous year preceded that particular state and are given in the same order as the values of the objective function.

For example, page 2 of Figure 8.4 shows that for the sixth year of study (year 2003), this DYNPRO run considered states: 30 to 80 (51 states in total). This is followed by the respective values of the objective function of these states, and the number of the state in the preceding year (2002) connected to the sub-optimum path. Therefore, state number 30 has a value of the objective function of 7873656 (thousand $, or K$ in the printout), and is preceded by state number 6 of year 2001, which in turn arises from state number 4 of year 2000, and so on. The path for state number 30 backward is: 6 - 4 - 3 - 2 - 1 (state 1 is the fixed system in 1998).

Similarly, the path for each of the states considered in this particular DYNPRO run (1339 states in total) can be traced by looking at the listing of the optimization pattern for the run.

In this listing, the states which would be given a zero for both, the objective function value and the number of the preceding year state, correspond to states not allowed by the constraints that may be imposed by the user in DYNPRO. In some cases, the listing of objective function values may contain stars (*) for one or more states of some years and a number for the respective preceding year state. This can be explained as follows:

> If the preceding year state is shown as zero ("0"), this means that there is no possible transition from the previous year (i.e., this year state cannot be reached from any of the "accepted" states in the previous year) even if the current year state fulfills the DYNPRO constraints.

If the preceding year state is marked with a number (not zero), this simply means that the format for printing the objective function value has been over flown (i.e. this year state's objective function is greater than or equal to 10^{11} K$).

Page 3 of Fig. 8.4 shows the report for the best solution (#1) found in the DYNPRO Run-2 which is similar to the one shown in Fig. 8.2 for the fixed expansion run except that here some of the states contain a DYNPRO "message." This is represented by a sign (+) or (-) to the right of the number of sets or projects of each expansion candidate, to indicate what restriction used in CONGEN has acted as a constraint on the solution.

For example, in year 2002 the state includes 2 sets of the expansion candidate number 1 (V-CC), followed by a sign (+) which means that more than 2 units of this plant may lead to a better solution (only up to 2 units of V-CC were permitted in this year in the CONGEN Run-2. Similarly, in year 2003 more than 3 units of this plant may lead to a better solution (only up to 3 units were permitted in this year in the CONGEN Run-2).

On the other hand, the sign (-) indicates that the minimum number of sets or projects required in CONGEN for the respective plant in the year is too high. Therefore, the configuration for year 2005 shows 1- unit of the expansion candidate number 2 (VLG1), telling the user that less than 1 unit of this plant may lead to a better solution (in CONGEN Run-2 for this year, one unit of VLG1 was specified as the minimum number of sets).

Number of sets or projects not marked with a sign mean *either* that the solution was not constrained by the restrictions in CONGEN if the tunnel width for the respective plant in that year was not zero in CONGEN, or that DYNPRO did not have another choice (i.e. tunnel width for the plant is zero in the respective year).

In CONGEN Run-2, in year 2010, for example, 2 units of VLG2 and 2 projects each of HYD1 and HYD2 appear without any sign. In this case, the tunnel width for VLG2 was 2 and the minimum number of sets one; the program had a choice of selecting 1, 2 or 3 units of this candidate plant, and selected 2 units which did not hit the upper or lower limits of the choices, and hence the result is without a sign. In the case of HYD1 and HYD2, on the other hand, the tunnel width was zero (because no more projects were available) and the program did not have any choice, thus showing no sign for these candidates. For variable expansion DYNPRO runs, a similar printout is produced by the program for as many best solutions as requested by the user on data record type-13 (if this record type is not used, DYNPRO reports 1 best solution).

The messages in the DYNPRO printout for variable expansion plans help the user in finding the optimum solution for the case study. Interpreting these messages, the user should proceed to execute new WASP iterations involving sequential runs of Modules 4 to 6, modifying each time the restrictions in CONGEN accordingly. (If for a candidate negative sign appears, its minimum number of sets on type-2 record of CONGEN should be reduced by one, and if a positive sign appears this should be increased by one). The process should be repeated until the best solution reported by DYNPRO is free of messages or, eventually, until the restrictions in CONGEN can no longer be relaxed due to some physical constraints. At each iteration, the value of the objective function for the best solution of DYNPRO is to be compared with the respective value for the best solution found in the previous iteration in order to determine that in fact a better solution has been achieved with the new iteration.

```
ALL COSTS WILL BE DISCOUNTED TO THE YEAR 1998
BASE YEAR FOR COST ESCALATION CALCULATION 1998
FIRST YEAR OF STUDY = 1998
DURATION OF STUDY = 20 YEARS
DISCOUNT RATE APPLIED TO ALL DOMESTIC COSTS - %/YR = 10.00
DISCOUNT RATE APPLIED TO ALL FOREIGN COSTS - %/YR = 10.00

          ***** INPUT OF YEAR 1998 *****

INDEX = 2

  -- C A P I T A L C O S T S ($/KW) --  PLANT    CONSTR.
  (DEPRECIABLE PART) (NON-DEPREC. PART)  LIFE  I.D.C.  TIME
PLANT DOMESTIC FOREIGN  DOMESTIC FOREIGN  (YEARS)  (%)  (YEARS)
V-CC  318.0  477.0  0.0  0.0  25.  11.92  3.0
VLG1  594.0  891.0  0.0  0.0  25.  19.20  5.0
VLG2  544.0  817.0  0.0  0.0  25.  19.20  5.0
VCOA  495.0  743.0  0.0  0.0  25.  19.20  5.0
NUCL  730.0 1703.0  0.0  0.0  30.  26.00  7.0

HYD1 HYDRO PROJECT(S) CAPITAL COSTS
VHY2  841.0  841.0       50.  22.67  6.0
VHY3  970.0  970.0       50.  22.67  6.0

HYD2 HYDRO PROJECT(S) CAPITAL COSTS
VHY1  742.0  742.0       50.  19.20  5.0
VHY4  866.0  866.0       50.  19.20  5.0

INDEX = 11
COEFFICIENTS FOR CALCULATION OF COST OF ENERGY NOT SERVED - IN $/KWH :
  CF1 = 1.0000 CF2 = 0.0000 CF3 = 0.0000

INDEX = 16
USE SINKING FUND DEPRECIATION METHOD FOR SALVAGE VALUE CALCULATION
```

Figure 8.4. (page 1) DYNPRO printout for the first variable expansion plan of the sample problem (DEMOCASE) DYNPRO Run-2. Input data for the run.

```
 INDEX = 1
OBJECTIVE FUNCTION STATE 1 TO 1
 1431395.
  1

          ***** INPUT OF YEAR 1999 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 2 TO 2
 2905646.
  1

          ***** INPUT OF YEAR 2000 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 3 TO 3
 3566760.
  2

          ***** INPUT OF YEAR 2001 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 4 TO 5
 4533259. 4860562.
  3   3

          ***** INPUT OF YEAR 2002 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 6 TO 29
 6890437. 5967573. 6675704. 8481546. 7026323. 7136445. 6397615. 7404958. 6877163. 8293960.
 7056652. 6535586. 6929435. 6057361. 7326836. 6668017. 8448862. 7035260. 7162074. 6489262.
 7386817. 6938212. 8233638. 7129829.
  4   4   4   4   4   4   4   4   4   4
  4   4   4   4   4   4   4   4   4   4
  4   4   4   4

          ***** INPUT OF YEAR 2003 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 30 TO 80
 7873656. 6911928. 7133947. 7828972. 7359769. 7222159. 7290013. 7614402. 7514742. 10181430.
 8015276. 7741312. 8004595. 7064819. 7288492. 7866821. 7515267. 7284685. 7445768. 7693262.
 7671063. 10223218. 8043360. 7897800. 7703015. 6990559. 7213639. 7798734. 7440064. 7204102.
 7370541. 7593076. 7595600. 10086040. 7964040. 7822223. 7631288. 7856528. 7144395. 7562012.
 7368782. 7839888. 7595859. 7311906. 7526617. 9938966. 7682837. 7752006. 10119354. 8054118.
 7978720.
  6   7   7   7   7   7   7   7   7   11
  7   7   6   7   7   7   7   7   7   7
  7   11   7   7   17   7   7   7   7   7
  7   7   7   24   7   7   17   17   7   7
  7   7   7   7   7   24   7   7   24   7
  7

          ***** INPUT OF YEAR 2004 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 81 TO 147
 7995395. 8195316. 8132562. 8107175. 8330900. 8322989. 8531534. 8897720. 7934326. 8131718.
 8332268. 8046120. 8269655. 8243611. 8468375. 8443927. 8669036. 9382208. 8420759. 8394799.
 8619824. 8594582. 8819885. 8533817. 8759688. 8692847. 8732817. 8958743. 8991070. 8932936.
 8065648. 8265935. 8203347. 8177583. 8401928. 8377602. 8602527. 8710245. 8004532. 8202366.
 8221460. 8403093. 8116407. 8340693. 8314381. 8539482. 9179509. 8514841. 8740075. 8995808.
 8971437. 9195550. 8266868. 8491818. 8465648. 8690967. 9077695. 8665507. 8891106. 8453948.
 8605002. 8831034. 8668647. 8804131. 9030164. 8920474. 9004367.
  31   31   31   31   31   31   31   42   31   31
  31   31   31   31   31   31   31   42   31   31
  31   31   31   31   31   47   31   31   47   31
  31   31   31   31   31   31   31   66   31   31
  31   31   31   31   31   31   73   31   31   66
  66   66   31   31   31   31   69   31   31   73
  31   31   73   31   31   73   31

          ***** INPUT OF YEAR 2005 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 148 TO 196
 8976672. 9154759. 9094321. 9274115. 9271020. 9627069. 9449146. 9760688. 9938925. 9220427.
 9199588. 9396366. 9377542. 9575045. 9319215. 9517023. 9850960. 9495132. 9693413. 10198855.
 9673133. 9871588. 9645490. 8918960. 9094982. 9590349. 9273290. 9082527. 9213157. 9287421.
 9389807. 9584803. 9567901. 9703767. 9879063. 10057491. 9339294. 9318071. 9515283. 9496313.
 9694007. 9438298. 9636262. 9869832. 9614220. 9812678. 10192506. 9792257. 9990831.
  89   89   89   92   89   92   89   130   130   133
  133   133   133   133   133   133   140   133   133   140
  133   133   118   89   89   121   89   92   89   92
  89   92   89   130   130   130   133   133   133   133
  133   133   133   140   133   133   140   133   133
```

Figure 8.4. (page 2) DYNPRO printout for the first variable expansion plan of the sample problem (DEMOCASE) DYNPRO Run-2. Objective function values and optimisation path.

```
SOLUTION # 1 VARIABLE ALTERNATIVES BY YEAR

 YEAR------ PRESENT WORTH COST OF THE YEAR ( K$ )------ OBJ.FUN. LOLP V-CC VLG2 NUCL HYD2

   CONCST SALVAL OPCOST ENSCST  TOTAL (CUMM.) %  VLG1 VCOA HYD1
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 2017 300999 271741 310695  643 340596 16365292 0.184 4+ 3- 6 8 4+ 2 2
 2016 129146 104453 337118  837 362648 16024696 0.214 4+ 3- 5 8- 3+ 2 2
 2015 371078 272350 351273  669 450669 15662048 0.166 4+ 3 5 7- 3+ 2 2
 2014 322135 209640 381735  1002 495232 15211379 0.216 4+ 2- 5 7- 2+ 2 2
 2013 271432 158076 400409  883 514648 14716147 0.182 4+ 2- 3- 6- 2+ 2 2
 2012 289433 150560 412298  1034 552205 14201499 0.195 4+ 1- 3 5- 2+ 2 2
 2011 422852 204475 427913  1310 647600 13649294 0.220 4+ 1- 2- 4- 2+ 2 2
 2010 242848 100117 468320  1316 612366 13001694 0.209 4+ 1- 2 4- 1+ 2 2
 2009 251669  91995 474968  1334 635976 12389328 0.194 4+ 1- 0 4 1+ 2 2
 2008 276836  89435 495185  637 683222 11753352 0.102 4+ 1- 0 3 1+ 2 2
 2007 446579 135619 512805  736 824501 11070130 0.107 4+ 1- 0 2- 1+ 2 2
 2006 681008 188781 531950  1025 1025202 10245629 0.131 4+ 1- 0 1- 1+ 2 1-
 2005 458148  99619 594439  591 953559 9220427 0.081 4+ 1- 0 1 0 2+ 1-
 2004 1002212 257571 608340  1958 1354940 8266868 0.204 3 0 0 1 0 2+ 1+
 2003 296180  47997 686748  9425 944355 6911928 0.686 3+ 0 0 1 0 0 0
 2002 816229 112702 723419  7370 1434315 5967573 0.537 2+ 0 0 1 0 0 0
 2001 358377  41673 647643  2152 966499 4533259 0.198 1 0 0 0 0 0 0
 2000   0   0 655157  5957 661114 3566760 0.458 0 0 0 0 0 0 0
 1999   0   0 664444 809808 1474252 2905646 4.304 0 0 0 0 0 0 0
 1998   0   0 664800 766594 1431395 1431395 4.281 0 0 0 0 0 0 0
```

Figure 8.4. (page 3) DYNPRO printout for the first variable expansion plan of the sample problem (DEMOCASE) DYNPRO Run-2. “Best” solution for the run.

```
SOLUTION # 1 VARIABLE ALTERNATIVES BY YEAR
 YEAR------ PRESENT WORTH COST OF THE YEAR ( K$ )------ OBJ.FUN. LOLP V-CC VLG2 NUCL HYD2
   CONCST SALVAL OPCOST ENSCST  TOTAL (CUMM.) %  VLG1 VCOA HYD1
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 2017 300999 271740 307806  605 337670 16204846 0.174 4+ 1 6 9 4+ 2 2
 2016 129146 104453 334168  789 359650 15867176 0.202 4+ 1 5 9 3+ 2 2
 2015 364209 267362 347929  627 445403 15507526 0.157 4+ 1 5 8 3+ 2 2
 2014 322135 209639 378213  944 491653 15062123 0.204 4+ 1 4 8 2+ 2 2
 2013 263121 153235 395488  837 506211 14570470 0.172 4+ 1 2 7 2+ 2 2
 2012 289433 150560 410445  994 550312 14064259 0.185 4+ 1 1 6 2+ 2 2
 2011 422852 204476 416527  1247 636150 13513947 0.208 4+ 1 0 5 2+ 2 2
 2010 228790  94321 457898  1246 593612 12877797 0.197 4+ 1 0 5 1+ 2 2
 2009 397404 145267 474968  1334 728440 12284185 0.194 4+ 1 0 4 1+ 2 2
 2008 276836  89436 489138  1300 677838 11555745 0.180 4+ 0 0 3 1+ 2 2
 2007 304519  86621 506003  1520 725421 10877907 0.192 4+ 0 0 2 1+ 2 2
 2006 681008 188781 521107  1421 1014755 10152486 0.171 4+ 0 0 1 1+ 2 2
 2005 540360 128861 582440  858 994798 9137731 0.109 4+ 0 0 1 0 2 2
 2004 711802 182935 607398  1842 1138107 8142933 0.192 4+ 0 0 0 0 2 1
 2003 505058  96636 678416  3802 1090640 7004826 0.317 4+ 0 0 0 0 1 1
 2002 773226 115623 718341  4984 1380928 5914187 0.380 3+ 0 0 0 0 0 1
 2001 358377  41673 647643  2152 966499 4533259 0.198 1 0 0 0 0 0 0
 2000   0    0 655157  5957 661114 3566760 0.458 0 0 0 0 0 0 0
 1999   0    0 664444 809808 1474252 2905646 4.304 0 0 0 0 0 0 0
 1998   0    0 664800 766594 1431395 1431395 4.281 0 0 0 0 0 0 0
```

Figure 8.5. DYNPRO printout for the last variable expansion plan of the sample problem (DEMOCASE) DYNPRO Run-3. Optimal solution.

Table 8.2. Variation of objective function for the various DYNPRO runs of DEMOCASE

DYNPRO Run	Solution	Configuration for Year 2017: Number of Units or Projects of Each Expansion Candidate							O.F. Cum. Value $\$\times10^6$	Change %
		V-CC	VLG1	VLG2	VCOA	NUCL	HYD1	HYD2		
3	1	4+	1	6	9	4+	2	2	16204846	-
	2	4+	2+	5-	9	4+	2	2	16206655	0.0112
	3	4+	1	6	10+	3	2	2	16208739	0.0240
2	1	4+	3-	6	8	4+	2	2	16365292	0.9901
1	1	3	4	6	9	4	2	2	18691688	15.35

Table 8.2 summarizes the configurations for year 2017 of the three best solutions of the last run of the variable expansion schedule (DYNPRO Run-3) and for one best solution for the first variable expansion schedule (DYNPRO Run-2) as well as for the fixed expansion schedule (DYNPRO Run-1). Table 8.2 also compares the objective functions of each solution. It is seen that the second best solution of the last run of the variable expansion plan (DYNPRO Run-3) increased the value of the objective function by only about 0.0112% compared to the optimal solution whereas the fixed expansion schedule resulted in an objective function 15.35% higher than that of the optimal solution. Also, comparing the objective function of the best solution for the first and last runs of the variable expansion plans, it can be seen that the dynamic optimization process reduced this value by about 1%. [Note: The objective function stands for present-worth of total values expansion costs. Thus, these apparently small differences in the objective function values can represent a large difference in terms of the annual expenditures associated to each solution].

Regarding the report of the optimal solution in Fig. 8.5, it can be seen that this still contains some messages concerning the constraints used in the respective CONGEN run (CONGEN Run-3). Some messages apply to the number of units of expansion candidates 1 and 5 (V-CC and NUCL), implying that a better solution could be achieved and a new CONGEN, MERSIM, DYNPRO iteration should be carried out opening the respective tunnel widths in the CONGEN run. However, in this Sample problem, it has been assumed that the pace of addition for these two candidates cannot be increased from the maximum allowed in the CONGEN constraints. Hence, these signs can be ignored (accepted) in the optimal solution. Nevertheless, if deemed necessary, sensitivity analysis may be carried out to evaluate the impact of relaxing these constraints. Furthermore, the number of hydro projects, for both types, appear without any sign in the final optimal solution. This has been due to the fact that after observing that these projects are accepted in all iteration in their first year of availability thus there was no need to keep tunnel width open for these candidates. Messages for the minimum number of sets or projects (-) may also appear in the optimal solution but the dynamic optimization process can be stopped. This occurs when the minimum number of sets or projects of the respective plant cannot be reduced any further owing to commitments of plant additions for the particular system.

Alternatively, the above messages can be eliminated from the DYNPRO printout by simply executing a new WASP iteration (executing Modules 4 to 6 in the same order). In the new CONGEN run, the expansion schedule is made "fixed" for the plants which are still acting as a constraint on the optimum solution. This is achieved by specifying in type-2 records of the CONGEN run, the same number of sets or projects contained in the optimal solution for the respective plants in each applicable year and setting the corresponding tunnel widths (records type-3) to zero. It should be stressed that regardless of the expansion rules and energy policies provided by the regulating authorities, it is always convenient to run an overall optimization of WASP for the case study, where only the physical constraints imposed by the construction periods of thermal and hydro expansion candidates, or the total amount of domestic fuel available for expansion, are respected. In such a run, additional constraints related to the availability of imported fuels should be waived. This will permit to provide a feedback as to how expensive the chosen "reference" optimal solution is when compared to the overall "unconstrained" optimal solution.

8.4. SPECIAL REMARKS ON THE DYNPRO CAPABILITIES

As mentioned in the section 8.1, DYNPRO is designed to calculate cost of each alternative policy for system expansion based on a performance criterion or an objective function. This objective function is evaluated as the algebraic sum of the present-worth values of all costs associated with each configuration integrating a given expansion policy through the study period. Present-worth (discounting) calculations are carried out using the appropriate discount rates (for foreign and local costs) given by the user and certain assumptions for the cash flows on the various expenditures. Escalation of costs can be also applied as the study progresses and using the appropriate escalation ratios specified by the user. These calculations also require the definition by the user of base years for present-worth (JHRPWB) and escalation (JHRFUL). These concepts were discussed briefly in Section 1.2.

It should be noted that the main assumptions behind the definitions of the reference years (JHRPWB, JHRFUL) to be used as input data for a DYNPRO run are the following:

- All cost information (capital or operating) is supposed to be given in monetary units of the base year for escalation (JHRFUL). Thus, no escalation effect is applied for the years up to JHRFUL (even if erroneously specified by the user) and the escalation effect in any year after JHRFUL takes into account the effect of any escalation in the preceding years combined with that of the year being considered.

- The base year simply represents a reference year to which all cash flows associated with an expansion policy are discounted supposing a certain occurrence of the expenditure flow and using appropriate discount factors. The discount factor for a given expenditure combines the effect of discount rates specified for the period of time from JHRPWB up to the moment the expenditure is assumed to occur.

According to the WASP capabilities to handle input information, DYNPRO can handle different escalation ratios for type of cost component, for type of expenditure and for type of plant. Additionally, these escalation ratios can be varied from one year to another over the study period. The idea behind these dimensions is to permit the user executing a broad range of sensitivity studies for his/her case, once the optimal solution has been found.

Chapter 9

EXECUTION OF REPROBAT

REPROBAT is Module 7 of WASP-IV and has the purpose of presenting either total or partial results of an electric power system planning study in a concise and easily read form. Partial results for the first three WASP modules can also be obtained as soon as any of them has been run successfully without the need of having run CONGEN, MERSIM, and DYNPRO (see Chapter 10). Once all previous six modules of WASP have been run successfully, a full REPROBAT report can be obtained. Partial reports can also be obtained by deleting the portions not required. For example, data on cash flow of construction costs may be requested for only a part of the study period. Also one complete module of WASP could be dropped from the report as explained in Section 9.2.

If a complete report of the optimal solution (or eventually of the best solution found by the latest DYNPRO run) is to be printed by REPROBAT, it is necessary to execute first a resimulation (REMERSIM) of this solution as described in Section 7.3.5 REPROBAT can also be used to produce a report on a fixed expansion schedule. The format of the report printed by REPROBAT is such that the printout can be included in the study report.

9.1. INPUT/OUT FILES

REPROBAT uses an input file, named REPROBAT.DAT, to be provided by the user defining necessary options for producing the reports by the present run. Besides, it uses various intermediate files, produced by all other modules for which the reports to be produced are selected. The results are reported in the REPROB1.REP file, which can be included in the study report. This output file should be reviewed carefully to examine correctness of the results of analyses.

9.2. INPUT DATA PREPARATION

REPROBAT can use up to 20 types of data records as shown and described in Table 9.1. In normal runs when the entire printout option is desired, records type-2 and type-3 are omitted.

The first data record is the type-X record giving the title of the study (centred to columns 30–31 of the record) and in column 63 a symbol which will be used by REPROBAT to fill the empty spaces of the matrices in some of the Tables included in the report. This is to be selected by the user for his/her convenience from symbols such as: star (*); hyphen (-); apostrophe ('); etc. A dot (.) is recommended. If no symbol appears in record type-X, the empty spaces in the Tables are simply left blank (default value).

A type-A data record gives, in the first two fields, the initial and last year of the study, which should be the same values used in FIXSYS. The next two fields of this record are used to specify the first and last year of the planning period, which must be embedded within the study period. This permits specifying a planning period covering only a few important years fewer than the total number of years of the study period.

Records type-1 with INDEX=1 to 8 are used to control the input data flow depending on the INDEX number. A type-1 INDEX=1 record tells the computer that all input data have been completed and that execution of REPROBAT can begin. A type-1 INDEX=2 (3 or 4) indicates that a record type-2 (-3 or -4) must be read next. Similarly, a type-1 INDEX=5 tells the computer that data records type-5a and -5b follow, and a type-1 INDEX=6 that records type-6 (up to 60) are to be read next. Finally groups of one type-1 INDEX=7 (or 8) record and the respective type-7a to -7g (or -8a to -8d) records are used following the sequence described in Table 9.1. Similar to all other WASP modules, it is important to use the proper sequence for the module to run, otherwise it may lead to wrong calculations for the run or stop of its execution (see Section 8 of Chapter 13).

A type-2 record is used if a partial report is asked for, i.e. if one or more modules are to be dropped from the report or if only reports on cash flows of operating and/or construction costs are needed. This type-2 record specifies eight output options controlling the logic of execution and the output. All options are set to "1" by default. If reset to "0", no output for the corresponding part is produced. For the convenience of the user, it is recommended to set the value equal to the number of the option as indicated below. The eight output options are:

Option	#1:	> 0 (i.e. "1")	load system description (LOADSY)
	2:	> 0 (i.e. "2")	fixed system description (FIXSYS)
	3:	> 0 (i.e. "3")	variable system description (VARSYS)
	4:	> 0 (i.e. "4")	constraints in the configuration generator module (CONGEN)
	5:	> 0 (i.e. "5")	optimum solution (DYNPRO)
	6:	> 0 (i.e. "6")	economic parameters and constraints (DYNPRO)
	7:	> 0 (i.e. "7")	expected costs of operation (MERSIM)
	8:	> 0 (i.e. "8")	cash flow of construction and fuel inventory costs

It should be noted that all eight options have to be defined if a record type-2 is used (blanks in the corresponding field are interpreted by the computer as zeroes, thus no output is produced). For example, if a partial report of the three first modules of WASP is required before executing modules 4 to 6 of WASP, the type-2 record for the REPROBAT run should contain a "1" in column 4, "2" in column 8 and "3" in column 12; columns 16, 20, 24, 28 and 32 being "0" (or left blank).

A type-3 record specifies three sub-options to option #8 (see type-2 record above) controlling the output of cash flows. They are all set to a value =1 by default (If type-7 records are used, option #8 > 0 and its suboptions must be greater than 0). For the convenience of the user it is recommended to set the values equal to the number of the option (see below). All three sub-options have to be defined if a type-3 record is used. The logic and output of the program for these three sub-options is as follows:

Cash flow of construction costs:

IOPCON(1)	> 0 (i.e. "1")	cash flow calculated and printed.
	= 0 -------->	no report.

Cash flow of interest during construction (IDC)

IOPCON(2) > 0 (i.e. "2") and IOPCON(1) > 0
--------> cash flow calculated & printed and summary report on investment costs is printed with IDC columns.

= 0 --------> no report and if IOPCON(1)>0, summary report of investment costs is printed without IDC columns.

Cash flow of construction + IDC costs

IOPCON(3) > 0 (i.e. "3") and IOPCON(1) & (2) > 0 report printed.
= 0 --------> no report.

Cash flow of fuel inventory (investment) cost

IOPCON(1) > 0 --------> cash flow calculated and printed.
= 0 --------> no report.

A type-1 INDEX=4 record followed by a type-4 record are used to specify the options for reporting detailed information about the simulation of system operation for the optimal solution. This options can only be used if a resimulation (REMERSIM) of the best solution found by DYNPRO (or eventually the optimal solution) has been carried out prior to the REPROBAT run. The following alternatives are available, depending on the value of these sub-options IOPSIM or IOPPOL respectively.

Sub-option:

= 2 Maximum output: the report includes summary tables of the fuel stock and consumption by thermal fuel type, and of the generation by plant type (for IOPSIM) and summery tables of group limitations (for IOPPOL) respectively both by hydro-condition and weighted by the probabilities of the hydro-conditions.

= 1 Same as =2 above, but no reports per hydro-condition.

= 0 No report printed (default value).

The type-5a and -5b data records are all identified by one "N" in column 1 of the record. The information given in these data records is used by REPROBAT to produce the cover page of the report. If a record type-1 INDEX=5 is used, one record type-5a and one record type-5b must also be used, even if the titles in any of these two records are to be left blank. If no record type-1 INDEX=5 is used, REPROBAT will set these titles to blank (default values).

Data records type-6 (identified by one "L" in column 1 of the record) are used if additional information is to be printed in the report. A maximum of 60 records type-6 can be used in a REPROBAT run. All this additional information is printed in a separate page of the report (see Figure 9.2) following the table of contents.

The remaining data record types (7 and 8) in the REPROBAT input data can be used as follows. Groups of type-7 records are included in the input data to specify which FIXSYS plants must be considered in the cash flow tables of capital costs of the REPROBAT report. The necessary data for these plants are also specified in these record types. Up to 20 sets of type-7 records can be used in a run of the module. The first record in each set must be a type-1 INDEX=7 accompanied by the following sequence of data records:

Record type-7a: to specify plant name, fuel type, the control key for fuel inventory cost data (IFC), first year of service and construction period.

Record type-7b: total domestic component of the "pure" construction costs and the annual distribution (%) of this total for as many years as the length of the construction period, including fraction of years (e.g. if the plant takes 52 months to be built, the annual distribution data must cover 5 years).

Record type-7c: same as type-7b above, but for the foreign component of these costs.

Record type-7d: total domestic component of the fuel inventory costs and the annual distribution (%) of these costs. Only two entries are required since the program assumes that these costs are always distributed over 18 months. This record is not needed for hydro or P-S projects. In addition, this record is not needed if IFC=0 in the type-7a record of this set for any of the FIXSYS thermal plants.

Record type-7e: same as type-7d above, but for foreign component of these costs.

Record type-7f: total domestic component of interest during construction (IDC) and the annual distribution (%) of this total for as many years as the length of the construction period, including fraction of years.

Record type-7g: same as type-7f above, but for the foreign component of these costs.

Table 9.1. (page 1) Types of data records used in REPROBAT

Record type	Columns	Format[1]	Fortran name	Information
	1–60	A	IDENT (COUNTR)	Title of the study which has to be centered in the given space (columns 30–31 are the center columns of the field).
X	63	A	LATICE	One character to pre-format empty spaces of matrices in the tables of the report. (Default value is blank; recommended value a dot [.]).
A	1–5	I	IYSTUD	Initial year of study (same as in FIXSYS).
	6–10	I	LYSTUD	Last year of study (same as in FIXSYS).
	11–15	I	IYPLAN	First year of planning period.
	16–20	I	LYPLAN	Last year of planning period. **Note**:The planning period must be embedded in the study period or be equal to it (default value). If IYPLAN = 0 or blank, the planning period is made equal to the study period.
1	1–4	I	INDEX	Index number from 1 to 8 telling the computer what to do next. An INDEX=1 means that input data have been completed and that the program can start execution. Other INDEX values indicate that records of type equal to the INDEX number follows; i.e.: INDEX=2, Record type-2 follows. INDEX=3, Record type-3 follows. INDEX=4, Record type-4 follows[2]. INDEX=5, Record type-5a and record type-5b follow, etc.
2	1–4, 5–8, 9–12, 13–16, 17–20, etc.	I I I I I	IOPLST	Eight printout options. Default value is "1" in all cases. To suppress printout of any part of the report, set to zero ("0") the corresponding field. In sequence, the eight options are: (1) load system description (LOADSY) (2) fixed system description (FIXSYS) (3) variable system description (VARSYS) (4) constraints in configuration generator module (CONGEN) (5)[3] optimum solution[4] (DYNPRO) (6) economic parameters and additional constraints (DYNPRO) (7) expected cost of operation (MERSIM) (8)[3] cash flow of construction and fuel inventory costs **Note**: All eight options must be specified if data record type-2 is used.

Table 9.1. (page 2) Types of data records used in REPROBAT

Record type	Columns	Format[1]	Fortran name	Information
3	1–4, 5–8, 9–12, etc.	I I I	IOPCON	Three sub-options to option #8 (see type-2 Record above). Default value=1 in all cases. By setting it to zero ("0"), the following parts of the printout will be suppressed: (1) Detailed output of cash flows by year and plant (2) Calculation and output of IDC (3) Listing of capital and IDC costs combined **Note**: All three sub-options must be specified if data record type-3 is used.
4[2]	1–4	I	IOPSIM	Sub-option to option #5 (see type-2 record above) for reports on fuel stock and consumption of thermal plants by fuel type, generation by plant type, by hydro-condition and weighted by the probability of the hydro-conditions. If: = 0 no report (default) = 1 only weighted values are reported (and not by hydro-condition) = 2 maximum output can only be active after resimulation. (reset by program)
	5–8	I	IOPPOL	Sub-option to option #5 (see type-2 record above) for reports on Group Limitation. = 0 no report (default) = 1 only weighted values are reported (and not by hydro-condition) = 2 maximum output can only be active after resimulation. (reset by program)
	1	A	NAM	An "N" indicating the type of record used to specify the contents of the footnote of the cover page of the report (one record type-5b must be used as well).
5a	5–24	A	NDAT	Date of the report (any set of 20 characters).
	25–60	A	NAMA	Text 1 (name of the author(s) or any other text. Up to 36 characters to be written after the header "STUDY CARRIED OUT BY:").
5b	1 5–64	A A	NAM COUNTR	An "N" (see record type-5a). Text 2 (up to 60 characters to be written on the report in the following line; or, if this text is to be aligned with and below text1, start in column 29 with up to 32 charecters).
6	1 5–64	A A	LEG COUNTR	An "L" indicating the type of record. Text 3 (up to 60 characters per record). Up to 60 type-6 records may be used to provide additional explanatory information by the author.

Table 9.1. (page 3) Types of data records used in REPROBAT

Record type	Columns	Format[1]	Fortran name	Information
7a[5]	1–4	A	NAMAD	Name of thermal plant unit, hydro or P-S project of the FIXSYS plant to be considered in the REPROBAT report.
	6–7	I	NTYP	Plant Fuel type (thermal: 0–9, hydro: 10,11 or P-S: 99).
	10	I	IFC	Key to control input of fuel inventory data for this plant. If = 1 the fuel inventory must be provided in the type-7d and -7e records. If = 0 (or blank) these two records will not be required. Leave blank for hydro or P-S.
	12–15	I	IY	First year of service of the plant.
	16–20	I	NY	Number of years of construction (maximum = 10).
7b[6]	1–10	F	TCTRL	Domestic total pure construction cost (million $).
	11–16 17–22 . 65–70	F F F	X1	Annual distribution of domestic pure construction cos (%) (As many entries as years of construction — NY).
7c[6]	1–10	F	TCTRF	Foreign total pure construction cost (million $).
	11–16 . 65–70	F F	X2	Annual distribution of foreign pure construction cost (%) (As many entries as years of construction — NY).
7d[7]	1–10	F	TSTKL	Domestic total fuel inventory cost (million $).
	11–16 17–22	F F	X3	Annual distribution of domestic fuel inventory cost (%). (Only two entries).
7e[7]	1–10	F	TSTKF	Foreign total fuel inventory cost (million $).
	11–16 17–22	F F	X4	Annual distribution of foreign fuel inventory cost (%). (Only two entries).
7g[6]	1–10	F	TXIDF	Foreign total interest during construction (million $).
	11–16 . 65–70	F . F	X6	Annual distribution of foreign interest during construction (%) (As many entries as years of construction — NY).

Table 9.1. (page 4) Types of data records used in REPROBAT

Record type	Columns	Format1	Fortran name	Information
8a[8]	1–4	A	NAMP	Thermal plant name, hydro or P-S plant type name (has to be equal to VARSYS name).
	6–9	A	NAMH	Hydro or P-S project name (must be equal to VARSYS name). Leave blank for thermal.
	10	I	IFC	Key to control input of fuel inventory data for this plant. If = 1 the fuel inventory must be provided in the type-8c and -8d records. If = 0 (or blank) these two records will not be required. Leave blank for hydro or P-S.
	11–16 . 65–70	F . F	PERCCL	Annual distribution of domestic pure construction costs (%) (as many entries as years of construction of the plant or project)
8b[8]	11–16 . 65–70	F . F	PERCCF	Annual distribution of foreign pure construction costs (%) (as many entries as years of construction of the plant or project).
8c[9]	11–16 17–22	F F	PERCFL	Annual distribution of domestic fuel inventory cost (%) (only 2 entries).
8d[9]	11–16 17–22	F F	PERCFF	Annual distribution of foreign fuel inventory cost (%) (only 2 entries).

Notes to Table 9.1.

(1) See Section 2.5 for Format description.
(2) A type-1 INDEX=4 and a type-4 record can be used only after a REMERSIM run has been made for the best solution being reported by DYNPRO. For the related output tables to be correct, the preceding run of REMERSIM *must* be executed using printout option IOPT ≥ 1 for all years of study. See Fig. 9.2 and description.
(3) Sub-options are also allowed (see record type-3 and-4).
(4) If the user is running Fixed Expansion plans and a REPROBAT of the solution reported by DYNPRO is required, it is necessary to run REMERSIM first.
(5) The set of data records type-7 can be repeated up to 20 times. These are used to include in the REPROBAT report the annual investment of some committed units specified in FIXSYS.
(6) Each record type-7b, -7c, -7f and -7g has as many entries as years of construction of the plant (NY).
(7) Data records type-7d and -7e require only two entries. They are used only if IFC=1 in the preceding type-7a record. No records type-7d or -7e are required for hydro or P-S project!
(8) This set of records is repeated for each thermal candidate, hydro project and/or P-S project for which a distribution of investment costs (different from the S-curve approach) is defined by the user.
(9) Data records type-8c and -8d require only two entries. They are used only if IFC=1 in the preceding type-8a record. No records type-8c or -8d are required for hydro or P-S project!

Similarly, a type-1 INDEX=8 record can be used to specify for which expansion candidates (VARSYS plants) a distribution of capital investment cost versus time (different from the standard "S" curve used as default) will be defined in subsequent records (type-8a through -8d). The sequence of these data record types is as follows:

Record type-8a: to specify plant name and plant type (for hydro or P-S projects), the control key for fuel inventory cost data (IFC), and the annual distribution (%) of domestic portion of pure construction cost (for as many years, including fractions, as the length of the construction period specified in DYNPRO for this expansion candidate or project).

Record type-8b: annual distribution (%) of the foreign portion of pure construction cost (as many entries as years of construction).

Record type-8c: annual distribution (%) of domestic fuel inventory cost (two entries are required since the program assumes that these costs are always distributed over 18 months). This record is not required for hydro or P-S projects, or if IFC=0 in the type-8a record for thermal expansion candidates.

Record type-8d: same as type-8c above but for the foreign component of these costs.

9.3. SAMPLE PROBLEM

9.3.1. Input data

After having found the optimum solution (in DYNPRO Run-3) of the sample problem and having executed the resimulation run described in Section 7.3.5, the REPROBAT module of WASP was run in order to obtain a complete report on this optimum solution. Figure 9.1 shows the input data used for this run.

The first data line in Fig. 9.1 is a type-X record with the title of the study (kept the same for all runs of the sample problem), and the symbol to be used for filling the empty spaces of the matrices in all tables of the report. A dot (.) has been selected as symbol for this particular run.

Record number 2 is a type-A record specifying in the two first fields the length of the study period (1998–2017), and in the last two fields, that of the planning period. In this case, these fields have been left blank so that the program sets it equal to the study period.

The next input line is a type-1 INDEX=2 record followed by a type-2 record to specify which part of the output are required to be printed. In this case, all options have been given values greater than zero so that the full REPROBAT report is requested[2] These are followed by a type-1 INDEX=3 and a type-3 record to give the sub-option values for printing option #8 of the type-2 record. Again, all three sub-options have been given values greater than zero, asking for complete report[1]. The next type-1 INDEX = 4 and type-4 record specify the two sub-option values for printing option # 5. The value “2” of these sub-options ask for maximum output, thus overwriting the default values (“0”).

The next type of input is a type-1 INDEX=5 record and is followed by the two type-5 (5a and 5b) records giving the date and author(s) of the study.

The next input line is a type-1 INDEX=6 record and is followed by 33 type-6 records providing information supplied by the user. Up to 60 lines of a text can be used here (as demonstrated by dummy records). In this case, they are used to summarise the main features of the power system being analysed.

[2] Note that the specified value(s) is (are) equal to the default value(s) contained in the program (see Table 9.1); therefore, these two records may have been omitted altogether, but they have been included here for demonstration purposes.

Next type of data in Fig. 9.1 correspond to two groups of one type-1 INDEX=7 record followed by several type-7 records to specify for which committed plants (i.e., included as part of the FIXSYS description) the REPROBAT report must contain capital investment information in a tabular form. The respective cost information is provided in the type-7 records of each group.

The first of such groups specifies in the corresponding type-7a record that the REPROBAT report has to include the cash flows for one unit of coal 580 MW. (FCOA in the first field) of fuel type 3 (second field). The zero in the third field of this record tells the computer that no fuel inventory cost information needs to be reported for this plant (and thus that no type-7d or -7e records are expected to be read). The last two fields in this record identify the year of start of operation (1999) and the construction period (5 years) of this plant. The next line is one type-7b record to specify the total domestic pure construction cost of this plant and the percent annual distribution of these costs over the construction period. This is followed by a corresponding type-7c record specifying similar information but concerning the foreign component of pure construction costs. The last two lines are a type-7f and a type-7g record giving similar information to the two last previous ones but for the interest during construction cost. [Note: all annual distribution of costs must add up to 100%].

The second group is identified in the type-7a record as hydro project FHY6 (first field) of type code 11 (HYD2 in second field). The third field in the record is left blank since this (fuel inventory cost) is not applicable to hydro. The fourth field indicates that the plant started operation in year 2000 and the last one a total of 5 years of construction period. The type-7b, 7c, -7f and -7g records that follow give cost information for this project in the same sequence as explained above for the FCOA thermal unit.

Next is a group of one type-1 INDEX=8 record and type-8 records to specify expansion candidate plants or projects for which the distribution of investment expenditures against time are different to the standard "S" curve function used as default by the program. This group of records, in this example, corresponds to a thermal expansion candidate and is identified in the type-8a record as NUCL (first field of the record). The second field of the record is left blank since this applies only to hydro projects. The third field shows a 0 indicating that no information on fuel inventory costs are to be reported for this plant (and thus the type-8c and -8d records are not used). The last seven fields in the record are used to give the annual percentage distribution of domestic pure construction costs of this plant. The annual distribution of foreign pure construction costs is given in the subsequent type-8b record. Note that in each case, the annual distribution of costs must add up to 100%. In addition, it is not necessary to specify the total costs of the plant since this information is already available to the program (read from DYNPRO).

The last data record is a type-1 INDEX=1 record indicating that all input data have been completed and that the module should be executed.

```
DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL   .
 1998 2017
  2
  1  2  3  4  5  6  7  8
  3
  1  1  1
  4
  2  2
  5
N  July 1998      NENP/PESS/IAEA
N              STUDY FOR THE WASP-IV USERS' MANUAL
  6
L  *********************************************
L  *     NEW VERSION OF WASP IV      *
L  *          IAEA           *
L  *                   *
L  *         JULY 1998         *
L  *********************************************
L
L  STUDY PERIOD       1998 - 2017
L  PLANNING PERIOD      1998 - 2017
L
L
L  THIS IS AN EXAMPLE OF WASP-IV CASE STUDY FOR
L  A HYPOTHETICAL POWER SYSTEM. THE SYSTEM CONSISTS
L  OF SIX THERMAL POWER PLANTS AND FIVE HYDRO PROJECTS.
L  ONE UNIT OF COAL BASED PLANT AND TWO UNITS OF
L  COMBINED CYCLE PLANT ARE UNDER CONSTRUCTION, WHILE
L  ONE PROJECT OF HYDRO TYPE-2 IS ALSO COMMITED.
L  SOME OF THE UNIT OF THERMAL PLANTS AND HYDRO PROJECTS
L  ARE ASSUMED TO RETIRE DURING THE STUDY PERIOD (AS
L  DETAILED IN THE REPORT).
L
L  FIVE THERMAL PLANTS AND FOUR HYDRO PROJECTS ARE
L  CONSIDERED AS CANDIDATES FOR FUTURE EXPANSION OF
L  THE SYSTEM.
L
L  FOUR MULTIPLE GROUP LIMITATIONS HAVE BEEN IMPOSED ON
L  THE SYSTEM; TWO OF SUCH LIMITATIONS ARE FUEL LIMITS
L  THE OTHER TWO ARE ENVIRONMENTAL EMISSION LIMITS.
L
L
L  ALL THE TECHNICAL AND ECONOMIC INFORMATION USED IN
L  THIS CASE IS HYPOTHETICAL AND SHOULD NOT BE CONSIDERED
L  AS REFERENCE DATA.
L
L
L
L
L
L
L  40
L  41
L  42
L  43
L  44
L  45
L  46
L  47
L  48
L  49
L  50
L  51
L  52
L  53
L  54
L  55
L  56
L  57
L  58
L  59
L  60
  7
FCOA 3 0 1999  5
   232.0  15.  25.  35.  15.  10.
   348.0  10.  25.  35.  20.  10.
   84.6  4.1 11.4 22.1 28.4 34.0
   120.0  2.9 10.4 21.6 29.6 35.5
  7
FHY6 11 0 2000  5
   126.0  10.  25.  30.  25.  10.
   126.0  5.  15.  25.  35.  20.
   42.7  3. 10.6 20.5 30.0 35.9
   34.8  1.8  7.4 17.2 31.6 42.0
  8
NUCL   0  5.0 10.0 15.0 20.0 25.0 15.0 10.0
       5.0  5.0 10.0 15.0 30.0 25.0 10.0
  1
```

Figure 9.1. Input data for REPROBAT run of the optimal solution for the sample problem (DEMOCASE).

9.3.2. Printout of REPROBAT of the optimal solution

Figure 9.2 illustrates the REPROBAT printout for the sample problem obtained from executing this module using the data records shown in Fig. 9.1. Except for the cover page of the report, all pages are automatically numbered by REPROBAT[2] as can be seen in Fig. 9.2. (In the following description of this figure, page numbers of the REPROBAT report will be referred). Page 1 is the *cover page* showing the title of study, the study and planning periods (specified in the type-A record), and the date and authors of the study (input data on type-5a and -5b records). This page bears a message telling the user that cash flows on construction cost and fuel inventory cost are reported only for plants added during the defined planning period. Thus if the user requires cash flows over the entire study period, the planning period to be specified (on the type-A record) must be equal to the study period (alternatively the corresponding fields are left blank and the planning period is set to default).

Page 2 is the *table of contents*, which is actually printed last by REPROBAT since the numbering of pages depends on the size of the problem and which REPROBAT output options are selected for the run. Page 3 contains the additional *information supplied by the user* on data records type-6. Page 4 identifies the *code numbers and code names* associated with the twelve types of generating plant ("fuel" type) used in the study. Although the WASP modules 5 (MERSIM) and 6 (DYNPRO) automatically assign the code number of hydro plant type A (HYD1 in this case) to 10 and of hydro plant type B (HYD2 in this case) to 11, these numbers are not shown on this page since all information included here is simply retrieved by REPROBAT from the FIXPLANT file (see Section 4.3 for description of the fuel types used for DEMOCASE). Penalty factors for group limitations and polluting materials are also shown on this page. Page 5 gives a *summary of the annual loads*, adding to the information read from the LOADDUCU file, the growth rates for the annual peak and minimum loads and for the annual energy demand.

Pages 6 to 11 give a *summary description of the fixed system* for all years of the study period. Page 6 corresponds to the description of *thermal plants* in the original fixed system, i.e. those thermal plants in FIXSYS for the first year of study (1998). This information is the same as shown on the table of thermal plants of the FIXSYS printout for the respective year (see page 4 of Fig. 4.2), except for the last columns of the table which are not reproduced in the REPROBAT printout.

Page 7 gives heat values and emission rates for the thermal plants in FIXSYS, and Page 8 summarizes the *characteristics of the composite hydroelectric plant type A* (HYD1) in FIXSYS while page 9 those of the FIXSYS *composite hydro plant type B* (HYD2). These characteristics are given (for each period and hydro-condition) each time a change (addition or retirement) is made to the respective hydro plant. In the case of the HYD1 hydro plant, for example, the characteristics are given for years 1998, 2002 and 2007, i.e. for years when a change was made to this plant type in FIXSYS. It should be noted that the number of projects of this plant in years 2002 and 2007 is increased by one in spite of the fact that an actual retirement was made from this plant in each of these years (see discussion of the FIXSYS printout for sample problem in Section 4.3.2). Similarly, the characteristics of the composite

[2] The report presented in Fig. 9.2 has been compressed as much as possible by deleting some empty lines with the view of reducing the size of this document. For the same reason, whenever possible, the pages of the figure contain more than one printout page.

hydro plant type B (HYD2) are given for 1998 and 2000. If pumped storage projects are also present in the fixsys, similar information will be reported for them as well.

Page 10 of the printout shows the *thermal additions and retirements* of the original fixed system. In this case one unit each of FLG1 is retired in years 2003 and 2014 respectively. Similar information is reported for all retirements. As for additions, a positive number will be reported indicating additions to the respective plant. For example, one unit of FCOA is added in 1999. Page 11 provides a *summary of installed capacities of the fixed system* (thermal + hydro) for each year of the study.

Pages 12 to 15 give a *description of the expansion candidates* provided in the variable system: Page 12 for thermal candidates (same information as in page 3 of Fig. 5.2) and Page 13 for heat values and emission factors for candidate thermal plants, while Pages 14 and 15 for the two composite hydro plant types. Here again only the characteristics of the respective composite hydro plant type (per period and hydro-condition) are given combining up to the first, the second, ... up to the last VARSYS hydro project of each type. Thus, Page 14 gives the characteristics of the composite hydro plant HYD1 in VARSYS up to 1 project, and up to 2 projects, and Page 15 those of the HYD2 hydro plant up to 1 and 2 projects, composed. In each case the year reported shows the year of availability of the last project added. Again, if pumped storage projects are included as candidates, similar information for them will be reported.

Page 16 reports definition of real emissions and group limitations for both fixed and variable systems. It includes, for real emissions, the type, number of plants and the names of plants involved. It may be noted that if all thermal plants in fixed or variable system are involved in real emissions, “COMPLETE SYSTEM” is reported instead of giving names of all plants, and if none of the plants is involved, “NO ACTIVE PLANTS” is written. Same also applies to definition of group limitations. This page also reports the initial group limitations imposed on the system. Page 17 gives the *constraints on configurations generated* that were imposed on the solution in Module 4 (CONGEN Run-3) for each year of study, showing also how many configurations were generated for each year and the total for all years (578 in this case).

Page 18 summarizes the *optimum solution* found by Module 6 for this expansion problem. In this table, the configuration and the LOLP along with the capacity additions (from VARSYS) are given for each year of the study. Examining this optimal solution, it can be seen that four 600 MW combined cycle units (V-CC), one 280 MW lignite-1 (VLG1), six 280 MW lignite-2 (VLG2), nine 580-MW coal-fired units (VCOA) and four 600 MW nuclear units (NUCL) were added in the study period. Two projects each of the two hydro types were also chosen by DYNPRO in the optimal solution. The annual average LOLP is shown to vary from 4.281% (in year 1998), down to 0.174% (in 2017).

For this optimal solution, page 19 gives a *summary of total installed capacities* for each year of the study and for each thermal fuel type combining all plants in FIXSYS plus the plants from VARSYS which are added by the optimal solution. Page 20 reports a similar information but focusing on a breakdown of the capacity by hydro plant type, while the thermal capacity is presented as total. This table also shows the system reserve capacity (% of installed capacity exceeding the annual peak demand) and the annual average LOLP. The last three columns correspond to the amount of energy not served calculated by MERSIM for each hydro-condition defined (3 in this case).

Pages 21 and 22 report the *fuel stock of thermal plants* for the FIXSYS and optimum solution for each year of study. Two pages are needed to cover the ten thermal fuel types allowed by WASP-IV (even if less fuel types are used in the study). Note that these tables assume that fuel stocks are accumulated one year prior to start of operation of the associated thermal power plants and therefore, the table begins one year before the study period. Also, all years appear in this table even if the corresponding information is zero. Thus, entries in this table are given for all years from 1997 through 2016. Non-zero entries correspond to the year before the associated plant is added to the system (either in FIXSYS or from the candidate plants).

Pages 23 to 25 summarize the *generation by plant type* for all FIXSYS plus optimum solution plants for each year of study and for each hydro-condition specified, while Page 26 lists the expected generation values (annual averages calculated from the values for each hydro-condition weighted by the hydro-condition probability). (Note: the output tables regarding Generation by fuel type illustrated here will show the appropriate entries only if the preceding REMERSIM run was executed specifying printout option 1 (or 2) for all years of study. If IOPT in REMERSIM is set to zero for some years, these years will show zero entries in the tables. This is also applicable to the output tables on fuel consumption by type described below).

The annual *fuel consumption of thermal plants by fuel type* of the fixed system plus optimal solution are reported in the subsequent pages, including in pages 27–28 those for hydro-condition 1, pages 29–30 for hydro-condition 2 and 31–32 for hydro-condition 3. Pages 33–34 report the annual expected values (weighted by the hydro-condition probabilities). Pages 35–37 report polluting material #1 (SO_2 in this case) by fuel type for the fixed system plus optimal solution for each hydro condition, while page 38 gives expected values of similar information weighted by probabilities of hydro-conditions. Likewise, pages 39–42 give similar information for the second polluting material (NO_x in this case).

Page 43 reports the actual contribution and the annual limits for the group limitations for each year of the study for the fixed system plus optimal solution. Pages 44–46 report the input data given in the respective DYNPRO run. Page 44 shows the summary of capital cost data on the OSDYNDAT (DYNPRO) file (see Page 1 of Fig. 8.4). The information on this page is reported only once by REPROBAT regardless of how many times records type-2 are used in the DYNPRO run to change capital cost data for the expansion candidates (For the sample problem records type-2 were used only once for all DYNPRO runs).

Pages 45–46 show the additional input data (economic parameters and constraints) for the respective DYNPRO run (DYNPRO Run-3). Here the values of the respective variables of DYNPRO are given for the first year of the study and for any change introduced later. In each case the headings indicate between parenthesis the type of data record INDEX used in the DYNPRO runs. When a zero appears between the parenthesis it means that the values which follow correspond to default values in the program, i.e. that the respective type record was not used in DYNPRO. Thus, although no escalation ratios on capital costs were specified in DYNPRO Run-3, the default values for these escalation ratios applied by DYNPRO are shown in Page 45 of the printout. Similarly, constraints on plant addition schedule, escalation ratios on operating costs and fuel cost, and penalty factor on foreign expenditures in DYNPRO Run-3 were all set to the respective default values.

For the optimal solution, pages 47 to 50 give the expected operating cost summary, by year and by plant (fuel) type, for domestic (page 47) and foreign (page 48) fuel costs; for operation and maintenance (O&M) and energy not served (ENS) costs (page 49), these costs considered as domestic expenditures; and for total operating costs (page 50). All these pages bear a heading EXPECTED COST OF OPERATION, meaning that all values shown have been weighted by the hydro-condition probabilities and that they are expressed in monetary units (million $) of the respective year (i.e. they are not present-worth values) taking into account all escalation ratios specified in DYNPRO. In the sample problem, since no escalation on operating costs has been used in DYNPRO, the results on page 50 are the same as for the resimulation run (REMERSIM) of the optimum solution shown in Fig. 7.7 excluding the costs of the energy not served (last column of the table on page 50) which were calculated in the respective DYNPRO run.

Pages 51–68 report the cash flows of construction costs of the VARSYS plants added by the optimal solution during the planning period. Pages 51 to 53 refer to the domestic component of construction cost and pages 54 to 56 to the foreign component. The information on construction costs of a plant starts earlier than the year of commercial operation by the length of the construction period of the plant. Thus, project 1 of hydro type-B (HYD2), for example, was added in year 2002 and the respective cost information starts in 1997 since the construction period of this project is 5 years (as shown on Page 44). It can be seen in Pages 51 to 53 that some years are repeated in the tables due to the year in which plants were actually added by the optimal solution and their respective construction period; the totals for these years are the same in all tables. As mentioned earlier all investment cost information is reported for plants added during the planning period. Hence, these tables show cash flows for years 1997–2016.

Pages 57–62 give the domestic and foreign components of the expenditures for interest during construction (IDC) associated with the capital investment costs above mentioned, and pages 63–68 the respective sums of construction plus IDC costs for each VARSYS plant added during the planning period. As indicated in the cover page of the printout, all values in these tables are given in million dollars (10^6 $) and since they report cash flows, all values are given in monetary units of the corresponding year (i.e. they are not discounted). On the other hand, these values do take into account escalation using the escalation ratios on these costs that have been specified in the DYNPRO run (not used in this case).

In the sample problem no fuel investment (fuel inventory) cost has been specified and such there is no table in the report for such investment costs. If fuel inventory costs are specified for some plants, then cash flow for domestic and foreign components of such cost will also be produced. Page 69 provides a cash flow summary of all capital investment costs by year and type of expenditure for all candidates added by the optimal solution. This includes in sequence: fuel inventory cost; construction cost; and interest during construction, each cost item broken down into domestic, foreign and total. A last column summarizes the grand totals per year. Contrary to other tables of the report, page 69 shows a zero for the empty spaces in the table (instead of the symbol (.) used for other tables).

The rest of the printout is produced only when the input data provides information for some of the committed (FIXSYS) plants. In the sample problem, this option was used for two FIXSYS plants (see Fig. 9.1) so that page 70 summarizes the capital cash flow summary of these plants. Note that these plants are not identified in the table on page 70. Finally, page 71 summarizes the global capital cash flow summary corresponding to the addition of the respective entries in pages 69 and 70.

Text cont. on p. 198.

```
             SUMMARY REPORT
        ON A GENERATION EXPANSION PLAN FOR

     DEMOCASE: CASE STUDY FOR THE WASP-IV USERS' MANUAL

     PROCESSED BY THE WASP-IV COMPUTER PROGRAM PACKAGE
              OF THE IAEA


             STUDY PERIOD

              1998 - 2017


             PLANNING PERIOD

              1998 - 2017


            CONSTRUCTION COSTS
              IN MILLION $
           ARE REPORTED ONLY FOR
            PLANTS COMMISSIONED
          DURING THE PLANNING PERIOD.
         ALL OTHER INFORMATION IS GIVEN
          FOR THE WHOLE STUDY PERIOD.


DATE OF REPORT    : July 1998
STUDY CARRIED OUT BY : NENP/PESS/IAEA
            STUDY FOR THE WASP-IV USERS' MANUAL
```

Figure 9.2 REPROBAT Printout for the Optimal Solution of DEMOCASE.

```
                                       PAGE 2

          TABLE OF CONTENTS
                          PAGE
```


Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

```
INFORMATION SUPPLIED BY USER :

********************************************
*     NEW VERSION OF WASP IV      *
*          IAEA          *
*                  *
*         JULY 1998         *
********************************************

STUDY PERIOD       1998 - 2017
PLANNING PERIOD      1998 - 2017


THIS IS AN EXAMPLE OF WASP-IV CASE STUDY FOR
A HYPOTHETICAL POWER SYSTEM. THE SYSTEM CONSISTS
OF SIX THERMAL POWER PLANTS AND FIVE HYDRO PROJECTS.
ONE UNIT OF COAL BASED PLANT AND TWO UNITS OF
COMBINED CYCLE PLANT ARE UNDER CONSTRUCTION, WHILE
ONE PROJECT OF HYDRO TYPE-2 IS ALSO COMMITTED.
SOME OF THE UNIT OF THERMAL PLANTS AND HYDRO PROJECTS
ARE ASSUMED TO RETIRE DURING THE STUDY PERIOD (AS
DETAILED IN THE REPORT).

FIVE THERMAL PLANTS AND FOUR HYDRO PROJECTS ARE
CONSIDERED AS CANDIDATES FOR FUTURE EXPANSION OF
THE SYSTEM.

FOUR MULTIPLE GROUP LIMITATIONS HAVE BEEN IMPOSED ON
THE SYSTEM; TWO OF SUCH LIMITATIONS ARE FUEL LIMITS
THE OTHER TWO ARE ENVIRONMENTAL EMISSION LIMITS.


ALL THE TECHNICAL AND ECONOMIC INFORMATION USED IN
THIS CASE IS HYPOTHETICAL AND SHOULD NOT BE CONSIDERED
AS REFERENCE DATA.
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 4

THIS IS A LIST OF THE DIFFERENT TYPES OF ELECTRIC POWER PLANTS
USED IN THE STUDY.
THE NUMERIC CODES ARE USED BY THE COMPUTER PROGRAMS

```
0 NUCL NUCLEAR PLANTS
1 LIG1 LIGNITE PLANTS
2 LIG2 LIGNITE PLANTS
3 COAL COAL PLANTS
4 FOIL OIL PLANTS
5 GTGO GAS TURBINES GAS-OIL
6 NGAS NATURAL GAS PLANTS
7 **** NOT APPLICABLE
8 **** NOT APPLICABLE
9 **** NOT APPLICABLE
```

SYSTEM WITHOUT PUMPED STORAGE PROJECTS:

HYD1 HYDRO PLANTS GROUP 1
HYD2 HYDRO PLANTS GROUP 2

GROUP LIMITATIONS FOR THE SYSTEM:
(DEFAULT WAS MODIFIED)

PENALTY FACTORS LOLP	ENS	POLLUTING MATERIALS	
0.00	1.00	SO2	NOx

PAGE 5

ANNUAL LOAD DESCRIPTION

PERIOD(S) PER YEAR : 4

YEAR	PEAKLOAD MW	GR.RATE %	MIN.LOAD MW	GR.RATE %	ENERGY GWH	GR.RATE %	LOADFACTOR %
1998	6000.0	-	2160.0	-	30353.4	-	57.75
1999	6333.0	5.6	2279.9	5.5	32038.0	5.5	57.75
2000	6725.6	6.2	2421.2	6.2	34024.4	6.2	57.75
2001	7109.0	5.7	2559.2	5.7	35963.8	5.7	57.75
2002	7496.5	5.4	2698.7	5.4	37923.8	5.4	57.75
2003	7897.5	5.3	2843.1	5.3	39952.7	5.3	57.75
2004	8304.2	5.1	2989.5	5.1	42010.3	5.1	57.75
2005	8702.8	4.8	3133.0	4.8	44026.7	4.8	57.75
2006	9120.6	4.8	3283.4	4.8	46141.8	4.8	57.75
2007	9558.4	4.8	3441.0	4.8	48356.6	4.8	57.75
2008	10017.2	4.8	3606.2	4.8	50677.9	4.8	57.75
2009	10488.0	4.7	3775.7	4.7	53059.7	4.7	57.75
2010	10980.9	4.7	3953.1	4.7	55553.3	4.7	57.75
2011	11497.0	4.7	4138.9	4.7	58164.3	4.7	57.75
2012	12025.9	4.6	4329.3	4.6	60840.1	4.6	57.75
2013	12579.1	4.6	4528.5	4.6	63638.7	4.6	57.75
2014	13157.7	4.6	4736.8	4.6	66565.9	4.6	57.75
2015	13749.8	4.5	4949.9	4.5	69561.4	4.5	57.75
2016	14368.5	4.5	5172.7	4.5	72691.5	4.5	57.75
2017	15015.1	4.5	5405.4	4.5	75962.7	4.5	57.75

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

```
                                              PAGE 6


                    FIXED SYSTEM
           SUMMARY DESCRIPTION OF THERMAL PLANTS IN YEAR 1998

              HEAT RATES   FUEL COSTS    FAST
    NO. MIN. CAPA  KCAL/KWH     CENTS/     SPIN FOR  DAYS MAIN O&M  O&M
    OF LOAD CITY BASE  AVGE  MILLION KCAL FUEL RES    SCHL CLAS (FIX) (VAR)
NO. NAME SETS MW  MW  LOAD  INCR  DMSTC  FORGN TYPE  %  %  MAIN  MW $/KWM $/MWH

 3 FLG1  4 150. 270. 3300. 2850. 600.0   0.0  1  10 10.0  56  280. 4.06 4.90
 4 FLG2  9 150. 276. 2900. 2550. 495.0   0.0  2  10  8.9  56  280. 1.91 2.00
 5 FCOA  1 400. 580. 2800. 2300. 800.0   0.0  3  10  8.0  48  600. 2.92 5.00
 6 FOIL  7  80. 145. 2450. 2150.   0.0 833.0  4  10  7.3  42  140. 4.57 1.60
 7 F-GT  4  50.  50. 3300. 3300. 420.0   0.0  5  0  6.0  42  50. 8.35 1.60
 8 F-CC  1  87. 174. 2048. 2048.   0.0 1266.0  6  0 15.0  28  180. 2.10 5.00
```

```
                                              PAGE 7


                    FIXED SYSTEM
                 EMISSION MATERIAL DATA

                      RATIO OF MATERIAL/FUEL
            NO. NAME  HEAT VALUE   SO2    NOx
                  kcal/kg    %      %

            3  FLG1   1800.0    2.5    1.0
            4  FLG2   1800.0    2.5    1.0
            5  FCOA   6000.0    1.0    2.0
            6  FOIL  10000.0    1.0    3.0
            7  F-GT  10000.0    0.5    0.5
            8  F-CC  11000.0    0.0    0.5
```

```
                                                                           PAGE 8


                    FIXED SYSTEM
        SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD1
             *** CAPACITY IN MW * ENERGY IN GWH ***
              FIXED O&M COSTS : 0.550 $/KW-MONTH

  P   HYDROCONDITION 1 HYDROCONDITION 2 HYDROCONDITION 3
  R P   PROB.: 0.45    PROB.: 0.30    PROB.: 0.25
  O E  CAPACITY ENERGY CAPACITY ENERGY CAPACITY ENERGY
YEAR J R BASE PEAK    BASE PEAK    BASE PEAK

1998 3 1  210. 965. 1335. 215. 780. 1065. 201. 1049. 1620.
    2  210. 975. 1385. 215. 800. 1115. 201. 1099. 1670.
    3  210. 1005. 1485. 215. 820. 1215. 201. 1149. 1770.
    4  210. 1035. 1535. 215. 860. 1315. 201. 1399. 1870.
    INST.CAP. 1650.
    TOTAL ENERGY  5740.       4710.       6930.

2002 4 1   0. 325. 135.  0. 295. 115.  0. 350. 170.
    2   0. 325. 135.  0. 295. 115.  0. 350. 170.
    3   0. 325. 135.  0. 295. 115.  0. 350. 170.
    4   0. 325. 135.  0. 295. 115.  0. 350. 170.
    INST.CAP. 400.
    TOTAL ENERGY   540.       460.       680.

2007 5 1   0. 240.  84.  0. 220.  73.  0. 260. 110.
    2   0. 240.  84.  0. 220.  73.  0. 260. 110.
    3   0. 240.  84.  0. 220.  73.  0. 260. 110.
    4   0. 240.  84.  0. 220.  73.  0. 260. 110.
    INST.CAP. 300.
    TOTAL ENERGY   336.       293.       440.
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

```
                                                PAGE 9


                        FIXED SYSTEM
            SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD2
                 *** CAPACITY IN MW * ENERGY IN GWH ***
                  FIXED O&M COSTS : 0.550 $/KW-MONTH

    P   HYDROCONDITION 1 HYDROCONDITION 2 HYDROCONDITION 3
    R P   PROB.: 0.45    PROB.: 0.30    PROB.: 0.25
    O E  CAPACITY ENERGY CAPACITY ENERGY CAPACITY ENERGY
 YEAR J R BASE PEAK    BASE PEAK    BASE PEAK

 1998 2 1   0. 187. 102.  0. 160.  70.  0. 206. 134.
     2   0. 187. 102.  0. 160.  70.  0. 206. 134.
     3   0. 187. 102.  0. 160.  70.  0. 206. 134.
     4   0. 187. 102.  0. 160.  70.  0. 206. 134.
     INST.CAP. 206.
     TOTAL ENERGY   408.       280.       536.

 2000 3 1   0. 342. 186.  0. 300. 139.  0. 371. 238.
     2   0. 342. 186.  0. 300. 139.  0. 371. 238.
     3   0. 342. 186.  0. 300. 139.  0. 371. 238.
     4   0. 342. 186.  0. 300. 139.  0. 371. 238.
     INST.CAP. 386.
     TOTAL ENERGY   743.       554.       951.

                                                PAGE 10


                        FIXED SYSTEM
                   THERMAL ADDITIONS AND RETIREMENTS

                  NUMBER OF SETS ADDED AND RETIRED(-)
                        1998 TO 2017
      YEAR: 19.. (200./20..)
   NO. NAME 99 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

   3 FLG1 . . . . -1 . . . . . . . . . . -1
   4 FLG2 . . . . . . . -1 . . -1 . . . . -1
   5 FCOA 1 . . . . . . . . . . . . . . .
   6 FOIL . . . . . . . . . . . . . -1 -1 .
   7 F-GT . . . . . . . . . . -1 . . . . .
   8 F-CC . 1 1 . . . . . . . . . . . . .

                                                PAGE 11



                        FIXED SYSTEM
                   SUMMARY OF INSTALLED CAPACITIES
                     (NOMINAL CAPACITIES (MW))

    HYDROELECTRIC                  THERMAL                TOTAL
    HYD1   HYD2              F U E L  T Y P E
              0   1   2   3   4   5   6   7   8   9
YEAR PR. CAP PR. CAP  NUCL  LIG1  LIG2  COAL  FOIL  GTGO  NGAS  ****  ****  ****

1998 3 1650. 2  206.   0. 1080. 2484.  580. 1015.  200.  174.   0.    0.    0.  7389.
1999 3 1650. 2  206.   0. 1080. 2484. 1160. 1015.  200.  174.   0.    0.    0.  7969.
2000 3 1650. 3  386.   0. 1080. 2484. 1160. 1015.  200.  348.   0.    0.    0.  8323.
2001 3 1650. 3  386.   0. 1080. 2484. 1160. 1015.  200.  522.   0.    0.    0.  8497.
2002 4  400. 3  386.   0. 1080. 2484. 1160. 1015.  200.  522.   0.    0.    0.  7247.
2003 4  400. 3  386.   0.  810. 2484. 1160. 1015.  200.  522.   0.    0.    0.  6977.
2004 4  400. 3  386.   0.  810. 2484. 1160. 1015.  200.  522.   0.    0.    0.  6977.
2005 4  400. 3  386.   0.  810. 2484. 1160. 1015.  200.  522.   0.    0.    0.  6977.
2006 4  400. 3  386.   0.  810. 2208. 1160. 1015.  200.  522.   0.    0.    0.  6701.
2007 5  300. 3  386.   0.  810. 2208. 1160. 1015.  200.  522.   0.    0.    0.  6601.
2008 5  300. 3  386.   0.  810. 2208. 1160. 1015.  200.  522.   0.    0.    0.  6601.
2009 5  300. 3  386.   0.  810. 1932. 1160. 1015.  150.  522.   0.    0.    0.  6275.
2010 5  300. 3  386.   0.  810. 1932. 1160. 1015.  150.  522.   0.    0.    0.  6275.
2011 5  300. 3  386.   0.  810. 1932. 1160. 1015.  150.  522.   0.    0.    0.  6275.
2012 5  300. 3  386.   0.  810. 1932. 1160.  870.  150.  522.   0.    0.    0.  6130.
2013 5  300. 3  386.   0.  810. 1932. 1160.  725.  150.  522.   0.    0.    0.  5985.
2014 5  300. 3  386.   0.  540. 1656. 1160.  725.  150.  522.   0.    0.    0.  5439.
2015 5  300. 3  386.   0.  540. 1656. 1160.  725.  150.  522.   0.    0.    0.  5439.
2016 5  300. 3  386.   0.  540. 1656. 1160.  725.  150.  522.   0.    0.    0.  5439.
2017 5  300. 3  386.   0.  540. 1656. 1160.  725.  150.  522.   0.    0.    0.  5439.
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

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                                                PAGE 12

                   VARIABLE SYSTEM
              SUMMARY DESCRIPTION OF THERMAL PLANTS

             HEAT RATES   FUEL COSTS    FAST
     NO. MIN. CAPA  KCAL/KWH     CENTS/     SPIN FOR  DAYS MAIN O&M  O&M
     OF LOAD CITY BASE  AVGE  MILLION KCAL FUEL RES    SCHL CLAS (FIX) (VAR)
 NO. NAME SETS MW  MW  LOAD  INCR  DMSTC  FORGN TYPE  %  %  MAIN  MW $/KWM $/MWH

 1 V-CC  0 300. 600. 1950. 1950.  0.0 1200.0  6  0 10.0  28  600. 2.10 4.00
 2 VLG1  0 150. 280. 3100. 2700. 710.0   0.0  1  10 10.0  56  280. 2.70 6.00
 3 VLG2  0 150. 280. 3000. 2600. 1100.0   0.0  2  10 10.0  56  280. 2.70 6.00
 4 VCOA  0 400. 580. 2600. 2200.  0.0  800.0  3  10  8.0  48  600. 2.92 5.00
 5 NUCL  0 300. 600. 2600. 2340.  0.0  194.0  0  7 10.0  42  600. 2.50 0.50
                                                PAGE 13

                   VARIABLE SYSTEM
                 EMISSION MATERIAL DATA

                     RATIO OF MATERIAL/FUEL
              NO. NAME  HEAT VALUE   SO2    NOx
                   kcal/kg    %     %

              1  V-CC  11000.0    0.0    0.5
              2  VLG1   1800.0    2.5    1.0
              3  VLG2   1800.0    2.5    1.0
              4  VCOA   6000.0    1.0    2.0
              5  NUCL    0.0    0.0    0.0
                                                PAGE 14

                   VARIABLE SYSTEM
          SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD1
               *** CAPACITY IN MW * ENERGY IN GWH ***
                FIXED O&M COSTS : 0.550 $/KW-MONTH

   P   HYDROCONDITION 1 HYDROCONDITION 2 HYDROCONDITION 3
   R P   PROB.: 0.45    PROB.: 0.30    PROB.: 0.25
   O E  CAPACITY ENERGY CAPACITY ENERGY CAPACITY ENERGY
YEAR J R BASE PEAK    BASE PEAK    BASE PEAK

2003 1 1   0. 160.  70.  0. 140.  43.  0. 200.  98.
    2   0. 160.  70.  0. 140.  43.  0. 200.  98.
    3   0. 160.  70.  0. 140.  43.  0. 200.  98.
    4   0. 160.  70.  0. 140.  43.  0. 200.  98.
    INST.CAP. 200.
    TOTAL ENERGY   281.       170.       392.

2004 2 1  137. 513. 690. 183. 447. 603.  91. 659. 798.
    2  91. 589. 790. 137. 518. 643.  46. 714. 888.
    3  68. 642. 890.  46. 624. 703.  23. 827. 1048.
    4  91. 609. 830. 137. 528. 663.  46. 754. 948.
    INST.CAP. 850.
    TOTAL ENERGY  3201.       2610.       3682.
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

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                                             PAGE 15

                    VARIABLE SYSTEM
          SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD2
               *** CAPACITY IN MW * ENERGY IN GWH ***
                FIXED O&M COSTS : 0.550 $/KW-MONTH

   P   HYDROCONDITION 1 HYDROCONDITION 2 HYDROCONDITION 3
   R P   PROB.: 0.45    PROB.: 0.30    PROB.: 0.25
   O E  CAPACITY ENERGY CAPACITY ENERGY CAPACITY ENERGY
YEAR J R BASE PEAK    BASE PEAK    BASE PEAK

2002 1 1   0. 100.  68.  0.  80.  51.  0. 120.  84.
    2   0. 100.  68.  0.  80.  51.  0. 120.  84.
    3   0. 100.  68.  0.  80.  51.  0. 120.  84.
    4   0. 100.  68.  0.  80.  51.  0. 120.  84.
    INST.CAP. 120.
    TOTAL ENERGY   270.       206.       335.

2005 2 1   0. 220. 156.  0. 180. 114.  0. 260. 198.
    2   0. 220. 156.  0. 180. 114.  0. 260. 198.
    3   0. 220. 156.  0. 180. 114.  0. 260. 198.
    4   0. 220. 156.  0. 180. 114.  0. 260. 198.
    INST.CAP. 313.
    TOTAL ENERGY   624.       458.       792.
```

```
                                             PAGE 16

             DEFINITION OF REAL EMISSION AND GROUP LIMITATION

                      **** FIXED SYSTEM ****

                 ACTIVE PLANTS FOR REAL EMISSIONS
       TYPE  NUMBER NAME OF PLANTS
         OF PLANTS

       SO2    6  C O M P L E T E  S Y S T E M
       NOx    6  C O M P L E T E  S Y S T E M

                ACTIVE PLANTS IN THE GROUP LIMITATIONS
      GROUP  NUMBER NAME OF PLANTS
       NO. OF PLANTS

       1    1  F-CC
       2    5  FLG1 FLG2 FCOA FOIL F-GT
       3    6  C O M P L E T E  S Y S T E M
       4    2  FLG1 FLG2

                    **** VARIABLE SYSTEM ****

                 ACTIVE PLANTS FOR REAL EMISSIONS
       TYPE  NUMBER NAME OF PLANTS
         OF PLANTS

       SO2    4  V-CC VLG1 VLG2 VCOA
       NOx    4  V-CC VLG1 VLG2 VCOA

                ACTIVE PLANTS IN THE GROUP LIMITATIONS
      GROUP  NUMBER NAME OF PLANTS
       NO. OF PLANTS

       1    1  VLG2
       2    3  VLG1 VLG2 VCOA
       3    4  V-CC VLG1 VLG2 VCOA
       4    0  N O A C T I V E P L A N T S


               INITIAL GROUP LIMITATIONS FOR THE SYSTEM

         GROUP LIMIT      ANNUAL  PERIOD RATIO
        NO. TYPE IND UNIT MODE LIMIT  1  2  3  4

        1 FUEL 1  kT  0  10000.0

        2 SO2  2  kT  0   600.0

        3 NOx  3  kT  0  1000.0

        4 FUEL 1  kT  0  20000.0
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

```
                C O N G E N
         CONSTRAINTS ON CONFIGURATIONS GENERATED
           CON: NUMBER OF CONFIGURATIONS
                 MIMIMUM
                 MAXIMUM

    RES. PERMITTED EXTREME CONFIGURATIONS OF ALTERNATIVES
    MAR- V-CC    VLG2    NUCL    HYD2
YEAR CON GIN     VLG1    VCOA    HYD1

1998  1 15  0  0  0  0  0  0  0
     50  0  0  0  0  0  0  0

1999  1 15  0  0  0  0  0  0  0
     50  0  0  0  0  0  0  0

2000  1 15  0  0  0  0  0  0  0
     50  0  0  0  0  0  0  0

2001  2 15  0  0  0  0  0  0  0
     50  2  0  0  0  0  0  0

2002 22 15  1  0  0  0  0  0  1
     50  3  2  0  2  0  0  1

2003 22 15  2  0  0  0  0  1  1
     50  4  2  0  2  0  1  1

2004 19 20  2  0  0  0  0  2  1
     40  4  2  0  2  0  2  1

2005 13 20  2  0  0  0  0  2  2
     40  4  2  0  2  0  2  2

2006 29 20  2  0  0  0  0  2  2
     40  4  2  0  2  1  2  2

2007 64 20  2  0  0  1  0  2  2
     40  4  2  2  3  1  2  2

2008 64 20  2  0  0  2  0  2  2
     40  4  2  2  4  1  2  2

2009 46 20  2  0  0  3  0  2  2
     40  4  2  2  5  1  2  2

2010 46 20  2  0  0  4  0  2  2
     40  4  2  2  6  1  2  2

2011 50 20  2  0  0  4  0  2  2
     40  4  2  2  6  2  2  2

2012 33 20  2  0  0  5  0  2  2
     40  4  2  2  7  2  2  2

2013 33 20  2  0  1  6  0  2  2
     40  4  2  3  8  2  2  2

2014 33 20  2  0  3  7  0  2  2
     40  4  2  5  9  2  2  2

2015 33 20  2  0  4  7  1  2  2
     40  4  2  6  9  3  2  2

2016 33 20  2  0  4  8  1  2  2
     40  4  2  6  10  3  2  2

2017 33 20  2  0  5  8  2  2  2
     40  4  2  7  10  4  2  2

  578 TOTAL NUMBER OF CONFIGURATIONS GENERATED
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

OPTIMUM SOLUTION
ANNUAL ADDITIONS: CAPACITY(MW) AND NUMBER OF UNITS OR PROJECTS
FOR DETAILS OF INDIVIDUAL UNITS OR PROJECTS SEE VARIABLE SYSTEM REPORT
SEE ALSO FIXED SYSTEM REPORT FOR OTHER ADDITIONS OR RETIREMENTS

NAME		:	V-CC	VLG1	VLG2	VCOA	NUCL	HYD1	HYD2
SIZE (MW):			600.	280.	280.	580.	600.	0.	0.
YEAR	%LOLP	CAP							
1998	4.281	0.	.	.	.	.	.	.	.
1999	4.304	0.	.	.	.	.	.	.	.
2000	0.458	0.	.	.	.	.	.	.	.
2001	0.198	600.	1	.	.	.	.	.	.
2002	0.380	1320.	2	.	.	.	.	.	1
2003	0.317	800.	1	.	.	.	.	1	.
2004	0.192	650.	.	.	.	.	.	1	.
2005	0.109	773.	.	.	.	1	.	.	1
2006	0.171	600.	.	.	.	.	1	.	.
2007	0.192	580.	.	.	.	1	.	.	.
2008	0.180	580.	.	.	.	1	.	.	.
2009	0.194	860.	.	1	.	1	.	.	.
2010	0.197	580.	.	.	.	1	.	.	.
2011	0.208	600.	.	.	.	.	1	.	.
2012	0.185	860.	.	.	1	1	.	.	.
2013	0.172	860.	.	.	1	1	.	.	.
2014	0.204	1140.	.	.	2	1	.	.	.
2015	0.157	880.	.	.	1	.	1	.	.
2016	0.202	580.	.	.	.	1	.	.	.
2017	0.174	880.	.	.	1	.	1	.	.
TOTALS		13143.	4	1	6	9	4	2	2

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
(NOMINAL CAPACITY (MW))

	THERMAL FUEL TYPE CAPACITIES										TOTAL CAP
YEAR	0	1	2	3	4	5	6	7	8	9	
	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	
1998	0	1080	2484	580	1015	200	174	0	0	0	5533
1999	0	1080	2484	1160	1015	200	174	0	0	0	6113
2000	0	1080	2484	1160	1015	200	348	0	0	0	6287
2001	0	1080	2484	1160	1015	200	1122	0	0	0	7061
2002	0	1080	2484	1160	1015	200	2322	0	0	0	8261
2003	0	810	2484	1160	1015	200	2922	0	0	0	8591
2004	0	810	2484	1160	1015	200	2922	0	0	0	8591
2005	0	810	2484	1740	1015	200	2922	0	0	0	9171
2006	600	810	2208	1740	1015	200	2922	0	0	0	9495
2007	600	810	2208	2320	1015	200	2922	0	0	0	10075
2008	600	810	2208	2900	1015	200	2922	0	0	0	10655
2009	600	1090	1932	3480	1015	150	2922	0	0	0	11189
2010	600	1090	1932	4060	1015	150	2922	0	0	0	11769
2011	1200	1090	1932	4060	1015	150	2922	0	0	0	12369
2012	1200	1090	2212	4640	870	150	2922	0	0	0	13084
2013	1200	1090	2492	5220	725	150	2922	0	0	0	13799
2014	1200	820	2776	5800	725	150	2922	0	0	0	14393
2015	1800	820	3056	5800	725	150	2922	0	0	0	15273
2016	1800	820	3056	6380	725	150	2922	0	0	0	15853
2017	2400	820	3336	6380	725	150	2922	0	0	0	16733

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 20

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
(NOMINAL CAPACITY IN MW, ENERGY IN GWH)

YEAR	PUMPED STORAGE PUMP PR.	CAP	HYDRO ELECTRIC HYDR PR.	CAP	TOTAL THERMAL CAPACITY	TOTAL CAP	SYSTEM RES. %	LOLP. %	ENERGY NOT SERVED HYDROCONDITION 1	2	3
1998	0	0	5	1856	5533	7389	23.2	4.281	747.3	1099.1	551.9
1999	0	0	5	1856	6113	7969	25.8	4.304	898.6	1254.6	614.0
2000	0	0	6	2036	6287	8323	23.8	0.458	5.8	14.7	2.2
2001	0	0	6	2036	7061	9097	28.0	0.198	2.3	5.9	0.8
2002	0	0	8	906	8261	9167	22.3	0.380	7.2	10.0	5.6
2003	0	0	9	1106	8591	9697	22.8	0.317	6.1	9.0	4.0
2004	0	0	10	1756	8591	10347	24.6	0.192	3.3	5.2	1.5
2005	0	0	11	1949	9171	11121	27.8	0.109	1.6	2.9	0.7
2006	0	0	11	1949	9495	11445	25.5	0.171	3.0	5.0	1.4
2007	0	0	12	1849	10075	11925	24.8	0.192	3.6	5.6	1.7
2008	0	0	12	1849	10655	12505	24.8	0.180	3.4	5.3	1.7
2009	0	0	12	1849	11189	13039	24.3	0.194	3.9	5.8	2.0
2010	0	0	12	1849	11769	13619	24.0	0.197	4.0	6.0	2.1
2011	0	0	12	1849	12369	14219	23.7	0.208	4.4	6.5	2.4
2012	0	0	12	1849	13084	14934	24.2	0.185	3.9	5.7	2.1
2013	0	0	12	1849	13799	15649	24.4	0.172	3.6	5.2	2.0
2014	0	0	12	1849	14393	16243	23.4	0.204	4.5	6.4	2.5
2015	0	0	12	1849	15273	17123	24.5	0.157	3.3	4.7	1.8
2016	0	0	12	1849	15853	17703	23.2	0.202	4.5	6.4	2.6
2017	0	0	12	1849	16733	18583	23.8	0.174	3.8	5.4	2.2

PAGE 21

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL STOCK OF THERMAL PLANTS BY FUEL TYPE (KTON)

THERMAL FUEL TYPES

YEAR	0 NUCL DOM.	FOR	1 LIG1 DOM.	FOR	2 LIG2 DOM.	FOR	3 COAL DOM.	FOR	4 FOIL DOM.	FOR
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00
2005	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00
2007	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00
2008	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00
2009	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00
2010	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	1000.00	0.00	0.00
2012	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	1000.00	0.00	0.00
2013	0.00	0.00	0.00	0.00	2000.00	0.00	0.00	1000.00	0.00	0.00
2014	0.00	1.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00
2016	0.00	1.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL STOCK OF THERMAL PLANTS BY FUEL TYPE (KTON)

THERMAL FUEL TYPES

	5		6		7		8		9	
YEAR	GTGO		NGAS		****		****		****	
	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	2000.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	2000.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2007	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
GENERATION BY PLANT TYPE (GWH)

HYDROCONDITION 1

THERMAL FUEL TYPES

	HYDROELECTRIC			0	1	2	3	4	5	6	7	8	9	GR.	
YEAR	HYD1	HYD2	TOTAL	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	TOTAL	TOTAL
1998	5740	408	6148	0	2557	9638	3295	5746	1404	818	0	0	0	23458	29606
1999	5740	408	6148	0	2869	9257	5899	4977	1425	564	0	0	0	24991	31139
2000	5740	743	6483	0	2351	9908	6763	5813	1457	1243	0	0	0	27535	34018
2001	5740	743	6483	0	2508	9861	6657	5622	1457	3374	0	0	0	29479	35962
2002	540	1013	1553	0	2867	9563	7354	6732	1457	8391	0	0	0	36364	37917
2003	821	1013	1834	0	2513	10053	7517	6846	1457	9725	0	0	0	38111	39945
2004	3741	1013	4754	0	2638	9927	7431	6881	1457	8918	0	0	0	37252	42006
2005	3741	1368	5109	0	2584	9717	10845	6786	1457	7527	0	0	0	38916	44025
2006	3741	1368	5109	4185	2861	9338	10649	6685	1457	5854	0	0	0	41029	46138
2007	3538	1368	4906	4185	2941	9259	13845	6606	1457	5154	0	0	0	43447	48353
2008	3538	1368	4906	4185	2922	9123	16990	6564	1457	4528	0	0	0	45769	50675
2009	3538	1368	4906	4185	4224	8134	20485	6595	1093	3434	0	0	0	48150	53056
2010	3538	1368	4906	4185	4103	7823	23693	6569	1093	3178	0	0	0	50644	55550
2011	3538	1368	4906	8369	4156	7941	22630	6380	1093	2686	0	0	0	53255	58161
2012	3538	1368	4906	8140	3623	8309	23564	4178	1093	7025	0	0	0	55932	60838
2013	3538	1368	4906	8153	3378	8280	26959	3773	1093	7095	0	0	0	58731	63637
2014	3538	1368	4906	8245	3021	8417	29835	4255	1093	6792	0	0	0	61658	66564
2015	3538	1368	4906	12194	3023	8432	29363	4182	1093	6367	0	0	0	64654	69560
2016	3538	1368	4906	12361	2932	8363	31034	4054	1093	7948	0	0	0	67785	72691
2017	3538	1368	4906	16618	2876	8525	29923	3948	1093	8072	0	0	0	71055	75961

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 24

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
GENERATION BY PLANT TYPE (GWH)

HYDROCONDITION 2

THERMAL FUEL TYPES

	HYDROELECTRIC			0	1	2	3	4	5	6	7	8	9	GR.		
YEAR	HYD1	HYD2	TOTAL	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****		TOTAL	TOTAL
1998	4710	280	4990	0	2713	9478	3501	6204	1384	985	0	0	0		24265	29255
1999	4710	280	4990	0	2645	9575	6206	5274	1414	680	0	0	0		25794	30784
2000	4710	554	5264	0	2432	9801	7167	6291	1457	1597	0	0	0		28745	34009
2001	4710	554	5264	0	2348	10040	6850	6070	1457	3927	0	0	0		30692	35956
2002	460	760	1220	0	2841	9580	7420	6745	1457	8651	0	0	0		36694	37914
2003	630	760	1390	0	2475	10085	7531	6856	1457	10149	0	0	0		38553	39943
2004	3070	760	3830	0	2538	10000	7554	6879	1457	9745	0	0	0		38173	42003
2005	3070	1012	4082	0	2575	9690	11118	6788	1457	8314	0	0	0		39942	44024
2006	3070	1012	4082	4185	2880	9285	10936	6684	1457	6627	0	0	0		42054	46136
2007	2903	1012	3915	4185	2911	9252	14402	6599	1457	5630	0	0	0		44436	48351
2008	2903	1012	3915	4185	2908	9104	17609	6557	1457	4938	0	0	0		46758	50673
2009	2903	1012	3915	4185	4245	8064	21093	6586	1093	3874	0	0	0		49140	53055
2010	2903	1012	3915	4185	4091	7791	24322	6556	1093	3595	0	0	0		51633	55548
2011	2903	1012	3915	8369	4158	7877	23288	6372	1093	3086	0	0	0		54243	58158
2012	2903	1012	3915	8169	3597	8338	23815	4698	1093	7210	0	0	0		56920	60835
2013	2903	1012	3915	8186	3521	8099	27255	4082	1093	7484	0	0	0		59720	63635
2014	2903	1012	3915	8231	3119	8239	30672	4257	1093	7035	0	0	0		62646	66561
2015	2903	1012	3915	12176	3076	8306	30135	4178	1093	6679	0	0	0		65643	69558
2016	2903	1012	3915	12337	2950	8108	33442	4212	1093	6629	0	0	0		68771	72686
2017	2903	1012	3915	16618	2899	8369	31260	4021	1093	7783	0	0	0		72043	75958

PAGE 25

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
GENERATION BY PLANT TYPE (GWH)

HYDROCONDITION 3

THERMAL FUEL TYPES

	HYDROELECTRIC			0	1	2	3	4	5	6	7	8	9	GR.		
YEAR	HYD1	HYD2	TOTAL	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****		TOTAL	TOTAL
1998	6930	536	7466	0	2780	9353	2964	5179	1435	625	0	0	0		22336	29802
1999	6930	536	7466	0	3192	8838	5313	4674	1423	519	0	0	0		23959	31425
2000	6930	951	7881	0	2756	9442	6328	5272	1457	885	0	0	0		26140	34021
2001	6930	951	7881	0	2843	9476	6384	5259	1457	2662	0	0	0		28081	35962
2002	680	1286	1966	0	2924	9526	7236	6723	1457	8087	0	0	0		35953	37919
2003	1072	1286	2358	0	2555	9997	7478	6840	1457	9263	0	0	0		37590	39948
2004	4362	1286	5648	0	2722	9891	7168	6890	1457	8233	0	0	0		36361	42009
2005	4362	1743	6105	0	2479	9857	10425	6813	1457	6888	0	0	0		37919	44024
2006	4362	1743	6105	4185	2683	9506	10317	6674	1457	5212	0	0	0		40034	46139
2007	4122	1743	5865	4185	2764	9456	13400	6618	1457	4610	0	0	0		42490	48355
2008	4122	1743	5865	4185	2744	9321	16523	6571	1457	4010	0	0	0		44811	50676
2009	4122	1743	5865	4185	4130	8261	19951	6597	1093	2976	0	0	0		47193	53058
2010	4122	1743	5865	4185	3976	7985	23167	6565	1093	2716	0	0	0		49687	55552
2011	4122	1743	5865	8369	4001	8145	22151	6334	1093	2203	0	0	0		52296	58161
2012	4122	1743	5865	8150	3797	8031	23018	3948	1093	6937	0	0	0		54974	60839
2013	4122	1743	5865	8217	3406	8270	26528	3485	1093	6776	0	0	0		57775	63640
2014	4122	1743	5865	8257	2868	8636	29287	4070	1093	6489	0	0	0		60700	66565
2015	4122	1743	5865	12251	2888	8744	27782	3756	1093	7182	0	0	0		63696	69561
2016	4122	1743	5865	12381	2865	8535	30104	3861	1093	7988	0	0	0		66827	72692
2017	4122	1743	5865	16643	2821	8690	28984	3767	1093	8100	0	0	0		70098	75963

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 26

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION

EXPECTED GENERATION BY PLANT TYPE (GWH),
WEIGHTED BY PROBABILITIES OF HYDRO CONDITIONS

	HYDROELECTRIC			THERMAL FUEL TYPES 0	1	2	3	4	5	6	7	8	9		GR.		
YEAR	HYD1	HYD2	TOTAL	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	TOTAL	TOTAL
1998	5729	402	6131	0	2660	9519	3274	5742	1406	820	0	0	0	23421	29552
1999	5729	402	6131	0	2883	9248	5845	4990	1421	587	0	0	0	24974	31105
2000	5729	738	6467	0	2477	9760	6776	5821	1457	1260	0	0	0	27551	34018
2001	5729	738	6467	0	2544	9818	6647	5666	1457	3362	0	0	0	29494	35961
2002	551	1005	1556	0	2873	9558	7344	6733	1457	8393	0	0	0	36358	37914
2003	827	1005	1832	0	2512	10049	7512	6847	1457	9737	0	0	0	38114	39946
2004	3695	1005	4700	0	2629	9940	7402	6883	1457	8995	0	0	0	37306	42006
2005	3695	1355	5050	0	2555	9744	10822	6793	1457	7603	0	0	0	38974	44024
2006	3695	1355	5050	4185	2822	9364	10652	6682	1457	5925	0	0	0	41087	46137
2007	3493	1355	4848	4185	2888	9306	13901	6607	1457	5161	0	0	0	43505	48353
2008	3493	1355	4848	4185	2873	9167	17059	6564	1457	4522	0	0	0	45827	50675
2009	3493	1355	4848	4185	4207	8145	20534	6593	1093	3452	0	0	0	48209	53057
2010	3493	1355	4848	4185	4068	7854	23751	6564	1093	3188	0	0	0	50703	55551
2011	3493	1355	4848	8369	4118	7973	22707	6366	1093	2685	0	0	0	53311	58159
2012	3493	1355	4848	8151	3659	8248	23503	4277	1093	7059	0	0	0	55990	60838
2013	3493	1355	4848	8179	3428	8223	26940	3794	1093	7132	0	0	0	58789	63637
2014	3493	1355	4848	8244	3012	8418	29949	4209	1093	6789	0	0	0	61714	66562
2015	3493	1355	4848	12203	3005	8472	29199	4074	1093	6665	0	0	0	64711	69559
2016	3493	1355	4848	12359	2921	8329	31524	4053	1093	7562	0	0	0	67841	72689
2017	3493	1355	4848	16624	2869	8520	30090	3925	1093	7992	0	0	0	71113	75961

PAGE 27

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON)

HYDROCONDITION 1

THERMAL FUEL TYPES

	0		1		2		3		4	
YEAR	NUCL		LIG1		LIG2		COAL		FOIL	
	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR
1998	0.00	0.00	4404.51	0.00	14671.91	0.00	1452.37	0.00	0.00	1330.46
1999	0.00	0.00	4941.17	0.00	14092.40	0.00	2600.40	0.00	0.00	1152.44
2000	0.00	0.00	4049.38	0.00	15082.85	0.00	2981.41	0.00	0.00	1346.02
2001	0.00	0.00	4318.86	0.00	15011.68	0.00	2934.41	0.00	0.00	1301.69
2002	0.00	0.00	4937.08	0.00	14557.45	0.00	3241.81	0.00	0.00	1558.76
2003	0.00	0.00	4328.58	0.00	15304.67	0.00	3313.77	0.00	0.00	1585.15
2004	0.00	0.00	4543.09	0.00	15112.72	0.00	3275.76	0.00	0.00	1593.20
2005	0.00	0.00	4449.36	0.00	14792.90	0.00	3163.21	1514.17	0.00	1571.22
2006	0.00	0.00	4927.63	0.00	14215.90	0.00	3102.78	1489.87	0.00	1547.89
2007	0.00	0.00	5065.38	0.00	14095.92	0.00	2955.03	2946.62	0.00	1529.66
2008	0.00	0.00	5031.98	0.00	13888.47	0.00	2868.00	4325.86	0.00	1519.93
2009	0.00	0.00	7146.46	0.00	12383.30	0.00	2828.74	5805.15	0.00	1527.07
2010	0.00	0.00	6940.87	0.00	11909.45	0.00	2788.61	7166.41	0.00	1521.11
2011	0.00	0.00	7039.81	0.00	12088.18	0.00	2636.72	6869.74	0.00	1477.39
2012	0.00	0.00	6142.80	0.00	12656.58	0.00	2454.78	7425.41	0.00	967.51
2013	0.00	0.00	5720.80	0.00	12622.16	0.00	2476.59	8805.99	0.00	873.69
2014	0.00	0.00	5107.50	0.00	12837.36	0.00	2444.56	10022.86	0.00	985.14
2015	0.00	0.00	5116.89	0.00	12857.82	0.00	2388.99	9880.08	0.00	968.28
2016	0.00	0.00	4974.91	0.00	12754.64	0.00	2102.70	10837.36	0.00	938.60
2017	0.00	0.00	4883.64	0.00	13005.15	0.00	1966.40	10506.73	0.00	914.21

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 28

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON)

HYDROCONDITION 1

THERMAL FUEL TYPES

	5		6		7		8		9	
YEAR	GTGO		NGAS		****		****		****	
	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR
1998	463.47	0.00	0.00	152.28	0.00	0.00	0.00	0.00	0.00	0.00
1999	470.20	0.00	0.00	105.05	0.00	0.00	0.00	0.00	0.00	0.00
2000	480.97	0.00	0.00	231.43	0.00	0.00	0.00	0.00	0.00	0.00
2001	480.97	0.00	0.00	610.94	0.00	0.00	0.00	0.00	0.00	0.00
2002	480.97	0.00	0.00	1499.78	0.00	0.00	0.00	0.00	0.00	0.00
2003	480.97	0.00	0.00	1733.02	0.00	0.00	0.00	0.00	0.00	0.00
2004	480.97	0.00	0.00	1590.06	0.00	0.00	0.00	0.00	0.00	0.00
2005	480.97	0.00	0.00	1340.11	0.00	0.00	0.00	0.00	0.00	0.00
2006	480.97	0.00	0.00	1040.70	0.00	0.00	0.00	0.00	0.00	0.00
2007	480.97	0.00	0.00	916.56	0.00	0.00	0.00	0.00	0.00	0.00
2008	480.97	0.00	0.00	804.71	0.00	0.00	0.00	0.00	0.00	0.00
2009	360.73	0.00	0.00	609.69	0.00	0.00	0.00	0.00	0.00	0.00
2010	360.73	0.00	0.00	564.26	0.00	0.00	0.00	0.00	0.00	0.00
2011	360.73	0.00	0.00	476.92	0.00	0.00	0.00	0.00	0.00	0.00
2012	360.73	0.00	0.00	1247.92	0.00	0.00	0.00	0.00	0.00	0.00
2013	360.73	0.00	0.00	1261.49	0.00	0.00	0.00	0.00	0.00	0.00
2014	360.73	0.00	0.00	1206.68	0.00	0.00	0.00	0.00	0.00	0.00
2015	360.73	0.00	0.00	1130.68	0.00	0.00	0.00	0.00	0.00	0.00
2016	360.73	0.00	0.00	1415.36	0.00	0.00	0.00	0.00	0.00	0.00
2017	360.73	0.00	0.00	1438.20	0.00	0.00	0.00	0.00	0.00	0.00

PAGE 29

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON)

HYDROCONDITION 2

THERMAL FUEL TYPES

	0		1		2		3		4	
YEAR	NUCL		LIG1		LIG2		COAL		FOIL	
	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR
1998	0.00	0.00	4672.14	0.00	14429.29	0.00	1543.22	0.00	0.00	1436.60
1999	0.00	0.00	4555.27	0.00	14576.64	0.00	2735.75	0.00	0.00	1221.11
2000	0.00	0.00	4188.16	0.00	14921.18	0.00	3159.25	0.00	0.00	1456.72
2001	0.00	0.00	4044.43	0.00	15283.78	0.00	3019.66	0.00	0.00	1405.58
2002	0.00	0.00	4893.37	0.00	14583.30	0.00	3270.83	0.00	0.00	1561.71
2003	0.00	0.00	4262.97	0.00	15352.89	0.00	3319.71	0.00	0.00	1587.44
2004	0.00	0.00	4371.76	0.00	15223.66	0.00	3329.95	0.00	0.00	1592.91
2005	0.00	0.00	4433.96	0.00	14751.15	0.00	3242.66	1552.17	0.00	1571.85
2006	0.00	0.00	4960.17	0.00	14135.35	0.00	3183.69	1532.34	0.00	1547.62
2007	0.00	0.00	5013.55	0.00	14084.29	0.00	3109.88	3031.67	0.00	1527.91
2008	0.00	0.00	5008.72	0.00	13858.87	0.00	2952.54	4502.28	0.00	1518.16
2009	0.00	0.00	7178.17	0.00	12276.13	0.00	2928.52	5962.46	0.00	1524.88
2010	0.00	0.00	6920.21	0.00	11860.28	0.00	2841.52	7376.43	0.00	1518.07
2011	0.00	0.00	7042.88	0.00	11991.60	0.00	2644.25	7134.12	0.00	1475.43
2012	0.00	0.00	6095.49	0.00	12701.84	0.00	2489.02	7497.22	0.00	1087.89
2013	0.00	0.00	5964.47	0.00	12348.33	0.00	2497.98	8908.23	0.00	945.27
2014	0.00	0.00	5272.95	0.00	12569.97	0.00	2472.76	10341.68	0.00	985.73
2015	0.00	0.00	5206.56	0.00	12669.38	0.00	2406.69	10182.11	0.00	967.36
2016	0.00	0.00	4992.30	0.00	12383.50	0.00	2322.17	11625.92	0.00	975.21
2017	0.00	0.00	4917.48	0.00	12777.27	0.00	2072.92	10958.83	0.00	931.03

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 30

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON)

HYDROCONDITION 2

THERMAL FUEL TYPES

	5		6		7		8		9	
YEAR	GTGO		NGAS		****		****		****	
	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR
1998	456.73	0.00	0.00	183.33	0.00	0.00	0.00	0.00	0.00	0.00
1999	466.72	0.00	0.00	126.55	0.00	0.00	0.00	0.00	0.00	0.00
2000	480.97	0.00	0.00	297.28	0.00	0.00	0.00	0.00	0.00	0.00
2001	480.97	0.00	0.00	711.17	0.00	0.00	0.00	0.00	0.00	0.00
2002	480.97	0.00	0.00	1546.13	0.00	0.00	0.00	0.00	0.00	0.00
2003	480.97	0.00	0.00	1808.48	0.00	0.00	0.00	0.00	0.00	0.00
2004	480.97	0.00	0.00	1737.20	0.00	0.00	0.00	0.00	0.00	0.00
2005	480.97	0.00	0.00	1481.69	0.00	0.00	0.00	0.00	0.00	0.00
2006	480.97	0.00	0.00	1179.67	0.00	0.00	0.00	0.00	0.00	0.00
2007	480.97	0.00	0.00	1002.05	0.00	0.00	0.00	0.00	0.00	0.00
2008	480.97	0.00	0.00	878.70	0.00	0.00	0.00	0.00	0.00	0.00
2009	360.73	0.00	0.00	688.20	0.00	0.00	0.00	0.00	0.00	0.00
2010	360.73	0.00	0.00	638.20	0.00	0.00	0.00	0.00	0.00	0.00
2011	360.73	0.00	0.00	548.20	0.00	0.00	0.00	0.00	0.00	0.00
2012	360.73	0.00	0.00	1281.71	0.00	0.00	0.00	0.00	0.00	0.00
2013	360.73	0.00	0.00	1330.85	0.00	0.00	0.00	0.00	0.00	0.00
2014	360.73	0.00	0.00	1250.13	0.00	0.00	0.00	0.00	0.00	0.00
2015	360.73	0.00	0.00	1186.34	0.00	0.00	0.00	0.00	0.00	0.00
2016	360.73	0.00	0.00	1178.74	0.00	0.00	0.00	0.00	0.00	0.00
2017	360.73	0.00	0.00	1386.17	0.00	0.00	0.00	0.00	0.00	0.00

PAGE 31

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON)

HYDROCONDITION 3

THERMAL FUEL TYPES

	0		1		2		3		4	
YEAR	NUCL		LIG1		LIG2		COAL		FOIL	
	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR
1998	0.00	0.00	4787.06	0.00	14238.26	0.00	1306.76	0.00	0.00	1199.18
1999	0.00	0.00	5497.01	0.00	13454.27	0.00	2342.09	0.00	0.00	1082.20
2000	0.00	0.00	4747.29	0.00	14374.69	0.00	2789.46	0.00	0.00	1220.71
2001	0.00	0.00	4895.51	0.00	14425.95	0.00	2814.19	0.00	0.00	1217.82
2002	0.00	0.00	5035.95	0.00	14501.30	0.00	3189.49	0.00	0.00	1556.66
2003	0.00	0.00	4399.53	0.00	15219.27	0.00	3296.51	0.00	0.00	1583.89
2004	0.00	0.00	4688.38	0.00	15057.05	0.00	3159.56	0.00	0.00	1595.42
2005	0.00	0.00	4269.76	0.00	15006.31	0.00	3010.34	1483.98	0.00	1577.66
2006	0.00	0.00	4621.04	0.00	14472.04	0.00	2986.22	1461.83	0.00	1545.34
2007	0.00	0.00	4759.49	0.00	14395.52	0.00	2887.19	2826.70	0.00	1532.30
2008	0.00	0.00	4726.33	0.00	14189.13	0.00	2848.65	4151.41	0.00	1521.55
2009	0.00	0.00	6984.83	0.00	12576.46	0.00	2821.02	5591.85	0.00	1527.60
2010	0.00	0.00	6722.69	0.00	12155.20	0.00	2777.52	6959.75	0.00	1520.16
2011	0.00	0.00	6774.90	0.00	12399.91	0.00	2624.24	6683.95	0.00	1466.65
2012	0.00	0.00	6445.83	0.00	12236.48	0.00	2410.40	7241.75	0.00	914.10
2013	0.00	0.00	5772.23	0.00	12604.58	0.00	2434.21	8667.78	0.00	806.91
2014	0.00	0.00	4845.64	0.00	13166.15	0.00	2430.74	9809.61	0.00	942.48
2015	0.00	0.00	4893.38	0.00	13319.14	0.00	2217.70	9387.99	0.00	869.80
2016	0.00	0.00	4862.70	0.00	13009.27	0.00	2004.10	10545.91	0.00	893.98
2017	0.00	0.00	4791.36	0.00	13246.69	0.00	1858.48	10220.37	0.00	872.14

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 32

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON)

HYDROCONDITION 3

THERMAL FUEL TYPES

	5		6		7		8		9	
YEAR	GTGO		NGAS		****		****		****	
	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR
1998	473.46	0.00	0.00	116.35	0.00	0.00	0.00	0.00	0.00	0.00
1999	469.53	0.00	0.00	96.54	0.00	0.00	0.00	0.00	0.00	0.00
2000	480.97	0.00	0.00	164.85	0.00	0.00	0.00	0.00	0.00	0.00
2001	480.97	0.00	0.00	482.28	0.00	0.00	0.00	0.00	0.00	0.00
2002	480.97	0.00	0.00	1445.15	0.00	0.00	0.00	0.00	0.00	0.00
2003	480.97	0.00	0.00	1651.07	0.00	0.00	0.00	0.00	0.00	0.00
2004	480.97	0.00	0.00	1467.64	0.00	0.00	0.00	0.00	0.00	0.00
2005	480.97	0.00	0.00	1224.98	0.00	0.00	0.00	0.00	0.00	0.00
2006	480.97	0.00	0.00	925.88	0.00	0.00	0.00	0.00	0.00	0.00
2007	480.97	0.00	0.00	818.47	0.00	0.00	0.00	0.00	0.00	0.00
2008	480.97	0.00	0.00	711.83	0.00	0.00	0.00	0.00	0.00	0.00
2009	360.73	0.00	0.00	528.28	0.00	0.00	0.00	0.00	0.00	0.00
2010	360.73	0.00	0.00	482.20	0.00	0.00	0.00	0.00	0.00	0.00
2011	360.73	0.00	0.00	391.16	0.00	0.00	0.00	0.00	0.00	0.00
2012	360.73	0.00	0.00	1233.89	0.00	0.00	0.00	0.00	0.00	0.00
2013	360.73	0.00	0.00	1204.43	0.00	0.00	0.00	0.00	0.00	0.00
2014	360.73	0.00	0.00	1152.48	0.00	0.00	0.00	0.00	0.00	0.00
2015	360.73	0.00	0.00	1276.74	0.00	0.00	0.00	0.00	0.00	0.00
2016	360.73	0.00	0.00	1422.83	0.00	0.00	0.00	0.00	0.00	0.00
2017	360.73	0.00	0.00	1443.34	0.00	0.00	0.00	0.00	0.00	0.00

PAGE 33

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION

EXPECTED FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON),
WEIGHTED BY PROBABILITIES OF HYDRO CONDITIONS

THERMAL FUEL TYPES

	0		1		2		3		4	
YEAR	NUCL		LIG1		LIG2		COAL		FOIL	
	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR
1998	0.00	0.00	4580.44	0.00	14490.71	0.00	1443.22	0.00	0.00	1329.48
1999	0.00	0.00	4964.36	0.00	14078.14	0.00	2576.43	0.00	0.00	1155.48
2000	0.00	0.00	4265.49	0.00	14857.31	0.00	2986.78	0.00	0.00	1347.90
2001	0.00	0.00	4380.69	0.00	14946.88	0.00	2929.93	0.00	0.00	1311.89
2002	0.00	0.00	4948.68	0.00	14551.17	0.00	3237.44	0.00	0.00	1559.12
2003	0.00	0.00	4326.63	0.00	15297.79	0.00	3311.24	0.00	0.00	1585.52
2004	0.00	0.00	4528.01	0.00	15132.08	0.00	3262.97	0.00	0.00	1593.67
2005	0.00	0.00	4399.84	0.00	14833.73	0.00	3148.83	1518.02	0.00	1573.02
2006	0.00	0.00	4860.75	0.00	14255.77	0.00	3097.91	1495.60	0.00	1547.17
2007	0.00	0.00	4973.36	0.00	14167.33	0.00	2984.52	2942.15	0.00	1529.79
2008	0.00	0.00	4948.59	0.00	13954.75	0.00	2888.52	4335.17	0.00	1519.80
2009	0.00	0.00	7115.56	0.00	12399.44	0.00	2856.75	5799.02	0.00	1526.55
2010	0.00	0.00	6880.12	0.00	11956.14	0.00	2801.71	7177.75	0.00	1519.96
2011	0.00	0.00	6974.50	0.00	12137.14	0.00	2635.86	6902.61	0.00	1474.11
2012	0.00	0.00	6204.36	0.00	12565.13	0.00	2453.96	7401.04	0.00	990.27
2013	0.00	0.00	5806.76	0.00	12535.62	0.00	2472.41	8802.11	0.00	878.47
2014	0.00	0.00	5091.67	0.00	12839.34	0.00	2449.57	10065.19	0.00	974.65
2015	0.00	0.00	5087.91	0.00	12916.62	0.00	2351.48	9847.67	0.00	943.38
2016	0.00	0.00	4952.08	0.00	12706.96	0.00	2143.89	11001.07	0.00	938.43
2017	0.00	0.00	4870.72	0.00	12997.17	0.00	1971.38	10570.77	0.00	908.74

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 34

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION

EXPECTED FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON),
WEIGHTED BY PROBABILITIES OF HYDRO CONDITIONS

	THERMAL FUEL TYPES									
	5		6		7		8		9	
YEAR	GTGO		NGAS		****		****		****	
	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR	DOM.	FOR
1998	463.94	0.00	0.00	152.61	0.00	0.00	0.00	0.00	0.00	0.00
1999	468.99	0.00	0.00	109.37	0.00	0.00	0.00	0.00	0.00	0.00
2000	480.97	0.00	0.00	234.54	0.00	0.00	0.00	0.00	0.00	0.00
2001	480.97	0.00	0.00	608.84	0.00	0.00	0.00	0.00	0.00	0.00
2002	480.97	0.00	0.00	1500.03	0.00	0.00	0.00	0.00	0.00	0.00
2003	480.97	0.00	0.00	1735.17	0.00	0.00	0.00	0.00	0.00	0.00
2004	480.97	0.00	0.00	1603.60	0.00	0.00	0.00	0.00	0.00	0.00
2005	480.97	0.00	0.00	1353.80	0.00	0.00	0.00	0.00	0.00	0.00
2006	480.97	0.00	0.00	1053.69	0.00	0.00	0.00	0.00	0.00	0.00
2007	480.97	0.00	0.00	917.68	0.00	0.00	0.00	0.00	0.00	0.00
2008	480.97	0.00	0.00	803.69	0.00	0.00	0.00	0.00	0.00	0.00
2009	360.73	0.00	0.00	612.89	0.00	0.00	0.00	0.00	0.00	0.00
2010	360.73	0.00	0.00	565.93	0.00	0.00	0.00	0.00	0.00	0.00
2011	360.73	0.00	0.00	476.86	0.00	0.00	0.00	0.00	0.00	0.00
2012	360.73	0.00	0.00	1254.55	0.00	0.00	0.00	0.00	0.00	0.00
2013	360.73	0.00	0.00	1268.03	0.00	0.00	0.00	0.00	0.00	0.00
2014	360.73	0.00	0.00	1206.16	0.00	0.00	0.00	0.00	0.00	0.00
2015	360.73	0.00	0.00	1183.89	0.00	0.00	0.00	0.00	0.00	0.00
2016	360.73	0.00	0.00	1346.24	0.00	0.00	0.00	0.00	0.00	0.00
2017	360.73	0.00	0.00	1423.88	0.00	0.00	0.00	0.00	0.00	0.00

PAGE 35

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
POLLUTING MATERIAL SO2 EMITTED BY FUEL TYPE IN (kT)

HYDROCONDITION 1

	THERMAL FUEL TYPES										
	0	1	2	3	4	5	6	7	8	9	
YEAR	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	TOTAL
1998	0	117	382	15	14	2	0	0	0	0	530
1999	0	131	367	27	12	2	0	0	0	0	539
2000	0	107	391	30	14	2	0	0	0	0	544
2001	0	114	384	30	13	2	0	0	0	0	543
2002	0	126	370	33	16	2	0	0	0	0	547
2003	0	110	386	33	16	2	0	0	0	0	547
2004	0	115	380	33	16	2	0	0	0	0	546
2005	0	113	372	47	16	2	0	0	0	0	550
2006	0	126	357	47	16	2	0	0	0	0	548
2007	0	129	355	60	15	2	0	0	0	0	561
2008	0	128	350	74	15	2	0	0	0	0	569
2009	0	183	312	88	15	2	0	0	0	0	600
2010	0	177	300	102	15	2	0	0	0	0	596
2011	0	180	305	98	15	2	0	0	0	0	600
2012	0	162	323	103	10	2	0	0	0	0	600
2013	0	150	322	117	9	2	0	0	0	0	600
2014	0	133	326	130	10	2	0	0	0	0	601
2015	0	133	327	128	10	2	0	0	0	0	600
2016	0	129	325	135	10	2	0	0	0	0	601
2017	0	127	332	130	9	2	0	0	0	0	600

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 36

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
POLLUTING MATERIAL SO2 EMITTED BY FUEL TYPE IN (kT)

HYDROCONDITION 2

THERMAL FUEL TYPES

	0	1	2	3	4	5	6	7	8	9	
YEAR	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	TOTAL
1998	0	124	375	16	15	2	0	0	0	0	532
1999	0	121	377	28	12	2	0	0	0	0	540
2000	0	111	387	32	15	2	0	0	0	0	547
2001	0	107	391	31	14	2	0	0	0	0	545
2002	0	125	371	33	16	2	0	0	0	0	547
2003	0	108	388	34	16	2	0	0	0	0	548
2004	0	111	384	34	16	2	0	0	0	0	547
2005	0	113	371	49	16	2	0	0	0	0	551
2006	0	126	356	48	16	2	0	0	0	0	548
2007	0	128	355	62	15	2	0	0	0	0	562
2008	0	128	349	76	15	2	0	0	0	0	570
2009	0	183	309	90	15	2	0	0	0	0	599
2010	0	177	299	104	15	2	0	0	0	0	597
2011	0	180	303	100	15	2	0	0	0	0	600
2012	0	160	323	104	11	2	0	0	0	0	600
2013	0	156	315	118	10	2	0	0	0	0	601
2014	0	136	319	133	10	2	0	0	0	0	600
2015	0	135	323	131	10	2	0	0	0	0	601
2016	0	129	315	144	10	2	0	0	0	0	600
2017	0	127	326	135	10	2	0	0	0	0	600

PAGE 37

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
POLLUTING MATERIAL SO2 EMITTED BY FUEL TYPE IN (kT)

HYDROCONDITION 3

THERMAL FUEL TYPES

	0	1	2	3	4	5	6	7	8	9	
YEAR	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	TOTAL
1998	0	127	372	13	12	2	0	0	0	0	526
1999	0	146	353	24	11	2	0	0	0	0	536
2000	0	126	374	29	13	2	0	0	0	0	544
2001	0	130	370	29	13	2	0	0	0	0	544
2002	0	129	368	32	16	2	0	0	0	0	547
2003	0	112	384	33	16	2	0	0	0	0	547
2004	0	119	378	32	16	2	0	0	0	0	547
2005	0	109	377	46	16	2	0	0	0	0	550
2006	0	119	364	45	16	2	0	0	0	0	546
2007	0	122	362	59	15	2	0	0	0	0	560
2008	0	121	357	72	15	2	0	0	0	0	567
2009	0	179	316	86	15	2	0	0	0	0	598
2010	0	173	306	100	15	2	0	0	0	0	596
2011	0	174	313	96	15	2	0	0	0	0	600
2012	0	170	317	101	10	2	0	0	0	0	600
2013	0	152	322	116	8	2	0	0	0	0	600
2014	0	127	334	128	10	2	0	0	0	0	601
2015	0	129	339	121	9	2	0	0	0	0	600
2016	0	127	331	131	9	2	0	0	0	0	600
2017	0	125	338	126	9	2	0	0	0	0	600

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION

EXPECTED POLLUTING MATERIAL SO_2 EMITTED BY FUEL TYPE IN (kT)

WEIGHTED BY PROBABILITIES OF HYDRO CONDITIONS

THERMAL FUEL TYPES

	0	1	2	3	4	5	6	7	8	9	
YEAR	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	TOTAL
1998	0	122	378	15	14	2	0	0	0	0	531
1999	0	132	366	27	12	2	0	0	0	0	539
2000	0	113	385	31	14	2	0	0	0	0	545
2001	0	116	383	30	13	2	0	0	0	0	544
2002	0	127	370	33	16	2	0	0	0	0	548
2003	0	110	386	33	16	2	0	0	0	0	547
2004	0	115	381	33	16	2	0	0	0	0	547
2005	0	112	373	47	16	2	0	0	0	0	550
2006	0	124	358	47	16	2	0	0	0	0	547
2007	0	127	356	60	15	2	0	0	0	0	560
2008	0	126	351	74	15	2	0	0	0	0	568
2009	0	182	312	88	15	2	0	0	0	0	599
2010	0	176	301	102	15	2	0	0	0	0	596
2011	0	179	307	98	15	2	0	0	0	0	601
2012	0	163	322	103	10	2	0	0	0	0	600
2013	0	152	320	117	9	2	0	0	0	0	600
2014	0	132	326	130	10	2	0	0	0	0	600
2015	0	133	329	127	10	2	0	0	0	0	601
2016	0	128	324	137	10	2	0	0	0	0	601
2017	0	126	332	131	9	2	0	0	0	0	600

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
POLLUTING MATERIAL NO_x EMITTED BY FUEL TYPE IN (kT)

HYDROCONDITION 1

THERMAL FUEL TYPES

	0	1	2	3	4	5	6	7	8	9	
YEAR	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	TOTAL
1998	0	47	153	30	41	2	1	0	0	0	274
1999	0	52	147	54	36	2	1	0	0	0	292
2000	0	43	156	61	41	2	1	0	0	0	304
2001	0	46	154	60	40	2	3	0	0	0	305
2002	0	51	148	66	47	2	7	0	0	0	321
2003	0	44	154	67	48	2	9	0	0	0	324
2004	0	46	152	66	48	2	8	0	0	0	322
2005	0	45	149	95	47	2	7	0	0	0	345
2006	0	50	143	93	47	2	5	0	0	0	340
2007	0	52	142	120	46	2	5	0	0	0	367
2008	0	51	140	147	46	2	4	0	0	0	390
2009	0	73	125	176	46	2	3	0	0	0	425
2010	0	71	120	204	46	2	3	0	0	0	446
2011	0	72	122	195	45	2	2	0	0	0	438
2012	0	65	129	206	30	2	6	0	0	0	438
2013	0	60	129	235	27	2	6	0	0	0	459
2014	0	53	130	259	30	2	6	0	0	0	480
2015	0	53	131	256	30	2	6	0	0	0	478
2016	0	52	130	270	29	2	7	0	0	0	490
2017	0	51	133	260	28	2	7	0	0	0	481

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 40

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
POLLUTING MATERIAL NOx EMITTED BY FUEL TYPE IN (kT)

HYDROCONDITION 2

THERMAL FUEL TYPES

	0	1	2	3	4	5	6	7	8	9	
YEAR	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	TOTAL
1998	0	50	150	31	44	2	1	0	0	0	278
1999	0	48	151	56	37	2	1	0	0	0	295
2000	0	44	155	64	44	2	1	0	0	0	310
2001	0	43	156	62	43	2	4	0	0	0	310
2002	0	50	148	66	47	2	8	0	0	0	321
2003	0	43	155	67	48	2	9	0	0	0	324
2004	0	44	154	67	48	2	9	0	0	0	324
2005	0	45	149	97	47	2	7	0	0	0	347
2006	0	50	142	96	47	2	6	0	0	0	343
2007	0	51	142	125	46	2	5	0	0	0	371
2008	0	51	140	152	46	2	4	0	0	0	395
2009	0	73	124	181	46	2	3	0	0	0	429
2010	0	71	120	208	46	2	3	0	0	0	450
2011	0	72	121	200	45	2	3	0	0	0	443
2012	0	64	129	208	33	2	6	0	0	0	442
2013	0	62	126	237	29	2	7	0	0	0	463
2014	0	54	128	266	30	2	6	0	0	0	486
2015	0	54	129	261	30	2	6	0	0	0	482
2016	0	52	126	289	30	2	6	0	0	0	505
2017	0	51	130	271	29	2	7	0	0	0	490

PAGE 41

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
POLLUTING MATERIAL NOx EMITTED BY FUEL TYPE IN (kT)

HYDROCONDITION 3

THERMAL FUEL TYPES

	0	1	2	3	4	5	6	7	8	9	
YEAR	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	TOTAL
1998	0	51	149	27	37	2	1	0	0	0	267
1999	0	58	141	49	34	2	0	0	0	0	284
2000	0	50	150	58	38	2	1	0	0	0	299
2001	0	52	148	58	38	2	2	0	0	0	300
2002	0	52	147	65	47	2	7	0	0	0	320
2003	0	45	153	67	48	2	8	0	0	0	323
2004	0	48	151	64	48	2	7	0	0	0	320
2005	0	44	151	92	48	2	6	0	0	0	343
2006	0	48	145	91	47	2	5	0	0	0	338
2007	0	49	145	117	46	2	4	0	0	0	363
2008	0	49	143	144	46	2	4	0	0	0	388
2009	0	72	127	173	46	2	3	0	0	0	423
2010	0	69	122	200	46	2	2	0	0	0	441
2011	0	70	125	192	44	2	2	0	0	0	435
2012	0	68	127	202	29	2	6	0	0	0	434
2013	0	61	129	231	25	2	6	0	0	0	454
2014	0	51	134	255	29	2	6	0	0	0	477
2015	0	51	136	243	27	2	6	0	0	0	465
2016	0	51	133	262	27	2	7	0	0	0	482
2017	0	50	135	253	27	2	7	0	0	0	474

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 42

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION

EXPECTED POLLUTING MATERIAL NOx EMITTED BY FUEL TYPE IN (kT)

WEIGHTED BY PROBABILITIES OF HYDRO CONDITIONS

	THERMAL FUEL TYPES										
	0	1	2	3	4	5	6	7	8	9	
YEAR	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	TOTAL
1998	0	49	151	29	41	2	1	0	0	0	273
1999	0	53	147	53	36	2	1	0	0	0	292
2000	0	45	154	61	41	2	1	0	0	0	304
2001	0	46	153	60	40	2	3	0	0	0	304
2002	0	51	148	66	47	2	8	0	0	0	322
2003	0	44	154	67	48	2	9	0	0	0	324
2004	0	46	152	66	48	2	8	0	0	0	322
2005	0	45	149	95	47	2	7	0	0	0	345
2006	0	50	143	93	47	2	5	0	0	0	340
2007	0	51	143	121	46	2	5	0	0	0	368
2008	0	51	141	148	46	2	4	0	0	0	392
2009	0	73	125	177	46	2	3	0	0	0	426
2010	0	70	121	204	46	2	3	0	0	0	446
2011	0	72	123	196	45	2	2	0	0	0	440
2012	0	65	129	205	31	2	6	0	0	0	438
2013	0	61	128	234	27	2	6	0	0	0	458
2014	0	53	130	260	30	2	6	0	0	0	481
2015	0	53	132	254	29	2	6	0	0	0	476
2016	0	51	129	274	29	2	7	0	0	0	492
2017	0	51	133	262	28	2	7	0	0	0	483

PAGE 43

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION

ACTUAL CONTRIBUTION VERSUS IMPOSED LIMITS OF GROUP LIMITATION

	1		2		3		4	
YEAR	FUEL kT		SO2 kT		NOx kT		FUEL	
	CONTRIB.	LIMIT	CONTRIB.	LIMIT	CONTRIB.	LIMIT	CONTRIB.	LIMIT
1998	152.62	10000.00	529.83	600.00	272.76	1000.00	19971.93	20000.00
1999	109.37	10000.00	538.91	600.00	290.94	1000.00	19924.48	20000.00
2000	234.54	10000.00	545.13	600.00	305.16	1000.00	19939.58	20000.00
2001	269.22	10000.00	544.40	600.00	305.17	1000.00	19941.25	20000.00
2002	256.23	10000.00	547.22	600.00	321.11	1000.00	19852.60	20000.00
2003	191.40	10000.00	547.77	600.00	324.17	1000.00	19838.86	20000.00
2004	189.36	10000.00	547.02	600.00	322.75	1000.00	19822.97	20000.00
2005	124.21	10000.00	550.75	600.00	345.47	1000.00	19405.19	20000.00
2006	68.83	10000.00	547.32	600.00	340.92	1000.00	19304.08	20000.00
2007	59.59	10000.00	561.56	600.00	367.46	1000.00	19331.60	20000.00
2008	44.51	10000.00	569.29	600.00	391.12	1000.00	19109.86	20000.00
2009	21.43	10000.00	599.60	600.00	425.44	1000.00	17671.50	20000.00
2010	17.68	10000.00	596.45	600.00	445.52	1000.00	17068.85	20000.00
2011	17.20	10000.00	600.00	600.00	438.86	1000.00	17511.98	20000.00
2012	403.05	10000.00	599.77	600.00	438.21	1000.00	17465.83	20000.00
2013	786.67	10000.00	600.00	600.00	458.40	1000.00	16577.82	20000.00
2014	1025.36	10000.00	600.00	600.00	481.08	1000.00	15771.65	20000.00
2015	803.90	10000.00	600.00	600.00	475.37	1000.00	16248.94	20000.00
2016	1194.92	10000.00	600.00	600.00	491.60	1000.00	15701.54	20000.00
2017	1257.26	10000.00	600.00	600.00	481.65	1000.00	16048.61	20000.00

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

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                                        PAGE 44

                  D Y N P R O

         SUMMARY OF CAPITAL COSTS OF ALTERNATIVES IN $/KW

       CAPITAL COSTS  INCLUSIVE CONSTR.  PLANT   CAPITAL COSTS
  PLANT  (DEPRECIABLE PART)   IDC   TIME   LIFE  (NON-DEPREC. PART)
      DOMESTIC  FOREIGN   %   (YEARS)  (YEARS) DOMESTIC FOREIGN

  THERMAL PLANT CAPITAL COSTS

  V-CC   318.0   477.0   11.92   3.00   25.    0.0    0.0
  VLG1   594.0   891.0   19.20   5.00   25.    0.0    0.0
  VLG2   544.0   817.0   19.20   5.00   25.    0.0    0.0
  VCOA   495.0   743.0   19.20   5.00   25.    0.0    0.0
  NUCL   730.0   1703.0   26.00   7.00   30.    0.0    0.0

  HYD1 - HYDRO PROJECT CAPITAL COSTS, PROJECT LIFE: 50.

   1   841.0   841.0   22.67   6.00
   2   970.0   970.0   22.67   6.00

  HYD2 - HYDRO PROJECT CAPITAL COSTS, PROJECT LIFE: 50.

   1   742.0   742.0   19.20   5.00
   2   866.0   866.0   19.20   5.00


                                        PAGE 45


                   D Y N P R O

              ECONOMIC PARAMETERS AND CONSTRAINTS

           ALL COSTS WILL BE DISCOUNTED TO YEAR  :  1998
           BASE YEAR FOR ESCALATION CALCULATION IS :  1998

DISCOUNT RATE APPLIED TO ALL DOMESTIC COSTS - %/YR  10.0
DISCOUNT RATE APPLIED TO ALL FOREIGN COSTS - %/YR  10.0

  1998 INITIAL VALUES : (XX) = INDEX NUMBER; ( 0) = NO INDEX READ
     **************

     NAME OF ALTERNATIVES :

     V-CC VLG1 VLG2 VCOA NUCL HYD1 HYD2

ESCALATION RATIOS FOR CAPITAL COSTS ( 0)
-----------------------------------

DOMESTIC 1.00 1.00 1.00 1.00 1.00 1.00 1.00
FOREIGN 1.00 1.00 1.00 1.00 1.00 1.00 1.00

MAXIMUM NUMBER OF UNITS WHICH CAN BE ADDED ( 0)
-------------------------------------------
     50  50  50  50  50  50  50

MINIMUM NUMBER OF UNITS WHICH MUST BE ADDED ( 0)
-------------------------------------------
      0   0   0   0   0   0   0
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

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                                              PAGE 46

                     D Y N P R O (CONTD.)

               ECONOMIC PARAMETERS AND CONSTRAINTS

   1998 INITIAL VALUES : (XX) = INDEX NUMBER; ( 0) = NO INDEX READ
      **************

 FUEL TYPE:           T H E R M A L            HYDRO  ENERGY
      NUCL LIG1 LIG2 COAL FOIL GTGO NGAS **** **** **** HYD1 HYD2 NOT
                                          SERVED

 ESCALATION RATIOS FOR OPERATING COSTS ( 0)
 -------------------------------------

 DOMESTIC 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
 FOREIGN  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00

 ESCALATION RATIOS FOR FUEL COSTS ( 0)
 --------------------------------

 DOMESTIC 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
 FOREIGN  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00


 COEFFICIENTS OF ENERGY NOT SERVED COST FUNCTION (11)  CF1    CF2    CF3
 -----------------------------------------------

                     ($/KWH)    1.0000  0.0000  0.0000

 PENALTY FACTOR ON FOREIGN EXPENDITURE  ( 0)     1.0000

 CRITICAL LOSS OF LOAD PROBABILITY IN % ( 0)    100.0000

 DEPRECIATION OPTION (16) : 1 = SINKING FUND


                                              PAGE 47


                 EXPECTED COST OF OPERATION
                     FUEL COST
                      DOMESTIC

      TYPE OF PLANT:  NUCL LIG1 LIG2 COAL FOIL GTGO NGAS **** **** ****

      YEAR   TOTAL        COST BY FUEL TYPE (MILLION $)

      1998   277.2  0.0 52.5 134.6 70.5  0.0 19.5  0.0  0.0  0.0  0.0
      1999   334.7  0.0 57.0 130.5 127.5  0.0 19.7  0.0  0.0  0.0  0.0
      2000   352.9  0.0 48.9 137.3 146.5  0.0 20.2  0.0  0.0  0.0  0.0
      2001   351.0  0.0 50.1 136.3 144.4  0.0 20.2  0.0  0.0  0.0  0.0
      2002   364.2  0.0 54.7 131.7 157.5  0.0 20.2  0.0  0.0  0.0  0.0
      2003   365.9  0.0 47.5 137.5 160.6  0.0 20.2  0.0  0.0  0.0  0.0
      2004   364.1  0.0 49.7 135.7 158.6  0.0 20.2  0.0  0.0  0.0  0.0
      2005   355.4  0.0 48.5 132.9 153.8  0.0 20.2  0.0  0.0  0.0  0.0
      2006   353.2  0.0 53.6 127.8 151.6  0.0 20.2  0.0  0.0  0.0  0.0
      2007   348.8  0.0 54.8 127.0 146.8  0.0 20.2  0.0  0.0  0.0  0.0
      2008   342.6  0.0 54.6 125.2 142.6  0.0 20.2  0.0  0.0  0.0  0.0
      2009   350.3  0.0 82.7 111.2 141.2  0.0 15.2  0.0  0.0  0.0  0.0
      2010   341.3  0.0 80.1 107.4 138.7  0.0 15.2  0.0  0.0  0.0  0.0
      2011   336.3  0.0 81.0 109.2 130.9  0.0 15.2  0.0  0.0  0.0  0.0
      2012   330.9  0.0 73.7 118.3 123.7  0.0 15.2  0.0  0.0  0.0  0.0
      2013   330.2  0.0 69.0 121.6 124.5  0.0 15.2  0.0  0.0  0.0  0.0
      2014   325.8  0.0 60.3 126.7 123.6  0.0 15.2  0.0  0.0  0.0  0.0
      2015   319.5  0.0 60.2 125.4 118.8  0.0 15.2  0.0  0.0  0.0  0.0
      2016   308.4  0.0 58.0 127.0 108.3  0.0 15.2  0.0  0.0  0.0  0.0
      2017   302.0  0.0 56.9 130.3 99.6  0.0 15.2  0.0  0.0  0.0  0.0

               0.0   2533.9     0.0     0.0     0.0
      TOTALS 6754.6    1193.8    2669.6    357.3     0.0     0.0
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 48

EXPECTED COST OF OPERATION
FUEL COST
FOREIGN

TYPE OF PLANT: NUCL LIG1 LIG2 COAL FOIL GTGO NGAS **** **** ****

COST BY FUEL TYPE (MILLION $)

YEAR	TOTAL	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****
1998	133.9	0.0	0.0	0.0	0.0	112.6	0.0	21.3	0.0	0.0	0.0
1999	114.3	0.0	0.0	0.0	0.0	99.1	0.0	15.2	0.0	0.0	0.0
2000	147.0	0.0	0.0	0.0	0.0	114.3	0.0	32.7	0.0	0.0	0.0
2001	193.8	0.0	0.0	0.0	0.0	111.5	0.0	82.3	0.0	0.0	0.0
2002	330.5	0.0	0.0	0.0	0.0	130.6	0.0	199.9	0.0	0.0	0.0
2003	363.1	0.0	0.0	0.0	0.0	132.7	0.0	230.4	0.0	0.0	0.0
2004	346.4	0.0	0.0	0.0	0.0	133.3	0.0	213.1	0.0	0.0	0.0
2005	385.0	0.0	0.0	0.0	73.7	131.7	0.0	179.6	0.0	0.0	0.0
2006	362.1	20.1	0.0	0.0	72.7	129.7	0.0	139.6	0.0	0.0	0.0
2007	413.4	20.1	0.0	0.0	143.4	128.4	0.0	121.6	0.0	0.0	0.0
2008	465.8	20.1	0.0	0.0	211.8	127.6	0.0	106.4	0.0	0.0	0.0
2009	512.4	20.1	0.0	0.0	283.2	128.1	0.0	81.1	0.0	0.0	0.0
2010	573.4	20.1	0.0	0.0	350.9	127.6	0.0	74.8	0.0	0.0	0.0
2011	566.3	40.1	0.0	0.0	339.1	124.1	0.0	63.1	0.0	0.0	0.0
2012	659.8	39.1	0.0	0.0	369.4	85.2	0.0	166.1	0.0	0.0	0.0
2013	720.4	39.2	0.0	0.0	438.1	75.1	0.0	168.0	0.0	0.0	0.0
2014	782.7	39.5	0.0	0.0	500.9	82.6	0.0	159.6	0.0	0.0	0.0
2015	786.6	58.6	0.0	0.0	491.3	80.1	0.0	156.6	0.0	0.0	0.0
2016	866.0	59.3	0.0	0.0	548.4	79.8	0.0	178.6	0.0	0.0	0.0
2017	874.4	79.7	0.0	0.0	528.2	77.5	0.0	189.0	0.0	0.0	0.0
TOTALS	9597.4	455.8	0.0	0.0	4351.1	2211.7	0.0	2578.9	0.0	0.0	0.0

PAGE 49

EXPECTED COST OF OPERATION
OPERATION & MAINTENANCE AND ENERGY NOT SERVED (ENS)
DOMESTIC

TYPE OF PLANT: NUCL LIG1 LIG2 COAL FOIL GTGO NGAS **** **** **** HYD1 HYD2 ENS

COST BY FUEL TYPE (MILLION $)

YEAR	TOTAL	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	HYD1	HYD2	ENS
1998	1090.2	0.0	65.6	76.0	36.7	64.8	22.3	8.5	0.0	0.0	0.0	10.9	1.4	804.0
1999	1251.8	0.0	66.7	75.4	69.9	63.6	22.3	7.3	0.0	0.0	0.0	10.9	1.4	934.3
2000	339.1	0.0	64.8	76.5	74.5	65.0	22.4	15.1	0.0	0.0	0.0	10.9	2.6	7.6
2001	362.2	0.0	65.1	76.6	73.9	64.7	22.4	43.2	0.0	0.0	0.0	10.9	2.6	3.0
2002	416.0	0.0	66.7	76.1	77.4	66.4	22.4	93.5	0.0	0.0	0.0	2.6	3.3	7.7
2003	423.3	0.0	51.8	77.0	78.2	66.6	22.4	113.6	0.0	0.0	0.0	4.0	3.3	6.4
2004	421.5	0.0	52.3	76.8	77.7	66.7	22.4	110.6	0.0	0.0	0.0	8.3	3.3	3.4
2005	451.7	0.0	52.0	76.4	115.1	66.5	22.4	104.7	0.0	0.0	0.0	8.3	4.6	1.8
2006	459.4	20.1	53.3	69.3	114.2	66.4	22.4	97.7	0.0	0.0	0.0	8.3	4.6	3.2
2007	492.9	20.1	53.6	69.2	150.8	66.2	22.4	94.6	0.0	0.0	0.0	7.6	4.6	3.8
2008	525.7	20.1	53.5	68.9	186.9	66.2	22.4	92.0	0.0	0.0	0.0	7.6	4.6	3.5
2009	562.5	20.1	70.5	60.6	224.6	66.2	16.8	87.6	0.0	0.0	0.0	7.6	4.6	4.0
2010	596.6	20.1	69.8	60.0	261.0	66.2	16.8	86.5	0.0	0.0	0.0	7.6	4.6	4.1
2011	610.0	40.2	70.0	60.2	255.8	65.8	16.8	84.5	0.0	0.0	0.0	7.6	4.6	4.5
2012	648.1	40.1	67.5	70.7	280.1	54.6	16.8	102.2	0.0	0.0	0.0	7.6	4.6	4.0
2013	685.7	40.1	66.4	80.6	317.6	45.8	16.8	102.6	0.0	0.0	0.0	7.6	4.6	3.7
2014	718.8	40.1	51.2	93.4	353.0	46.5	16.8	101.1	0.0	0.0	0.0	7.6	4.6	4.6
2015	741.6	60.1	51.0	102.1	349.2	46.3	16.8	100.6	0.0	0.0	0.0	7.6	4.6	3.3
2016	778.8	60.2	50.5	102.6	381.2	46.2	16.8	104.5	0.0	0.0	0.0	7.6	4.6	4.6
2017	801.9	80.3	50.2	112.1	374.0	46.0	16.8	106.4	0.0	0.0	0.0	7.6	4.6	3.9
TOTALS	12378.2	461.5	1192.5	1560.4	3851.7	1206.9	397.0	1656.6	0.0	0.0	0.0	158.4	77.9	1815.2

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

EXPECTED COST OF OPERATION
TOTAL COST
DOMESTIC AND FOREIGN

TYPE OF PLANT: NUCL LIG1 LIG2 COAL FOIL GTGO NGAS **** **** **** HYD1 HYD2 ENS

YEAR	TOTAL	NUCL	LIG1	LIG2	COAL	FOIL	GTGO	NGAS	****	****	****	HYD1	HYD2	ENS
		COST BY FUEL TYPE (MILLION $)												
1998	1501.3	0.0	118.2	210.6	107.2	177.5	41.8	29.7	0.0	0.0	0.0	10.9	1.4	804.0
1999	1700.8	0.0	123.7	206.0	197.3	162.7	42.0	22.6	0.0	0.0	0.0	10.9	1.4	934.3
2000	839.0	0.0	113.6	213.8	221.0	179.3	42.6	47.7	0.0	0.0	0.0	10.9	2.6	7.6
2001	907.1	0.0	115.2	212.9	218.2	176.3	42.6	125.5	0.0	0.0	0.0	10.9	2.6	3.0
2002	1110.7	0.0	121.4	207.8	234.9	197.1	42.6	293.3	0.0	0.0	0.0	2.6	3.3	7.7
2003	1152.3	0.0	99.3	214.6	238.8	199.3	42.6	344.0	0.0	0.0	0.0	4.0	3.3	6.4
2004	1132.0	0.0	102.0	212.5	236.2	200.0	42.6	323.7	0.0	0.0	0.0	8.3	3.3	3.4
2005	1192.2	0.0	100.5	209.3	342.6	198.3	42.6	284.3	0.0	0.0	0.0	8.3	4.6	1.8
2006	1174.8	40.1	106.9	197.1	338.6	196.1	42.6	237.3	0.0	0.0	0.0	8.3	4.6	3.2
2007	1255.1	40.1	108.4	196.2	441.0	194.6	42.6	216.2	0.0	0.0	0.0	7.6	4.6	3.8
2008	1334.2	40.1	108.1	194.2	541.3	193.8	42.6	198.4	0.0	0.0	0.0	7.6	4.6	3.5
2009	1425.3	40.1	153.2	171.8	649.0	194.3	31.9	168.6	0.0	0.0	0.0	7.6	4.6	4.0
2010	1511.3	40.1	149.9	167.4	750.6	193.8	31.9	161.3	0.0	0.0	0.0	7.6	4.6	4.1
2011	1512.7	80.3	151.0	169.5	725.8	189.9	31.9	147.5	0.0	0.0	0.0	7.6	4.6	4.5
2012	1638.7	79.2	141.2	189.0	773.1	139.8	31.9	268.3	0.0	0.0	0.0	7.6	4.6	4.0
2013	1736.4	79.3	135.3	202.2	880.2	121.0	31.9	270.5	0.0	0.0	0.0	7.6	4.6	3.7
2014	1827.3	79.7	111.5	220.1	977.6	129.1	31.9	260.7	0.0	0.0	0.0	7.6	4.6	4.6
2015	1847.8	118.7	111.2	227.5	959.3	126.4	31.9	257.2	0.0	0.0	0.0	7.6	4.6	3.3
2016	1953.2	119.5	108.5	229.6	1037.8	126.0	31.9	283.1	0.0	0.0	0.0	7.6	4.6	4.6
2017	1978.3	160.0	107.1	242.4	1001.8	123.5	31.9	295.4	0.0	0.0	0.0	7.6	4.6	3.9
TOTALS	28730.2	917.3	2386.3	4094.3	10872.4	3418.6	754.3	4235.5	0.0	0.0	0.0	158.4	77.9	1815.2

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 51

DOMESTIC CONSTRUCTION COSTS (MILLION $)

YEAR	#	PLANT	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	SUM
2001	1	V-CC	.	16.5	98.5	53.1	.	.	.	.	.	.	.	.	168.1
2002	2	V-CC	.	.	33.0	196.9	106.2	.	.	.	.	.	.	.	336.1
2002	1	VHY1	2.6	10.9	24.6	25.5	8.3	.	.	.	.	.	.	.	71.9
2003	1	V-CC	.	.	.	16.5	98.5	53.1	.	.	.	.	.	.	168.1
2003	1	VHY2	3.7	9.1	28.1	48.1	32.1	9.0	.	.	.	.	.	.	130.1
2004	1	VHY3	.	13.7	34.1	105.2	180.5	120.5	33.6	.	.	.	.	.	487.6
2005	1	VCOA	.	.	.	8.5	35.2	79.3	82.3	26.6	.	.	.	.	232.0
2005	1	VHY4	.	.	.	4.9	20.5	46.3	48.0	15.5	.	.	.	.	135.3
2006	1	NUCL	.	.	16.2	32.4	48.6	64.8	81.0	48.6	32.4	.	.	.	324.1
2007	1	VCOA	.	.	.	.	.	8.5	35.2	79.3	82.3	26.6	.	.	232.0
2008	1	VCOA	.	.	.	.	.	.	8.5	35.2	79.3	82.3	26.6	.	232.0
2009	1	VLG1	.	.	.	.	.	.	.	4.9	20.4	46.0	47.7	15.4	134.4
2009	1	VCOA	.	.	.	.	.	.	.	8.5	35.2	79.3	82.3	26.6	232.0

END TOTAL 6.3 234.4 529.9 288.6 290.6 313.8
50.3 491.3 381.4 234.9 318.1 288.5

PAGE 52

DOMESTIC CONSTRUCTION COSTS (MILLION $) (CONTD.)

YEAR	#	PLANT	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	SUM
2010	1	VCOA	.	8.5	35.2	79.3	82.3	26.6	.	.	.	.	.	.	232.0
2011	1	NUCL	16.2	32.4	48.6	64.8	81.0	48.6	32.4	.	.	.	.	.	324.1
2012	1	VLG2	.	.	.	4.5	18.7	42.1	43.7	14.1	.	.	.	.	123.1
2012	1	VCOA	.	.	.	8.5	35.2	79.3	82.3	26.6	.	.	.	.	232.0
2013	1	VLG2	.	.	.	.	4.5	18.7	42.1	43.7	14.1	.	.	.	123.1
2013	1	VCOA	.	.	.	.	8.5	35.2	79.3	82.3	26.6	.	.	.	232.0
2014	2	VLG2	.	.	.	.	.	9.0	37.3	84.2	87.4	28.2	.	.	246.1
2014	1	VCOA	.	.	.	.	.	8.5	35.2	79.3	82.3	26.6	.	.	232.0
2015	1	VLG2	.	.	.	.	.	.	4.5	18.7	42.1	43.7	14.1	.	123.1
2015	1	NUCL	.	.	.	.	16.2	32.4	48.6	64.8	81.0	48.6	32.4	.	324.1
2016	1	VCOA	.	.	.	.	.	.	.	8.5	35.2	79.3	82.3	26.6	232.0

END TOTAL 234.9 318.1 288.5 421.8 421.9 252.0
290.6 313.8 300.4 454.7 310.0 118.9

PAGE 53

DOMESTIC CONSTRUCTION COSTS (MILLION $) (CONTD.)

YEAR	#	PLANT	2010	2011	2012	2013	2014	2015	2016	SUM
2017	1	VLG2	.	.	4.5	18.7	42.1	43.7	14.1	123.1
2017	1	NUCL	16.2	32.4	48.6	64.8	81.0	48.6	32.4	324.1

END TOTAL 421.8 421.9 252.0 46.5
454.7 310.0 118.9 5754.2

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

```
                                                    PAGE 54

  FOREIGN CONSTRUCTION COSTS (MILLION $)

YEAR # PLANT 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008   SUM

2001 1 V-CC    .  24.7 147.7 79.6  .    .    .    .    .    .    .    .  252.1
2002 2 V-CC    .    .  49.5 295.4 159.3  .    .    .    .    .    .    .  504.2
2002 1 VHY1  2.6 10.9 24.6 25.5  8.3  .    .    .    .    .    .    .   71.9
2003 1 V-CC    .    .    .  24.7 147.7 79.6  .    .    .    .    .    .  252.1
2003 1 VHY2  3.7  9.1 28.1 48.1 32.1  9.0  .    .    .    .    .    .  130.1
2004 1 VHY3    .  13.7 34.1 105.2 180.5 120.5 33.6  .    .    .    .    .  487.6
2005 1 VCOA    .    .    .  12.7 52.8 119.1 123.6 40.0  .    .    .    .  348.2
2005 1 VHY4    .    .    .   4.9 20.5 46.3 48.0 15.5  .    .    .    .  135.3
2006 1 NUCL    .    .  37.8 37.8 75.6 113.4 226.8 189.0 75.6  .    .    .  756.1
2007 1 VCOA    .    .    .    .    .  12.7 52.8 119.1 123.6 40.0  .    .  348.2
2008 1 VCOA    .    .    .    .    .    .  12.7 52.8 119.1 123.6 40.0  .  348.2
2009 1 VLG1    .    .    .    .    .    .    .   7.4 30.6 68.9 71.6 23.1  201.6
2009 1 VCOA    .    .    .    .    .    .    .  12.7 52.8 119.1 123.6 40.0  348.2

 END TOTAL   6.3    321.8    676.8    497.6    452.3    487.1
          58.5    634.2    500.6    474.3    480.1    551.7
```

```
                                                    PAGE 55

  FOREIGN CONSTRUCTION COSTS (MILLION $) (CONTD.)

YEAR # PLANT 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015   SUM

2010 1 VCOA    .  12.7 52.8 119.1 123.6 40.0  .    .    .    .    .    .  348.2
2011 1 NUCL  37.8 37.8 75.6 113.4 226.8 189.0 75.6  .    .    .    .    .  756.1
2012 1 VLG2    .    .    .   6.7 28.0 63.2 65.6 21.2  .    .    .    .  184.8
2012 1 VCOA    .    .    .  12.7 52.8 119.1 123.6 40.0  .    .    .    .  348.2
2013 1 VLG2    .    .    .    .   6.7 28.0 63.2 65.6 21.2  .    .    .  184.8
2013 1 VCOA    .    .    .    .  12.7 52.8 119.1 123.6 40.0  .    .    .  348.2
2014 2 VLG2    .    .    .    .    .  13.5 56.1 126.4 131.2 42.4  .    .  369.7
2014 1 VCOA    .    .    .    .    .  12.7 52.8 119.1 123.6 40.0  .    .  348.2
2015 1 VLG2    .    .    .    .    .    .   6.7 28.0 63.2 65.6 21.2  .  184.8
2015 1 NUCL    .    .    .    .  37.8 37.8 75.6 113.4 226.8 189.0 75.6  .  756.1
2016 1 VCOA    .    .    .    .    .    .    .  12.7 52.8 119.1 123.6 40.0  348.2

 END TOTAL  474.3    480.1    551.7    676.2    741.3    510.5
         452.3    487.1    556.2    687.9    597.6    294.6
```

```
                                                    PAGE 56

  FOREIGN CONSTRUCTION COSTS (MILLION $) (CONTD.)

YEAR # PLANT 2010 2011 2012 2013 2014 2015 2016   SUM

2017 1 VLG2    .    .   6.7 28.0 63.2 65.6 21.2  184.8
2017 1 NUCL  37.8 37.8 75.6 113.4 226.8 189.0 75.6  756.1

 END TOTAL  676.2    741.3    510.5    96.8
         687.9    597.6    294.6    9302.2
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

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                                              PAGE 57

  DOMESTIC INT. DURING CONSTR. (MILLION $)

YEAR # PLANT 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008   SUM

2001 1 V-CC   .  0.8  6.6 14.8  .    .    .    .    .    .    .    .    22.2
2002 2 V-CC   .    .  1.6 13.1 29.7  .    .    .    .    .    .    .    44.5
2002 1 VHY1  0.1  0.8  2.7  5.4  7.7  .    .    .    .    .    .    .    16.7
2003 1 V-CC   .    .    .  0.8  6.6 14.8  .    .    .    .    .    .    22.2
2003 1 VHY2  0.2  0.8  2.8  6.8 11.5 14.8  .    .    .    .    .    .    36.9
2004 1 VHY3   .  0.7  3.1 10.3 25.6 43.3 55.3  .    .    .    .    .   138.3
2005 1 VCOA   .    .    .  0.4  2.6  8.6 17.5 24.8  .    .    .    .    53.9
2005 1 VHY4   .    .    .  0.2  1.5  5.0 10.2 14.4  .    .    .    .    31.4
2006 1 NUCL   .    .  0.8  3.3  7.7 14.1 22.8 31.6 38.8  .    .    .   119.0
2007 1 VCOA   .    .    .    .    .  0.4  2.6  8.6 17.5 24.8  .    .    53.9
2008 1 VCOA   .    .    .    .    .    .  0.4  2.6  8.6 17.5 24.8  .    53.9
2009 1 VLG1   .    .    .    .    .    .    .  0.2  1.5  5.0 10.1 14.3  31.2
2009 1 VCOA   .    .    .    .    .    .    .  0.4  2.6  8.6 17.5 24.8  53.9

 END TOTAL   0.3    17.5    92.9    108.9    72.7    75.7
          3.1    55.4    100.9    83.4    66.1    84.8
```

```
                                              PAGE 58

  DOMESTIC INT. DURING CONSTR. (MILLION $) (CONTD.)

YEAR # PLANT 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015   SUM

2010 1 VCOA   .  0.4  2.6  8.6 17.5 24.8  .    .    .    .    .    .    53.9
2011 1 NUCL  0.8  3.3  7.7 14.1 22.8 31.6 38.8  .    .    .    .    .   119.0
2012 1 VLG2   .    .    .  0.2  1.4  4.5  9.3 13.1  .    .    .    .    28.6
2012 1 VCOA   .    .    .  0.4  2.6  8.6 17.5 24.8  .    .    .    .    53.9
2013 1 VLG2   .    .    .    .  0.2  1.4  4.5  9.3 13.1  .    .    .    28.6
2013 1 VCOA   .    .    .    .  0.4  2.6  8.6 17.5 24.8  .    .    .    53.9
2014 2 VLG2   .    .    .    .    .  0.4  2.8  9.1 18.6 26.3  .    .    57.2
2014 1 VCOA   .    .    .    .    .  0.4  2.6  8.6 17.5 24.8  .    .    53.9
2015 1 VLG2   .    .    .    .    .    .  0.2  1.4  4.5  9.3 13.1  .    28.6
2015 1 NUCL   .    .    .    .  0.8  3.3  7.7 14.1 22.8 31.6 38.8  .   119.0
2016 1 VCOA   .    .    .    .    .    .    .  0.4  2.6  8.6 17.5 24.8  53.9

 END TOTAL  83.4    66.1    84.8    92.8    111.8    96.8
          72.7    75.7    77.6    101.6    115.9    65.6
```

```
                                              PAGE 59

  DOMESTIC INT. DURING CONSTR. (MILLION $) (CONTD.)

YEAR # PLANT 2010 2011 2012 2013 2014 2015 2016   SUM

2017 1 VLG2   .    .  0.2  1.4  4.5  9.3 13.1  28.6
2017 1 NUCL  0.8  3.3  7.7 14.1 22.8 31.6 38.8  119.0

 END TOTAL  92.8    111.8    96.8    51.9
         101.6    115.9    65.6    1475.7
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

```
                                      PAGE 60

  FOREIGN INT. DURING CONSTR. (MILLION $)

YEAR # PLANT 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008   SUM

2001 1 V-CC   .  1.2  9.9 22.3  .    .    .    .    .    .    .    .    33.3
2002 2 V-CC   .    .  2.4 19.7 44.5  .    .    .    .    .    .    .    66.7
2002 1 VHY1  0.1  0.8  2.7  5.4  7.7  .    .    .    .    .    .    .    16.7
2003 1 V-CC   .    .    .  1.2  9.9 22.3  .    .    .    .    .    .    33.3
2003 1 VHY2  0.2  0.8  2.8  6.8 11.5 14.8  .    .    .    .    .    .    36.9
2004 1 VHY3   .  0.7  3.1 10.3 25.6 43.3 55.3  .    .    .    .    .   138.3
2005 1 VCOA   .    .    .  0.6  3.9 12.9 26.3 37.2  .    .    .    .    80.9
2005 1 VHY4   .    .    .  0.2  1.5  5.0 10.2 14.4  .    .    .    .    31.4
2006 1 NUCL   .    .  1.9  5.8 12.0 22.7 41.9 66.9 86.9  .    .    .   238.0
2007 1 VCOA   .    .    .    .    .  0.6  3.9 12.9 26.3 37.2  .    .    80.9
2008 1 VCOA   .    .    .    .    .    .  0.6  3.9 12.9 26.3 37.2  .    80.9
2009 1 VLG1   .    .    .    .    .    .    .  0.4  2.3  7.4 15.2 21.5  46.8
2009 1 VCOA   .    .    .    .    .    .    .  0.6  3.9 12.9 26.3 37.2  80.9

 END TOTAL   0.3    22.7    116.7    138.3    138.7    115.2
           3.5    72.5    121.5    138.1    99.7    135.7


                                      PAGE 61

  FOREIGN INT. DURING CONSTR. (MILLION $) (CONTD.)

YEAR # PLANT 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015   SUM

2010 1 VCOA   .  0.6  3.9 12.9 26.3 37.2  .    .    .    .    .    .    80.9
2011 1 NUCL  1.9  5.8 12.0 22.7 41.9 66.9 86.9  .    .    .    .    .   238.0
2012 1 VLG2   .    .    .  0.3  2.1  6.8 14.0 19.7  .    .    .    .    42.9
2012 1 VCOA   .    .    .  0.6  3.9 12.9 26.3 37.2  .    .    .    .    80.9
2013 1 VLG2   .    .    .    .  0.3  2.1  6.8 14.0 19.7  .    .    .    42.9
2013 1 VCOA   .    .    .    .  0.6  3.9 12.9 26.3 37.2  .    .    .    80.9
2014 2 VLG2   .    .    .    .    .  0.7  4.2 13.7 27.9 39.5  .    .    85.9
2014 1 VCOA   .    .    .    .    .  0.6  3.9 12.9 26.3 37.2  .    .    80.9
2015 1 VLG2   .    .    .    .    .    .  0.3  2.1  6.8 14.0 19.7  .    42.9
2015 1 NUCL   .    .    .    .  1.9  5.8 12.0 22.7 41.9 66.9 86.9  .   238.0
2016 1 VCOA   .    .    .    .    .    .    .  0.6  3.9 12.9 26.3 37.2  80.9

 END TOTAL  138.1    99.7    135.7    169.2    176.1    181.6
          138.7    115.2    136.9    154.9    195.1    118.0


                                      PAGE 62

  FOREIGN INT. DURING CONSTR. (MILLION $) (CONTD.)

YEAR # PLANT 2010 2011 2012 2013 2014 2015 2016   SUM

2017 1 VLG2   .    .  0.3  2.1  6.8 14.0 19.7  42.9
2017 1 NUCL  1.9  5.8 12.0 22.7 41.9 66.9 86.9  238.0

 END TOTAL  169.2    176.1    181.6    106.6
          154.9    195.1    118.0    2341.1
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

```
                                                PAGE 63

  DOMESTIC CONSTRUCTION & IDC (MILLION $)

YEAR # PLANT 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008   SUM

2001 1 V-CC    .  17.3 105.0 67.9  .    .    .    .    .    .    .    .  190.3
2002 2 V-CC    .    .  34.6 210.1 135.9  .    .    .    .    .    .    .  380.6
2002 1 VHY1  2.8 11.7 27.3 31.0 15.9  .    .    .    .    .    .    .   88.7
2003 1 V-CC    .    .    .  17.3 105.0 67.9  .    .    .    .    .    .  190.3
2003 1 VHY2  3.8  9.9 30.8 55.0 43.7 23.7  .    .    .    .    .    .  167.0
2004 1 VHY3    .  14.4 37.2 115.6 206.1 163.7 88.9  .    .    .    .    .  625.9
2005 1 VCOA    .    .    .  8.9 37.8 87.9 99.9 51.4  .    .    .    .  285.9
2005 1 VHY4    .    .    .  5.2 22.1 51.3 58.3 30.0  .    .    .    .  166.8
2006 1 NUCL    .    .  17.0 35.7 56.3 78.9 103.8 80.2 71.2  .    .    .  443.1
2007 1 VCOA    .    .    .    .    .  8.9 37.8 87.9 99.9 51.4  .    .  285.9
2008 1 VCOA    .    .    .    .    .    .  8.9 37.8 87.9 99.9 51.4  .  285.9
2009 1 VLG1    .    .    .    .    .    .    .  5.1 21.9 50.9 57.8 29.8  165.6
2009 1 VCOA    .    .    .    .    .    .    .  8.9 37.8 87.9 99.9 51.4  285.9

 END TOTAL   6.6    252.0    622.7    397.5    363.3    389.5
          53.4    546.6    482.4    318.3    384.2    373.3

                                                PAGE 64

  DOMESTIC CONSTRUCTION & IDC (MILLION $) (CONTD.)

YEAR # PLANT 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015   SUM

2010 1 VCOA    .  8.9 37.8 87.9 99.9 51.4  .    .    .    .    .    .  285.9
2011 1 NUCL  17.0 35.7 56.3 78.9 103.8 80.2 71.2  .    .    .    .    .  443.1
2012 1 VLG2    .    .    .  4.7 20.1 46.6 53.0 27.3  .    .    .    .  151.7
2012 1 VCOA    .    .    .  8.9 37.8 87.9 99.9 51.4  .    .    .    .  285.9
2013 1 VLG2    .    .    .    .  4.7 20.1 46.6 53.0 27.3  .    .    .  151.7
2013 1 VCOA    .    .    .    .  8.9 37.8 87.9 99.9 51.4  .    .    .  285.9
2014 2 VLG2    .    .    .    .    .  9.4 40.1 93.3 106.0 54.5  .    .  303.3
2014 1 VCOA    .    .    .    .    .  8.9 37.8 87.9 99.9 51.4  .    .  285.9
2015 1 VLG2    .    .    .    .    .    .  4.7 20.1 46.6 53.0 27.3  .  151.7
2015 1 NUCL    .    .    .    .  17.0 35.7 56.3 78.9 103.8 80.2 71.2  .  443.1
2016 1 VCOA    .    .    .    .    .    .    .  8.9 37.8 87.9 99.9 51.4  285.9

 END TOTAL  318.3    384.2    373.3    514.5    533.7    348.8
         363.3    389.5    378.0    556.2    425.9    184.5

                                                PAGE 65

  DOMESTIC CONSTRUCTION & IDC (MILLION $) (CONTD.)

YEAR # PLANT 2010 2011 2012 2013 2014 2015 2016   SUM

2017 1 VLG2    .    .  4.7 20.1 46.6 53.0 27.3  151.7
2017 1 NUCL  17.0 35.7 56.3 78.9 103.8 80.2 71.2  443.1

 END TOTAL  514.5    533.7    348.8    98.5
         556.2    425.9    184.5    7230.0
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

PAGE 66

FOREIGN CONSTRUCTION & IDC (MILLION $)

YEAR	#	PLANT	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	SUM
2001	1	V-CC	.	26.0	157.6	101.9	.	.	.	.	.	.	.	.	285.4
2002	2	V-CC	.	.	51.9	315.1	203.8	.	.	.	.	.	.	.	570.9
2002	1	VHY1	2.8	11.7	27.3	31.0	15.9	.	.	.	.	.	.	.	88.7
2003	1	V-CC	.	.	.	26.0	157.6	101.9	.	.	.	.	.	.	285.4
2003	1	VHY2	3.8	9.9	30.8	55.0	43.7	23.7	.	.	.	.	.	.	167.0
2004	1	VHY3	.	14.4	37.2	115.6	206.1	163.7	88.9	.	.	.	.	.	625.9
2005	1	VCOA	.	.	.	13.3	56.8	132.0	149.9	77.1	.	.	.	.	429.1
2005	1	VHY4	.	.	.	5.2	22.1	51.3	58.3	30.0	.	.	.	.	166.8
2006	1	NUCL	.	.	39.7	43.6	87.7	136.1	268.7	255.9	162.5	.	.	.	994.2
2007	1	VCOA	.	.	.	.	.	13.3	56.8	132.0	149.9	77.1	.	.	429.1
2008	1	VCOA	.	.	.	.	.	.	13.3	56.8	132.0	149.9	77.1	.	429.1
2009	1	VLG1	.	.	.	.	.	.	.	7.7	32.9	76.4	86.8	44.6	248.4
2009	1	VCOA	.	.	.	.	.	.	.	13.3	56.8	132.0	149.9	77.1	429.1

END TOTAL 6.6 344.5 793.5 635.9 590.9 602.3
62.0 706.7 622.0 612.4 579.8 687.3

PAGE 67

FOREIGN CONSTRUCTION & IDC (MILLION $) (CONTD.)

YEAR	#	PLANT	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	SUM
2010	1	VCOA	.	13.3	56.8	132.0	149.9	77.1	.	.	.	.	.	.	429.1
2011	1	NUCL	39.7	43.6	87.7	136.1	268.7	255.9	162.5	.	.	.	.	.	994.2
2012	1	VLG2	.	.	.	7.1	30.1	70.1	79.6	40.9	.	.	.	.	227.8
2012	1	VCOA	.	.	.	13.3	56.8	132.0	149.9	77.1	.	.	.	.	429.1
2013	1	VLG2	.	.	.	.	7.1	30.1	70.1	79.6	40.9	.	.	.	227.8
2013	1	VCOA	.	.	.	.	13.3	56.8	132.0	149.9	77.1	.	.	.	429.1
2014	2	VLG2	.	.	.	.	.	14.2	60.3	140.1	159.1	81.9	.	.	455.5
2014	1	VCOA	.	.	.	.	.	13.3	56.8	132.0	149.9	77.1	.	.	429.1
2015	1	VLG2	.	.	.	.	.	.	7.1	30.1	70.1	79.6	40.9	.	227.8
2015	1	NUCL	.	.	.	.	39.7	43.6	87.7	136.1	268.7	255.9	162.5	.	994.2
2016	1	VCOA	.	.	.	.	.	.	.	13.3	56.8	132.0	149.9	77.1	429.1

END TOTAL 612.4 579.8 687.3 845.4 917.3 692.1
590.9 602.3 693.1 842.8 792.7 412.6

PAGE 68

FOREIGN CONSTRUCTION & IDC (MILLION $) (CONTD.)

YEAR	#	PLANT	2010	2011	2012	2013	2014	2015	2016	SUM
2017	1	VLG2	.	.	7.1	30.1	70.1	79.6	40.9	227.8
2017	1	NUCL	39.7	43.6	87.7	136.1	268.7	255.9	162.5	994.2

END TOTAL 845.4 917.3 692.1 203.4
842.8 792.7 412.6 11643.3

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

CAPITAL CASH FLOW SUMMARY OF CANDIDATES (MILLION $)

YEAR	FUEL DOM.	FUEL FOR.	FUEL TOTAL	CONSTRUCTION DOM.	CONSTRUCTION FOR.	CONSTRUCTION TOTAL	IDC DOM.	IDC FOR.	IDC TOTAL	GR. TOT.
1997	0.00	0.00	0.00	6.29	6.29	12.59	0.31	0.31	0.62	13.21
1998	0.00	0.00	0.00	50.26	58.50	108.76	3.13	3.54	6.67	115.43
1999	0.00	0.00	0.00	234.45	321.78	556.22	17.53	22.69	40.22	596.44
2000	0.00	0.00	0.00	491.25	634.15	1125.40	55.36	72.50	127.86	1253.26
2001	0.00	0.00	0.00	529.85	676.81	1206.66	92.89	116.72	209.61	1416.27
2002	0.00	0.00	0.00	381.43	500.57	882.01	100.94	121.45	222.39	1104.40
2003	0.00	0.00	0.00	288.65	497.59	786.24	108.89	138.27	247.16	1033.40
2004	0.00	0.00	0.00	234.89	474.32	709.21	83.41	138.12	221.53	930.74
2005	0.00	0.00	0.00	290.57	452.25	742.82	72.71	138.70	211.41	954.24
2006	0.00	0.00	0.00	318.09	480.05	798.15	66.09	99.74	165.83	963.98
2007	0.00	0.00	0.00	313.80	487.09	800.89	75.71	115.16	190.87	991.76
2008	0.00	0.00	0.00	288.45	551.67	840.12	84.83	135.66	220.49	1060.61
2009	0.00	0.00	0.00	300.41	556.20	856.61	77.60	136.86	214.47	1071.08
2010	0.00	0.00	0.00	421.75	676.24	1098.00	92.78	169.17	261.95	1359.95
2011	0.00	0.00	0.00	454.69	687.91	1142.60	101.55	154.87	256.42	1399.02
2012	0.00	0.00	0.00	421.90	741.25	1163.15	111.81	176.08	287.89	1451.05
2013	0.00	0.00	0.00	310.01	597.58	907.60	115.93	195.07	311.00	1218.59
2014	0.00	0.00	0.00	252.01	510.49	762.50	96.75	181.59	278.34	1040.84
2015	0.00	0.00	0.00	118.93	294.60	413.53	65.61	117.99	183.60	597.12
2016	0.00	0.00	0.00	46.53	96.82	143.36	51.92	106.61	158.53	301.89

	FUEL	CONSTRUCTION	IDC	GR. TOT.
DOM.	0.00	5754.24	1475.75	18873.25
FOREIGN	0.00	9302.18	2341.09	
TOTAL	0.00	15056.42	3816.84	

CAPITAL CASH FLOW SUMMARY OF DECIDED SYSTEM (MILLION $)

YEAR	FUEL DOM.	FUEL FOR.	FUEL TOTAL	CONSTRUCTION DOM.	CONSTRUCTION FOR.	CONSTRUCTION TOTAL	IDC DOM.	IDC FOR.	IDC TOTAL	GR. TOT.
1994	0.00	0.00	0.00	34.80	34.80	69.60	3.47	3.48	6.95	76.55
1995	0.00	0.00	0.00	70.60	93.30	163.90	10.93	13.11	24.03	187.93
1996	0.00	0.00	0.00	112.70	140.70	253.40	23.22	28.50	51.72	305.12
1997	0.00	0.00	0.00	72.60	101.10	173.70	32.78	41.51	74.29	247.99
1998	0.00	0.00	0.00	54.70	78.90	133.60	41.57	53.60	95.17	228.77

	FUEL	CONSTRUCTION	IDC	GR. TOT.
DOM.	0.00	345.40	111.97	1046.35
FOREIGN	0.00	448.80	140.18	
TOTAL	0.00	794.20	252.15	

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

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                                            PAGE 71

GLOBAL CAPITAL CASH FLOW SUMMARY (MILLION $)

      FUEL        CONSTRUCTION         IDC
YEAR  DOM.  FOR.  TOTAL  DOM.  FOR.  TOTAL  DOM.  FOR.  TOTAL GR. TOT.

1994  0.00  0.00  0.00  34.80  34.80  69.60  3.47  3.48  6.95   76.55
1995  0.00  0.00  0.00  70.60  93.30 163.90  10.93  13.11  24.03  187.93
1996  0.00  0.00  0.00 112.70 140.70 253.40  23.22  28.50  51.72  305.12
1997  0.00  0.00  0.00  78.89 107.39 186.29  33.09  41.82  74.90  261.19
1998  0.00  0.00  0.00 104.96 137.40 242.36  44.71  57.13 101.84  344.20
1999  0.00  0.00  0.00 234.45 321.78 556.22  17.53  22.69  40.22  596.44
2000  0.00  0.00  0.00 491.25 634.15 1125.40  55.36  72.50 127.86  1253.26
2001  0.00  0.00  0.00 529.85 676.81 1206.66  92.89 116.72 209.61  1416.27
2002  0.00  0.00  0.00 381.43 500.57 882.01 100.94 121.45 222.39  1104.40
2003  0.00  0.00  0.00 288.65 497.59 786.24 108.89 138.27 247.16  1033.40
2004  0.00  0.00  0.00 234.89 474.32 709.21  83.41 138.12 221.53  930.74
2005  0.00  0.00  0.00 290.57 452.25 742.82  72.71 138.70 211.41  954.24
2006  0.00  0.00  0.00 318.09 480.05 798.15  66.09  99.74 165.83  963.98
2007  0.00  0.00  0.00 313.80 487.09 800.89  75.71 115.16 190.87  991.76
2008  0.00  0.00  0.00 288.45 551.67 840.12  84.83 135.66 220.49  1060.61
2009  0.00  0.00  0.00 300.41 556.20 856.61  77.60 136.86 214.47  1071.08
2010  0.00  0.00  0.00 421.75 676.24 1098.00  92.78 169.17 261.95  1359.95
2011  0.00  0.00  0.00 454.69 687.91 1142.60 101.55 154.87 256.42  1399.02
2012  0.00  0.00  0.00 421.90 741.25 1163.15 111.81 176.08 287.89  1451.05
2013  0.00  0.00  0.00 310.01 597.58 907.60 115.93 195.07 311.00  1218.59
2014  0.00  0.00  0.00 252.01 510.49 762.50  96.75 181.59 278.34  1040.84
2015  0.00  0.00  0.00 118.93 294.60 413.53  65.61 117.99 183.60  597.12
2016  0.00  0.00  0.00  46.53  96.82 143.36  51.92 106.61 158.53  301.89

DOM.  0.00          6099.64          1587.72          19919.61
FOREIGN     0.00          9750.98          2481.27
TOTAL          0.00          15850.62          4068.99
```

Figure 9.2. REPROBAT printout for the optimal solution of DEMOCASE (cont.).

9.4. SPECIAL REMARKS ON THE REPROBAT CAPABILITIES

Table 1.1 summarizes the principal capabilities of the WASP-IV code. They concern mainly the abilities of Modules 1 to 6 and the limits to carry out a planning study for an electric power system. In principle, the same limits are also applicable for REPROBAT with the following exceptions:

(1) Capital cost data (record type-2 and type-2a of DYNPRO) can also be changed, but only 10 times throughout the study period in the respective DYNPRO run (but only the first set is reported under option 6).

(2) Construction time of decided (committed) plants to be specified in type-7 data records can extend up to 10 years. In addition, only up to twenty thermal units and hydro/P-S projects of the decided system can be considered in the REPROBAT report.

These limitations arise from the capability of REPROBAT to handle and store information on the temporary working files.

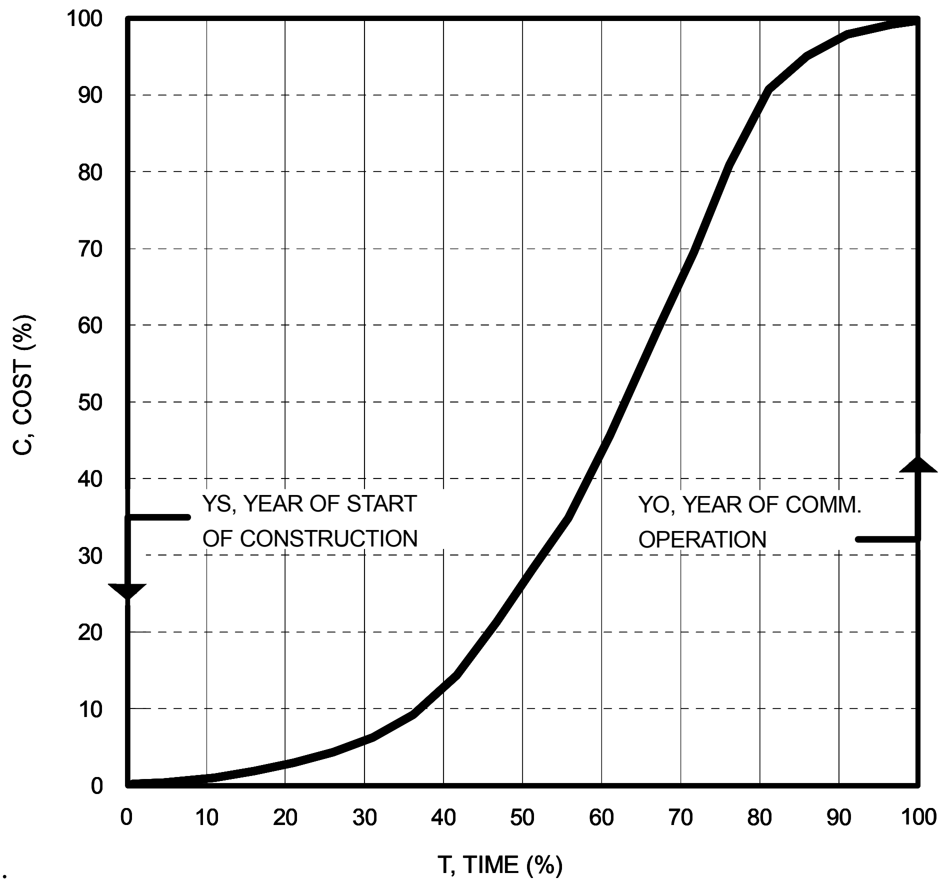
Concerning the cash flow on construction costs reported by REPROBAT for the expansion candidates added by the DYNPRO solution (see Pages 51–68 of Fig. 9.2), this information is calculated by the program using the plant data on capital cost given in DYNPRO. The yearly expenditures are then calculated based on either a cost distribution with time provided by the user or an internal cost distribution function (see below) used as default.

For the default option, the program calculates first the total investment cost of the plant as: unitary investment cost of the plant ($/kW) times plant size (MW) times 1000. Then, this is separated into pure construction cost and IDC cost deducted from the total cost; the percentage of IDC specified in DYNPRO for this plant. The distribution of these costs (domestic and foreign components separately) over the construction period of the plant is carried out by REPROBAT assuming an "S" curve shape for the function relating expenditures to time as shown in Figure 9.3. The distribution of IDC requires in addition the specification of an interest rate. This is assumed by REPROBAT to be equal to the discount rate on capital costs used in DYNPRO. Table 9.2 gives the resulting IDC percentages for different interest rates and construction periods as calculated using the expenditure versus time function of Figure 9.3. The values shown in Table 9.2 are to be used in the DYNPRO run for the case being studied if it is required that the REPROBAT report gives the correct distribution between pure construction and IDC costs.

Alternatively, the user may specify the annual distribution (%) of the pure construction costs over the years of the construction period of the plant and the program will simply calculate the corresponding annual IDC like shown in Table 9.3 (see use of type-8 records).

In each case, the total investment cost to be considered is escalated to the year of start of operation of the plant using the cost escalation information provided in the DYNPRO run.

If for the case under study, the user provides capital cost estimates of the expansion alternatives not calculated under the same assumptions above mentioned and if these data are used in DYNPRO, it will be necessary to provide the corresponding cost distribution data to REPROBAT to guarantee consistency of the report.



$$T = f(C) = a_0 + a_1 * C + a_2 * C^2 + a_3 * C^3 + a_4 * C^4 + a_5 * C^5 + a_6 * C^6 + a_7 * C^7$$

a_0 =	+0.72954	a_4 =	$-7.36442 * 10^{-4}$
a_1 =	+7.17832	a_5 =	$+1.00715 * 10^{-4}$
a_2 =	$-6.16794 * 10^{-1}$	a_6 =	$-7.02449 * 10^{-8}$
a_3 =	$+2.91329 * 10^{-2}$	a_7 =	$+1.95903 * 10^{-10}$

Figure 9.3. Plant capital investment expenditure against time ("S" curve shape).

It should be noticed that the optimization process is not affected since DYNPRO only considers total construction cost of the plants being added. If the estimates of pure construction cost for a particular expansion candidate are known but its distribution along the construction period is not available, the user may proceed with either of the following approaches[3]:

(a) Use of the "S" curve approximation: In this case, for the REPROBAT results to be consistent with the DYNPRO input data, it would be necessary that the user calculates the total capital investment cost using the values of Table 9.3. To do so, the percentage of IDC on Table 9.3 (for the respective construction period and interest rate considered) must be added to the pure construction cost data to calculate the actual construction cost to be given in DYNPRO, and the corresponding %IDC must be taken from Table 9.2. In effect Tables 9.2 and 9.3 are interrelated as follows:

$$\frac{\%IDC(Table9.3)}{1.0+[\frac{\%IDC(Table9.3)}{100.0}]} = \%IDC(Table9.2)$$

As an example, let us assume that the estimate of pure construction cost for a 1000 MW plant is 1000 x 10^6 \$; a 5-years construction period and that the applicable interest rate is 11%. From Table 9.3, the percentage of IDC cost to be added to estimates of pure construction costs is 26.47% for the construction period and the interest rate assumed. Thus, the total construction cost and respective %IDC to be used for this plant in DYNPRO are:

$$\text{Construction Cost} = \frac{1000*10^6*(1.0+0.2647)\$}{1000*10^3\,kW} = 1264.7\$/kW$$

$$\%IDC = 20.93(Table9.2) = \frac{26.47}{(1.0+0.2647)}$$

(b) User-defined distribution: In this case, the user can estimate the total IDC for the given construction period and interest rate based on experience for similar projects already in operation or under construction. Then, calculate the total investment cost of the unit (or hydro/P-S project) and give this as input data to DYNPRO. Prepare a fixed expansion run of CONGEN-MERSIM-DYNPRO in which the given plant or project is added in a given year. Then run REPROBAT giving as input data an estimated capital cost distribution versus time for the plant and review the results to ensure that the total calculated IDC are in agreement with the specified values in DYNPRO.

Alternatively, the user can calculate the annual (and total) IDC corresponding to a given annual distribution of costs following the same procedure as the one that is used in REPROBAT.

[3] Note that this process should be done during the phase of Fixed Expansion Runs of WASP-IV for the case study that is during the phase of definition of the data that will be retained for the overall expansion runs.

Table 9.2. Interest during construction (IDC) in percent of total construction cost (Input of DYNPRO)

Construction Period (Years)	Interest Rate										
	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
1.0	2.08	2.49	2.90	3.31	3.71	4.11	4.51	4.90	5.30	5.69	6.08
1.5	3.11	3.72	4.33	4.93	5.52	6.11	6.70	7.28	7.86	8.43	9.00
2.0	4.13	4.94	5.74	6.52	7.31	8.08	8.85	9.61	10.37	11.11	11.85
2.5	5.15	6.14	7.13	8.10	9.07	10.02	10.96	11.89	12.82	13.73	14.63
3.0	6.15	7.33	8.50	9.66	10.80	11.92	13.03	14.13	15.21	16.28	17.34
3.5	7.14	8.51	9.86	11.19	12.50	13.79	15.06	16.32	17.56	18.77	19.98
4.0	8.13	9.68	11.20	12.70	14.18	15.63	17.06	18.46	19.85	21.21	22.54
4.5	9.11	10.83	12.53	14.19	15.83	17.44	19.01	20.56	22.08	23.58	25.05
5.0	10.08	11.98	13.84	15.67	17.46	19.21	20.93	22.62	24.27	25.89	27.48
5.5	11.04	13.11	15.13	17.12	19.06	20.96	22.81	24.63	26.41	28.15	29.85
6.0	11.99	14.23	16.41	18.55	20.63	22.67	24.66	26.60	28.50	30.35	32.16
6.5	12.94	15.33	17.68	19.96	22.18	24.35	26.47	28.53	30.54	32.49	34.40
7.0	13.87	16.43	18.92	21.35	23.71	26.00	28.24	30.41	32.53	34.58	36.58
7.5	14.80	17.52	20.15	22.72	25.21	27.63	29.98	32.26	34.47	36.62	38.71
8.0	15.72	18.59	21.37	24.07	26.69	29.22	31.68	34.06	36.37	38.61	40.77
8.5	16.63	19.65	22.57	25.40	28.14	30.79	33.35	35.83	38.22	40.54	42.78
9.0	17.54	20.70	23.76	26.71	29.57	32.32	34.98	37.55	40.03	42.42	44.73
9.5	18.43	21.74	24.93	28.01	30.97	33.83	36.59	39.24	41.80	44.26	46.62
10.0	19.32	22.77	26.09	29.28	32.36	35.31	38.16	40.89	43.52	46.04	48.46

Table 9.3. Interest during construction (IDC) in percent of pure construction cost

Construction Period (Years)	Interest Rate										
	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
1.0	2.13	2.56	2.99	3.42	3.85	4.29	4.72	5.16	5.59	6.03	6.47
1.5	3.21	3.87	4.52	5.18	5.84	6.51	7.18	7.85	8.53	9.21	9.89
2.0	4.31	5.20	6.08	6.98	7.88	8.79	9.71	10.63	11.56	12.50	13.45
2.5	5.43	6.54	7.67	8.82	9.97	11.13	12.31	13.50	14.70	15.91	17.14
3.0	6.55	7.91	9.29	10.69	12.10	13.54	14.99	16.45	17.94	19.45	20.98
3.5	7.69	9.30	10.94	12.60	14.29	16.00	17.74	19.50	21.29	23.11	24.96
4.0	8.85	10.72	12.62	14.55	16.52	18.53	20.57	22.64	24.76	26.91	29.11
4.5	10.02	12.15	14.32	16.54	18.81	21.12	23.48	25.89	28.34	30.85	33.41
5.0	11.21	13.61	16.06	18.58	21.15	23.78	26.47	29.23	32.05	34.94	37.89
5.5	12.41	15.09	17.83	20.65	23.54	26.51	29.55	32.68	35.89	39.18	42.55
6.0	13.63	16.59	19.64	22.77	25.99	29.31	32.73	36.24	39.85	43.57	47.40
6.5	14.86	18.11	21.47	24.93	28.50	32.19	35.99	39.91	43.96	48.14	52.44
7.0	16.11	19.66	23.34	27.14	31.07	35.14	39.35	43.70	48.21	52.87	57.69
7.5	17.37	21.23	25.24	29.40	33.70	38.17	42.81	47.62	52.61	57.78	63.15
8.0	18.65	22.83	27.18	31.70	36.40	41.29	46.37	51.66	57.16	62.88	68.84
8.5	19.95	24.46	29.15	34.05	39.16	44.48	50.03	55.83	61.87	68.18	74.76
9.0	21.26	26.10	31.16	36.45	41.98	47.76	53.81	60.14	66.75	73.68	80.93
9.5	22.60	27.78	33.21	38.90	44.87	51.13	57.70	64.58	71.81	79.39	87.35
10.0	23.95	29.48	35.30	41.41	47.84	54.59	61.70	69.18	77.04	85.33	94.04

Chapter 10

SEARCH FOR OPTIMAL SOLUTION

10.1. BASIC INFORMATION

The running of the WASP-IV modules requires a certain number of input data which are essential in the search for an optimal expansion schedule for the power system being studied. Table 10.1 depicts in a conceptual way the most important data linked to the WASP module where either these data have to be input or they have an impact on the results. No attempt has been made to include in Table 10.1 all the input data and their corresponding physical units since the full description of each piece of information needed by the WASP modules is contained in the preceding sections.

It should be stressed here the importance of data preparation for the various WASP modules, particularly concerning: the load forecast and load seasonal variation; the hydrological conditions (years of rainfall); the technical and economic characteristics of thermal, hydroelectric and pumped storage plants to be included in FIXSYS, and those for the plants to be used as candidates for system expansion in VARSYS; the construction cost of these expansion candidates; the discount rate(s) on the various types of expenditure; the escalation ratios (if any) on capital and operating costs; the loading order of the plants as required for the simulation of system operation; the acceptable limit for system reliability (reserve margins and the annual LOLP); external constraints (if any) on environmental emissions, fuel availability and energy generation by some plants; etc. All these data must be decided with great care before undertaking a WASP study, since changes introduced later may imply repeating the whole dynamic optimization process; thus, leading to wasting of time.

As mentioned in Chapter 3 through Chapter 9, some data are internally checked by the WASP modules for consistency with data given in other modules, and also to make sure that the capabilities of the program for storing information (i.e. the dimensions of the respective variables in the program) are not exceeded (see Chapter 13 for description of the corresponding checks). However, a large amount of input data is simply read (and used) by the computer as it appears on the respective data record. Therefore, it is very important to check carefully all printouts produced by the WASP modules especially during the debugging phase of data records of WASP treated in the following section.

10.2. INPUT DATA VALIDATION AND DEBUGGING: RUNNING A PREDETERMINED EXPANSION PLAN

It is recommended that the input data validation and debugging of the WASP modules be done running a predetermined expansion plan, in other words, running WASP for an expansion plan composed of only one configuration of the system for every year in the study period. Figure 10.1 is a flow chart of this procedure, in which a symbol indicates the appropriate points for user-machine interaction. Table 10.2 stresses additional points to be kept in mind when running the various WASP modules for the input data validation and debugging.

It is important to remember that modules LOADSY, FIXSYS and VARSYS are all independent between each other so that they can be run in any order, but they must be run before the first CONGEN run. Besides, once modules LOADSY, FIXSYS and VARSYS are debugged and found correct, there is no need to run any of them again, unless inconsistency or incorrectness in the data were detected when running CONGEN, MERSIM, DYNPRO or REPROBAT.

Table 10.1. Most important data for WASP-IV computer runs

TYPE OF DATA	LOADSY	FIXSYS	VARSYS	CONGEN	MERSIM	DYNPRO	REPROBAT
LOAD FORECAST							
First year of study	X	X	-	X	X	X	X
Study period	X	X	-	X	X	X	X
Number of periods per year	X	X	X	X	X	X	X
Load duration curves	X	-	-	-	X	-	-
Maximum demands	X	-	-	X	X	-	X
Seasonal multipliers of peak demands	X	-	-	X	X	-	-
HYDROELECTRIC PROJECTS							
Number of hydro conditions	-	X	X	-	X	X	X
Probability of hydro conditions	-	X	X	-	X	-	-
Technical data	-	X	X	X	X	-	X
Grouping of hydro projects	-	X	X	-	X	-	X
Preferred sequences of hydro projects	-	-	X	X	-	X	X
Addition or retirement of projects	-	X	-	X	X	-	X
Spinning reserve capabilities	-	-	-	-	X	-	-
THERMOELECTRIC UNITS							
Technical data	-	X	X	X	X	-	X
Fuel types, heat contents	-	X	X	-	X	-	X
Maintenance requirements	-	X	X	-	X	-	-
Forced outages	-	X	X	-	X	-	-
Spinning reserve capabilities	-	X	X	-	X	-	-
Addition/retirement of units	-	X	-	X	X	-	X
SYSTEM ECONOMICS							
L.O. order of thermal plants	-	-	-	-	X	-	-
Fuel costs	-	X	X	-	X	X	X
O&M (non-fuel) costs	-	X	X	-	X	X	X
Capital investment costs	-	-	-	-	-	X	X
Interest during construction	-	-	-	-	-	X	X
Plant economic life	-	-	-	-	-	X	X
Construction periods	-	-	-	-	-	X	X
Depreciation option	-	-	-	-	-	X	-
Cost of energy not served	-	-	-	-	-	X	X
Reference date for present worth calculations	-	-	-	-	-	X	-
Reference date for calculation of cost escalation	-	-	-	-	-	X	-
Discount rates	-	-	-	-	-	X	X
Escalation rates	-	-	-	-	-	X	X
SYSTEM RELIABILITY							
Maximum and minimum reserve margins	-	-	-	X	-	-	X
LOLP limits	-	-	-	X	-	X	X
Spinning reserve requirements	-	-	-	-	X	-	-
Maximum unit size	-	-	X	X	-	-	-
ACCURACY OF COMPUTATION							
Number of Fourier terms	X	-	-	-	X	-	-
REPORTING OPTIONS	X			X	X	X	X

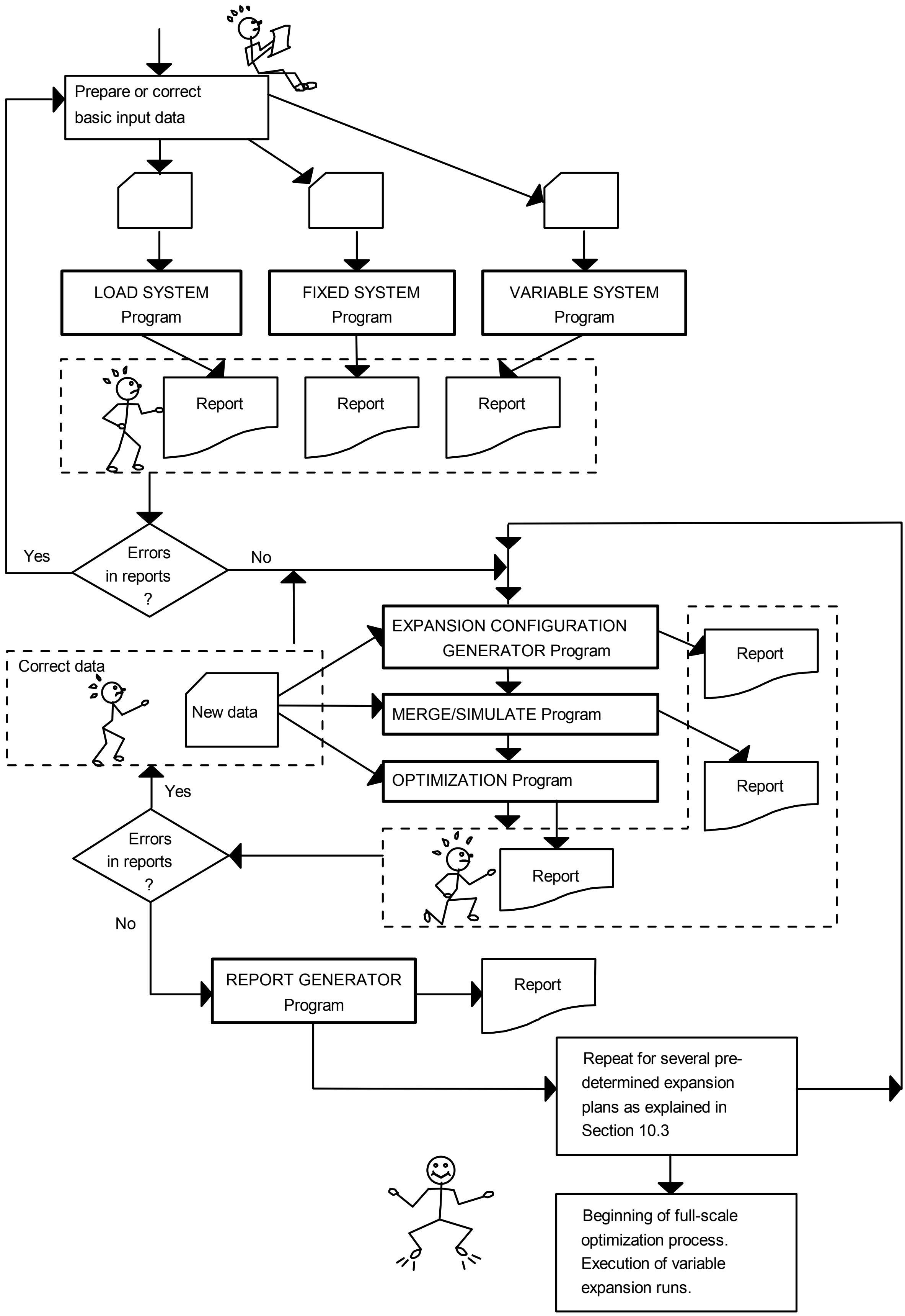


Figure 10.1. User-computer interaction in running the WASP code for a pre-determined expansion plan (adapted from ORNL 73-7759 RI).

Table 10.2. Input data validation and debugging: Running a predetermined expansion plan

STEP	MODULE	OUTPUT OPTIONS REQUIRED			REMARKS
		Printing of:	First run	Last run	
STEP 1	LOADSY	Fourier coef.	Yes	No	These modules can be run in any order.
	FIXSYS	No option	-	-	
	VARSYS	No option	-	-	
STEP 2	REPROBAT	Report options:	LOADSY FIXSYS VARSYS only		To obtain a handy output for quick reference and check of the files from LOADSY through VARSYS.
STEP 3A	REPROBAT	report option: CONGEN only			To document variation of constraints
STEP 3	CONGEN	FIXSYS and VARSYS files	Yes	No	To be run after LOADSY, FIXSYS and VARSYS have been successfully run.
STEP 4	MERSIM	FIXSYS and VARSYS files	Yes	No	To be run after CONGEN has been successfully run
		Results of simulation	Maximum for some years; intermediate for other years and minimum for remaining years	Intermediate for all years	
STEP 5	DYNPRO	VARSYS file	Yes	No	To be run after MERSIM has been successfully run
		Listing of the states considered in the run	Yes	No	
STEP 6	REMERSIM	No printing of FIXSYS and VARSYS files	-	Output maximum for selected years; Intermediate for all;	To be run after last DYNPRO run.
STEP 7	REPROBAT	Full report	-	Yes	To be run after all other modules have been successfully run.

Note: REPROBAT can be run after the STEPS 1 or 3 has been successfully completed but the report output options should obviously cover only those modules already run. To run after STEP 4, it is necessary to run STEP 6 first.

The *first step* is, thus, to run LOADSY (with the option for printing of Fourier coefficients =1), FIXSYS and VARSYS in order to peruse input data and correctness of the results. See Chapters 3, 4 and 5 for the procedures to prepare the input data files and to revise the output report files of these modules. Once the user is satisfied with the results, a last run of these modules (setting in LOADSY the Fourier coefficients printing option = 0) is recommended.

An additional comment must be made regarding the option for the load duration curve (LDC) input data to be used in the LOADSY run(s) for a particular case study. As explained in Chapter 3, the LDC input data for each period can be given optionally, in polynomial form or by points of the curve. If the latter option is used, it is recommended that the user revises the output of LOADSY to check that the energies and load factors calculated by the program from the input representation point-by-point match the respective values calculated by LOADSY using the Fourier series approximation to LDC. If these results are too divergent (difference > 1%), it is suggested to use the polynomial form option for LDC input data. This requires running first any program which calculates the coefficients of the polynomial representing the LDC of the periods.

In spite of the above, the use of the point-by-point option is strongly recommended since this permits a closer representation of the system load duration curve particularly for the points of greatest importance, namely the inflexion at the knee of the base load where generation by baseload plants (the most economic) are to be measured, and the area closer to the peaking portion, where LOLP and ENS will be determined as well as generation by peaking (expensive) units are to be calculated.

The *second step* is to run the REPROBAT module with the output options limited to LOADSY, FIXSYS, and VARSYS in order to make further analysis of the information contained in their respective files (LOADDUCU-, FIXPLANT-, and VARPLANT.BIN). This analysis may still reveal that some additional changes are needed in the data supplied to these modules before proceeding to the next step. See Chapter 9 for preparing the input data file for REPROBAT.

The *third step* is to run the CONGEN module with a pre-determined expansion plan for the system being studied (see Chapter 6 for preparing the CONGEN input data file). The first run of CONGEN should be done using the *maximum* output option, i.e. requesting printing of the FIXSYS and VARSYS files, again to ascertain that these are correct and that they are properly read by the program.

The step 3A can run the REPROBAT module with the output options for CONGEN to check EXPANALT.BIN and document the various attempts for an acceptable fixed expansion plan.

Step 4 is to run the MERSIM module following the procedure explained in Chapter 7. The first MERSIM run should be also executed requesting printing of the FIXSYS and VARSYS files for the same reasons described above for the first CONGEN run. For this first MERSIM run, the user should judge in which years of the study period, maximum, intermediate or minimum outputs of the results of the simulation are necessary for perusal of the correctness of data and results. The printout of the run ought to be revised very carefully as explained in Section 7.3.2, and any error in input data corrected and the program re-run before proceeding to other steps. As a result of this revision, it may be necessary to correct some input data of the preceding WASP modules (and re-run the applicable module(s)).

Great care should be devoted to input a realistic economic loading order of the plants since annual operating costs calculated by MERSIM are function of this L.O. If the multiple group limitations are imposed on the system, meeting these limitations would result in changes in the loading order. The impact of these constraints on units generations should be carefully noted (the detailed information on this will be available in MERSIM1.REP and GROUPLIM.REP files). Several runs may be performed to investigate the effect of varying the number of Fourier terms used in the representation of the inverted load duration curve, upon the calculation of the system's annual operating costs, LOLP and energy not served. A compromise should be reached between accuracy of the results and the computation time required to perform the simulations, by selecting as low a number of Fourier terms as deemed necessary by the user's judgment and experience. A last run in this series would need using only intermediate output option for all years of study (and without requesting printing of FIXSYS and VARSYS files) in order to reduce the size of output report file.

Module DYNPRO is run in the *fifth step*, after MERSIM's last successful run and using the procedure detailed in Chapter 8. As mentioned before, great care should be exercised in checking all economic data and constraints given in this module. It is advisable that, before proceeding to the dynamic optimization phase of the WASP study, the user performs simple hand calculations to total annual production costs for different capacity factors of the plants which are to be used as expansion candidates as illustrated in Table 10.3 for a thermal candidate (NUCL) and a hydro project (VHY3 of HYD1) of DEMOCASE.

For thermal units, calculations are carried out for 0% and 100% of plant capacity factor (all data for these capacity factors are known). Plotting these two values on a graph the curve of annual production costs versus plant capacity factor can be approximated to a straight line as shown in Figure 10.2 for the thermal plants considered as expansion candidates in our sample problem. A graph such as in Fig. 10.2 (usually called Screening Curve[4]) helps the user in checking whether the plants used as expansion candidates are actually competitive (at least theoretically, since operating costs are calculated in MERSIM weighing the results for different hydro conditions by their respective probabilities). For instance, it can be seen in Fig. 10.2 that the nuclear plant (NUCL) is more economical than any other thermal candidate for annual capacity factors greater than 70% (except compared to V-CC, for which it is economical at capacity factor greater than 90%, but the number of units of V-CC that can be added are limited due to other physical constraints assumed for this case); coal plants (VCOA) for capacity factors less than 70%. Break-even points between two plants at a time can also be determined from Fig. 10.2[4]. In the case of hydro, since the simulation module will try to make use of all available hydro energy to off-load thermal plants, the representation of these projects on screening curve becomes a single point (Note that if it were not for this premise in module MERSIM, the theoretical representation of hydro projects on screening curve should be also a straight line parallel to the x-axis, since annual production costs are independent of capacity factors). After plotting the graph for the user's case, obviously those plants which are not actually competitive for a wide range of capacity factors should be eliminated from the list of expansion candidates in the VARSYS module. This is also very important for hydro projects and their respective sequence to be used in VARSYS since the ranking of these projects must be decided by the user.

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[4] The use of Screening Curves is described in detail in Section 6.6 of the publication Electric Generating System Expansion, A Guidebook, IAEA TRS 241, Vienna, 1984.

Step 6 is to be executed if full scope of REPROBAT output is wanted (at least intermediate output for all years and active INDEX 7 or fuel consumption and fuel stock). Same input data as for Step 4 (make sure IOPT > 1 for all years and INDEX 7).

Step 7 Execute REPROBAT to obtain full printout report by activating all/partial output options.

Table 10.3. Example of calculations of total annual production costs using data for DEMOCASE

I. PLANT DATA

Plant		FC	O&M Cost		I	FIC	T
Name	Size (MW)	Fuel Cost at f=100% ($/MWh)	Fixed ($/KW-m)	Variable ($/MWh)	Investment Cost ($/KW)	Fuel Inventory Cost ($/KW)	Life time (years)
NUCL	600	4.8	2.5	0.50	2432.5	0.0	30
VHY3 (HYD1)	650	-	0.55	-	1939.60	-	50

II. CALCULATIONS OF ANNUAL PRODUCTION COSTS [APC ($/kW-year)]

$$(APC)_f = [r]_i^T \text{ x } I + \frac{i \text{ x } (FIC)}{100} + 12 \text{ x } (O\&M_{fixed}) +$$

$$8.76 \text{ x } [(FC)_f + (O\&M_{variable})_f] \text{ x } \frac{f}{100}$$

$$[r]_i^T = \frac{i \text{ x } (1+i)^T}{(1+i)^T - 1}$$

where:

i = annual interest rate (10% in this case)

f = average annual capacity factor of the plant (in %)

$[r]_i^T$ = annual capital recovery factor: (Levelized annual fixed charge rate)

A. For the VNUC Plant

$[r]_{10\%}^{30} = 0.10608$

$(APC)_{f=0\%}$ = 0.10608 x 2432.5 + 12 x 2.5 = 288.04 $/kW/year

$(APC)_{f=100\%}$ = $(APC)_{f=0\%}$ + 8.76 x [4.8 + 0.5] x 1.00 = 334.4 $/KW-year

B. *For the VHY3 hydro project*

The annual available energy in the "normal" year (hydro condition 1 for DEMOCASE) of this project is 2920 GWh. Thus, its average capacity factor (referred to the installed capacity, 650 MW in this case) is 51%.

$[r]_{10\%}^{50} = 0.10086$

$(APC)_{f=51\%}$ = 0.10086 x 1939.60 + 12 x 0.55 = 202.23 $/KW-year

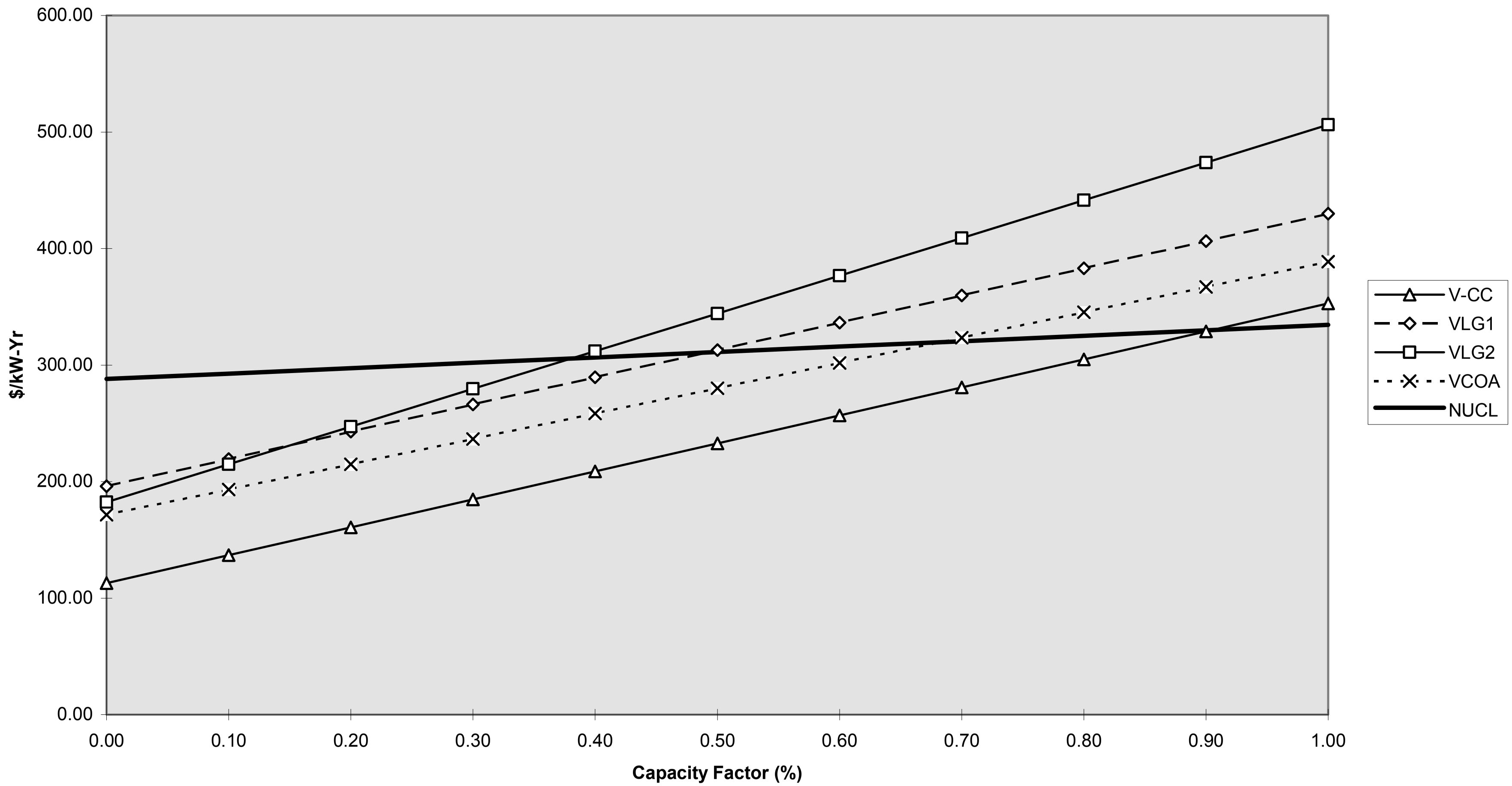


Figure 10.2. Annual production costs versus plant capacity factor of expansion candidates for the sample case. Screening curve.

10.3. EXECUTION OF A SERIES OF WASP RUNS FOR PRE-DETERMINED EXPANSION PLANS

As explained in Chapters 1 and 6, the computer time requirements for a WASP study are highly dependent on the total number of configurations generated throughout the dynamic optimization phase (in the search for the optimal solution for the expansion problem), which in turn depends greatly on the starting point selected by the user for the full-scale dynamic optimization phase of his/her study. Thus, after having executed the WASP runs corresponding to the data validation and debugging of the modules, it is advisable to evaluate a certain number of predetermined expansion patterns of system development to select a favorable area to be used as starting point for the dynamic optimization phase, as shown in Fig. 10.1.

The step required to execute such series of runs is essentially similar to the ones explained in Section 10.2 except for the following (these are summarized in Table 10.4): *Steps 1 and 2* of Section 10.2 are not required since LOADSY, FIXSYS and VARSYS have been already successfully run.

The execution of the CONGEN run (*third step* of Section 10.2) is done without requesting printing of the FIXSYS and VARSYS files since these files have been already checked for the first pre-determined expansion plan. Each new CONGEN should be selected by the user according to own experience and judgement, in order to study several combinations of the candidate plants and to use the WASP modules to evaluate the corresponding costs.

STEP 3A can run the REPROBAT module with only the output option for CONGEN to document the various attempts which led to the series of pre-determined expansion plans.

Step 4 (MERSIM run) is executed following the same procedure as explained in Section 10.2 for the first predetermined expansion plan without requesting printing of the FIXSYS and VARSYS files. For these runs, the intermediate or minimum output options may be asked for, as conveniently.

Step 5 (DYNPRO run) is done without asking for printing of the VARSYS file. After this run, if it is required to keep a record of the REPROBAT report for each satisfying expansion pattern, the REMERSIM module has to be executed (Step 6), following the procedure already described in Section 10.2, before running the REPROBAT module (Step 7). The report options to be asked for in REPROBAT are left to the discretion of the user; however, the LOADSY, FIXSYS and VARSYS reports should be eliminated to reduce the length of the printout.

As mentioned in chapter 2, the execution of various modules of WASP-IV is performed using appropriate batch files, which take care of files assignment (if applicable), execution of the module and restructuring of the output reports. Special care has to be taken for executing the REMERSIM module. Its batch file re-assigns/renames a number of files, which in case of a unsuccessful REMERSIM run have to be restored to the actual names. This can be done by executing the batch file RESFILES.BAT before attempting re-run of REMERSIM.

Table 10.4. Execution of a series of predetermined expansion plans

STEP[1]	MODULE	OUTPUT OPTIONS REQUIRED Printing of:	REMARKS
STEP 1	-	-	Not required
STEP 2	-	-	Not required
STEP 3	CONGEN	FIXSYS and VARSYS files not required.	To be executed after the debugging phase has been completed for all modules.
STEP 3A	REPROBAT	report option: CONGEN only	To document variation of constraints
STEP 4	MERSIM	FIXSYS and VARSYS files not required. Minimum or Intermediate results of simulation for all years as required	To be run after CONGEN has been successfully run.
STEP 5	DYNPRO	VARSYS file not required Listing of states considered in the run may be required (optional)	To be run after MERSIM has been run.
STEP 6	REMERSIM	No printing of FIXSYS and VARSYS files Maximum output for selected years	To be executed after successful run of DYNPRO to obtain detailed reports on group limitations and simulation results.
STEP 7	REPROBAT	Use report options as necessary (e.g. deleting LOADSY, FIXSYS and VARSYS)	Optional To be run after successful run of all modules.

[1] Using same step numbers as Table 10.2

10.4. SEARCH FOR THE OPTIMAL SOLUTION: RUNNING VARIABLE EXPANSION PLANS

Once the series of pre-determined expansion plan runs have been successfully completed, the user can start performing the series of variable expansion plan runs for the dynamic optimization of the system expansion. A flow chart of this procedure is illustrated in Figure 10.3, where the appropriate user-machine interaction points are indicated. Some important points, to be remembered while performing the computer runs, are emphasized in Table 10.5.

The *first step* of the full-scale dynamic optimization process is to prepare a CONGEN run following the procedure explained in Chapter 6, and using the information (starting point) derived from the series of predetermined expansion plan runs. (For execution of CONGEN module for the Variable Expansion case, VCON.BAT file should be used). Great care should be devoted to the selection of tunnel widths for the various candidate thermal plants and hydroelectric and pumped storage projects since too wide tunnel widths will lead to a large number of possible configurations, whereas too-narrow tunnel widths will produce a reduced number of configurations on a limited number of expansion paths. Table 10.6 may be used as a guide for tunnel width selection as described below.

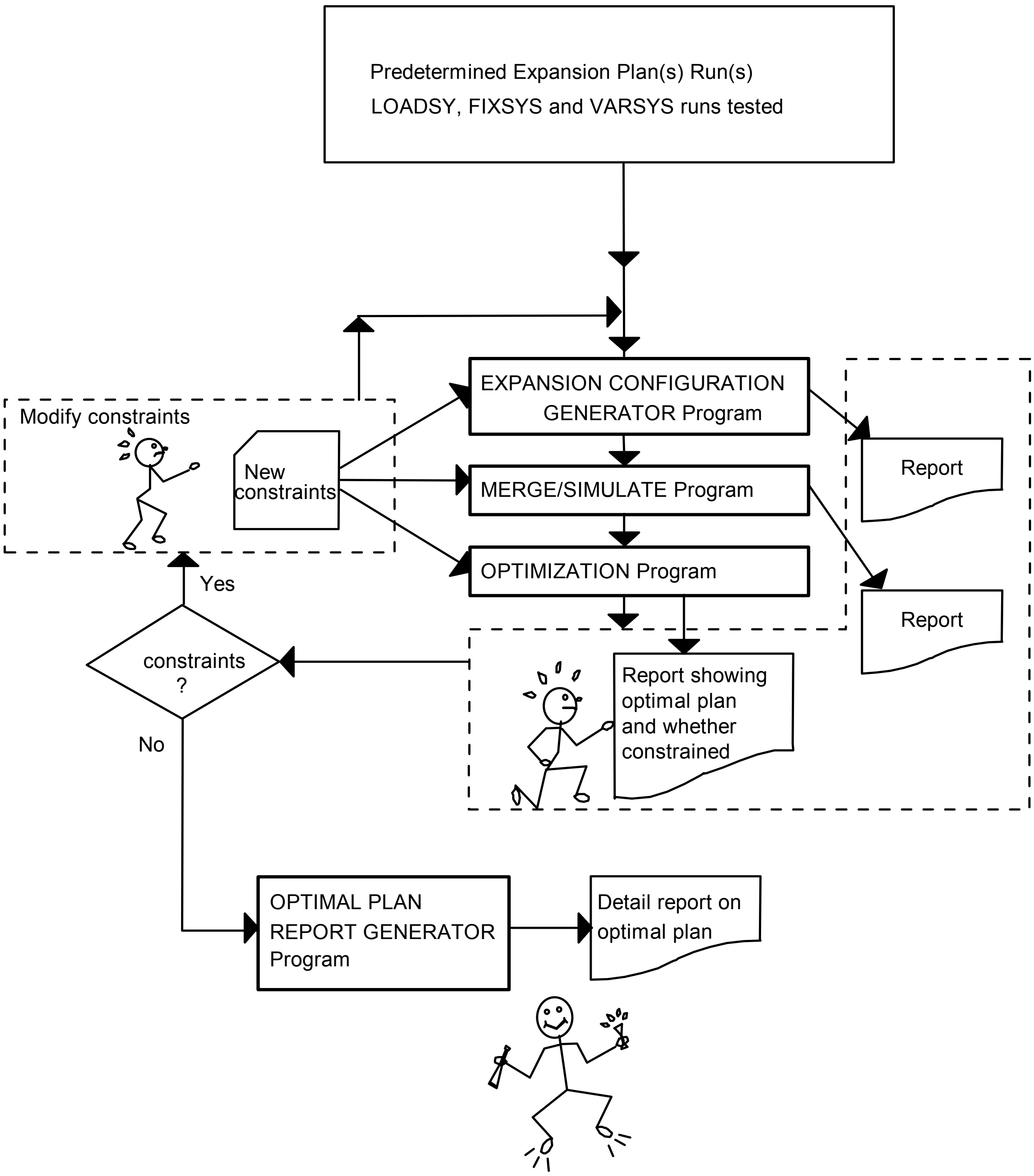


Figure 10.3. User-computer interaction in running the WASP code for variable expansion plans (adapted from ORNL 73-7759 RI).

Table 10.5. Search for optimal solution; running variable expansion plans

STEP	MODULE	OUTPUT OPTIONS REQUIRED	REMARKS
STEP 1	CONGEN	No printing of FIXSYS and VARSYS files	Open or modify tunnel widths and/or minimum configuration and/or reserve margin.
STEP 2	MERSIM	No printing of FIXSYS and VARSYS files	"Merge" mode of operation of MERSIM is used. MERSIM is to be run after CONGEN was successfully run.
		Minimum output of results of simulation for all years.	
STEP 3	DYNPRO	No printing of VARSYS file	To be run after MERSIM. Request up to five solutions. Examine the messages in the printout and use them as a guide for relaxing the constraints in following CONGEN run accordingly.
		No printing of list of states considered in the run	
STEP 4	REMERSIM	Maximum output for the optimal solution As necessary for intermediate best solution	To be run after DYNPRO has found the message-free (unconstrained) solution or eventually to obtain a REPROBAT report of the best solution found by the current DYNPRO run.
STEP 5	REPROBAT	Full report for optimal solution. As necessary for intermediate best solution	To be run only after REMERSIM has been run.
		To document CONGEN, DYNPRO only	For each CONGEN-MERSIM-DYNPRO Cycle.

Table 10.6. Range of tunnel widths and possible number of configurations in the year as a function of the number of competing candidate plants

Number of Competing Candidate Plants	Guide for Tunnel Widths for each Candidate Plant	Maximum Possible Number of Yearly Configurations
2	3 to 9	16 to 100
3	2 to 4	27 to 125
4	2 to 3	81 to 256
5	1 to 2	32 to 243
6 or more(*)	1 to 2	64 to 729

(*) In this case keep the reserve margins as narrow as judged necessary in order to avoid having an exploding number of configurations.

For example, if in a given year a tunnel width of 3 units (or projects) is selected for each of 5 candidates plants, all combinations of them will produce: $4 \times 4 \times 4 \times 4 \times 4 = 1024$ possible configurations in the year; many of them, of course, may be rejected by the constraints imposed by the reserve margins. However, with such a choice it is likely that the 500 configurations per year capability of CONGEN will be exceeded.

On the other hand, if a tunnel width of 1 unit is selected in a given year for each of 6 candidates plants, a maximum of 2 ×2 × 2 × 2 × 2 × 2 = 64 configurations in that year can be expected, of which only a few may survive the reserve margins constraints. It will be shown later, when discussing the run of DYNPRO, that a tunnel width of at least 2 units (or projects) is required for a candidate plant in order to obtain an unconstrained expansion plan for that plant. For a set of 6 candidate plants with a tunnel width of 2 units or projects for each candidate, a maximum of 729 configurations can be expected in a year, as shown in Table 10.6.

The *second step* is to run MERSIM following instruction explained in Section 7.3. Only minimum printout option for the results of the simulation should be requested. It is important to check that the MERSIM run was successful and that all years of the study are shown "closed" (a -1 in the printout indicates end of year). It may be emphasised that during MERSIM runs for Variable Expansion no change can be made in its input, except output option, because during successive iterations MERSIM will use results of configurations already simulated in previous runs. If a change in loading order, maintenance schedule, spinning reserves or group limitations is made, the earlier simulation will not be compatible with the new ones.

Step 3 is to run DYNPRO (refer to Chapter 8 for running this module). In general, for each variable expansion plan, a best solution for the run will be reported containing yearly indications of which plants have been constrained by the tunnel widths used in CONGEN. These messages should be used as a guide for changing (relaxing) the constraints for the next CONGEN run as explained in Chapter 8. Figure 10.4 will help in the understanding of the logic to be followed when changing the minimum number of units (or projects) and tunnel widths constraints selected for a given candidate plant. This figure shows how the value of the objective function for a given case changes according to the permitted number of one single expansion candidate.

For example, Case (a) of Fig. 10.4 gives the option taking either 4, 5, or 6 units of the candidate plant (minimum number of units, or projects =4; tunnel width =2). If the objective function versus number of units of this plant has a shape as shown in Fig. 10.4, DYNPRO will choose 4 units of the plant and will report that the solution is constrained by the lower limit, i.e. 4- will appear in the printout. This is so because the DYNPRO run did not have the chance of testing 3 units for this plant. A subsequent run (Case (b) in the figure) allowing a minimum number of units =3 and tunnel width =2 (options are now 3, 4, or 5 units of the plant) will permit the computer to detect that the objective function is minimum for 4 units of the plant considered. Case (c) of Fig. 10.4 will report the best solution as 2+ (against upper limit) since the options left to the computer were 0, 1, or 2 units only. A run such as Case (d), giving the computer the choice between 0, 1, 2, 3, 4, or 5 units of the plant, will also detect that 4 units minimize the objective function for this case. Figure 10.4 also makes clear that a message-free solution is only possible if the computer is allowed to test at least one unit above and one unit below the optimum; in other words allowing a tunnel width of *2 units*.

After the first variable expansion DYNPRO run is successfully done, several iterations involving sequential execution of CONGEN-MERSIM-DYNPRO will in general be needed to reach a message-free solution (or unconstrained solution) in DYNPRO. The key point in reaching quickly the optimum is to make a careful analysis of the messages provided by DYNPRO in order to prepare the subsequent CONGEN run for the next iteration. As a rule of thumb in the preparation of a new CONGEN run, the user can simply keep the same tunnel widths of the previous run but increasing by one the minimum number of units (or projects) required of those plants marked with (+) messages, and decreasing by one the minimum number of units (or projects) required for those plants with (-) messages.

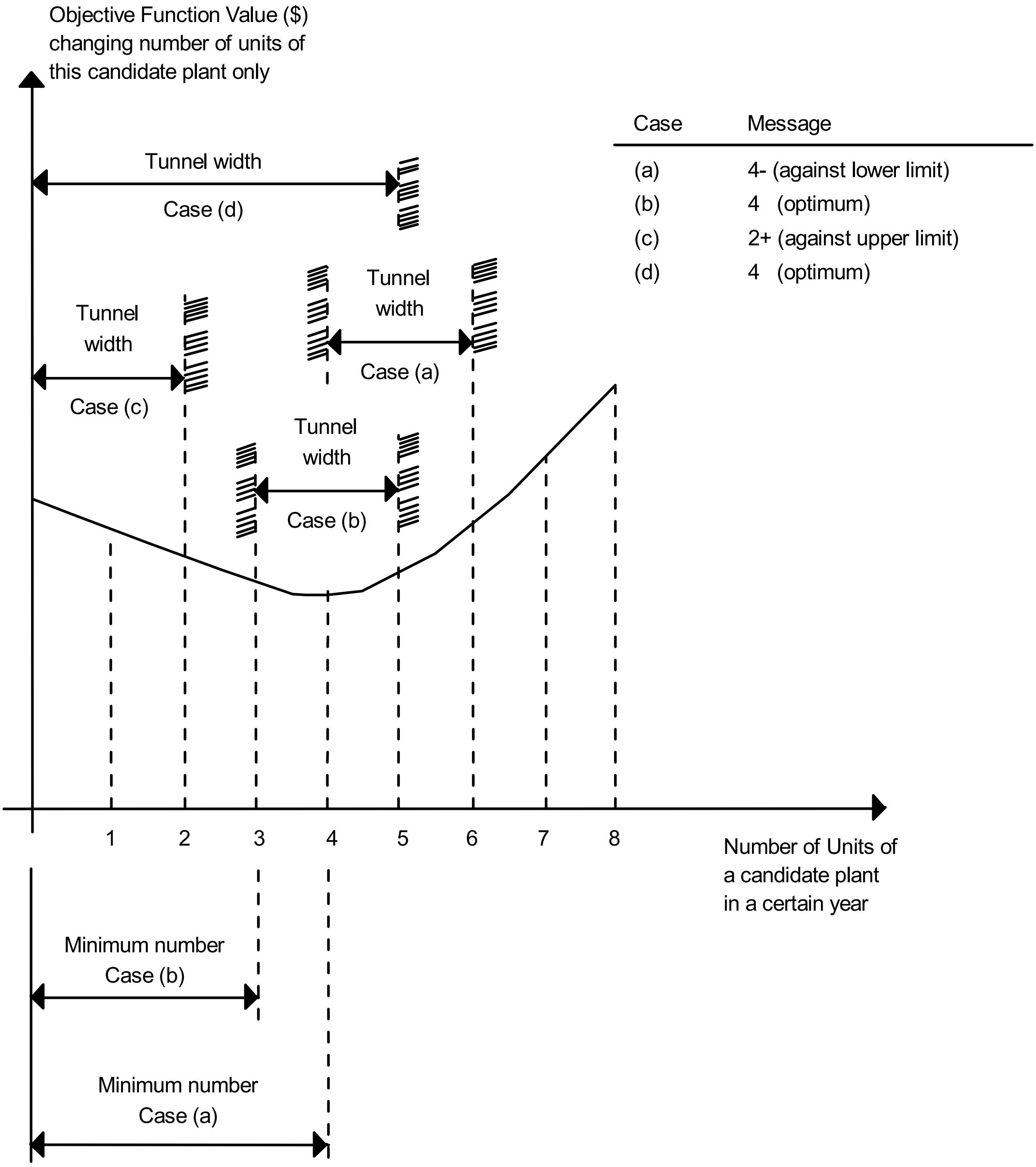


Figure 10.4. Interpretation of the messages reported by DYNPRO.

It is also advisable that the user plots in a graph the value of the objective function for the solution #1 reported by each DYNPRO run versus the respective iteration number. Figure 10.5 plots these values for the sample problem illustrated in this manual. It is interesting to notice in this figure that the last two iterations did not produce an improvement of the value of the Objective Function. Nevertheless, they were required to eliminate some of the DYNPRO messages for intermediate years.

Once the unconstrained solution is reported by DYNPRO, the user must proceed to *Step 4*, i.e. to run REMERSIM for re-simulation of the optimal solution, following the explanation given in Section 7.3.5. It must be remembered that the same input data used in the standard MERSIM run should be used, except that the output option must be changed to maximum output for all or some years of the study.

As explained in Section 7.3.5, careful revision of the REMERSIM output is needed in order to check that the system operation as simulated by the program for each configuration (period and hydro condition) can be considered as reasonable according to user's judgment and experience on power system analysis and on the particular power system on study. In some cases, as a consequence of the revision of the REMERSIM printout, it may be required to continue the dynamic optimization process by executing new iterations with variable expansion plans and correcting input data to Module 4 so as to remove the unsatisfactory results reported by REMERSIM. In this case, the RESFILES.BAT file has to be executed before re-entering the CONGEN-MERSIM-DYNPRO cycle. In some other cases, even the input data to Modules 2, 3 or 5 must be corrected and the applicable module(s) re-run in order to remove the incorrect results of the re-simulation. Obviously, these data corrections (particularly those concerning plant characteristics and costs, loading order instructions, etc.) will affect the simulation of system operation, making the new MERSIM results no longer compatible with those of previous runs. Thus, this would correspond to re-starting the whole WASP study as explained in Section 10.2 onward i.e. delete SIMULNEW & SIMULOLD.BIN but avoiding execution of those steps already successfully completed (for example, it would not be required to re-run LOADSY (first step of Section 10.2) nor the series of predetermined expansion plans (Section 10.3)).

After the above step is successfully completed, the REPROBAT module can be run (*Step 5*) to obtain a full report on the optimal solution, and selecting the proper output options for the run.

In some cases, a total or partial report of the best solution found by DYNPRO so far (in the current iteration) may be required, even if this solution has been constrained by the restrictions in CONGEN (i.e. not the optimal solution). If so the user should follow the procedure explained above.

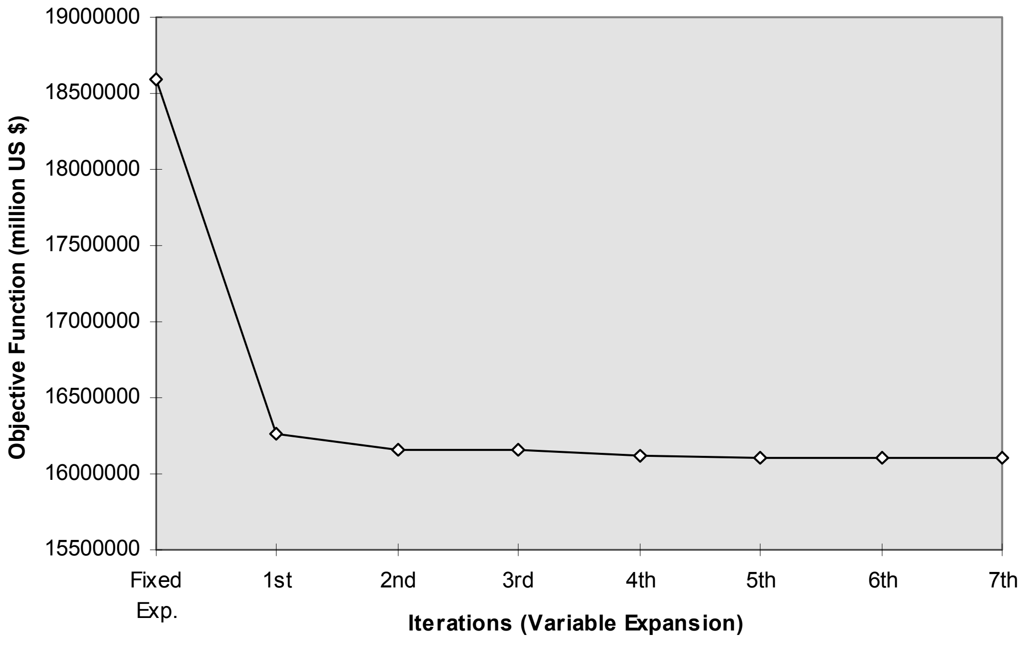


Figure 10.5 Evolution of the Objective Function Value During the Optimization Process for the Sample Problem (DEMOCASE).

10.5. ANALYSIS OF THE OPTIMAL SOLUTION

Once the overall optimal solution for the expansion problem has been found by WASP, the user must analyze the results in order to determine whether this economic optimal expansion schedule is also a feasible program from the stand-point of the system's characteristics and the country's economic and financial situation. In this analysis, the planner will check such aspects as:

- *Frequency stability* to determine whether the largest unit (or project) capacity included in the optimal schedule might produce instability of the system frequency.

- *Transmission system development* (network development for bulk power transmission) and associated costs.

- *Plant additions schedule* and costs.

- *O&M costs* of the system.

- *Manpower requirements* for additions of nuclear and conventional stations and the associated transmission system.

- *Fuel requirements* to satisfy the expansion schedule.

- *Financial capabilities* of the country to undertake the program.

- *Environmental constraints.*

As a result of these analyses, it might be required to revise some of the inputs to various modules of WASP and conduct a new series of variable expansion plans to calculate a new optimal solution which fulfills the above checks.

The procedure is illustrated in a simplified way in Figure 10.6, where WASP related computer programs (available at IAEA) for helping the user in this analysis have been identified between parenthesis. In the figure, the above-mentioned checks are displayed in separate blocks; the proper path to reach any block is identified with arrows (full line); and the arrows in dashed line show the paths for the cases needing executing of new WASP runs.

Apart from the necessary sequence identified by the paths in Fig. 10.6, there is no special order in which these checks should be carried out although a logical order would follow quite closely the above list, so that the process is stopped if the optimal solution is feasible from the financial capability of the country to undertake the expansion program. This solution could be used as "reference" solution for the execution of the sensitivity analysis explained in the following section.

It should be emphasized that the analysis of the WASP best generation expansion schedule proposed in this section does not constitute a feasibility study for any of the power plants that are included in the schedule, nor of the whole generation addition schedule and related investments. Detailed feasibility studies for establishing technical, economic and financial soundness of individual projects will have to be conducted.

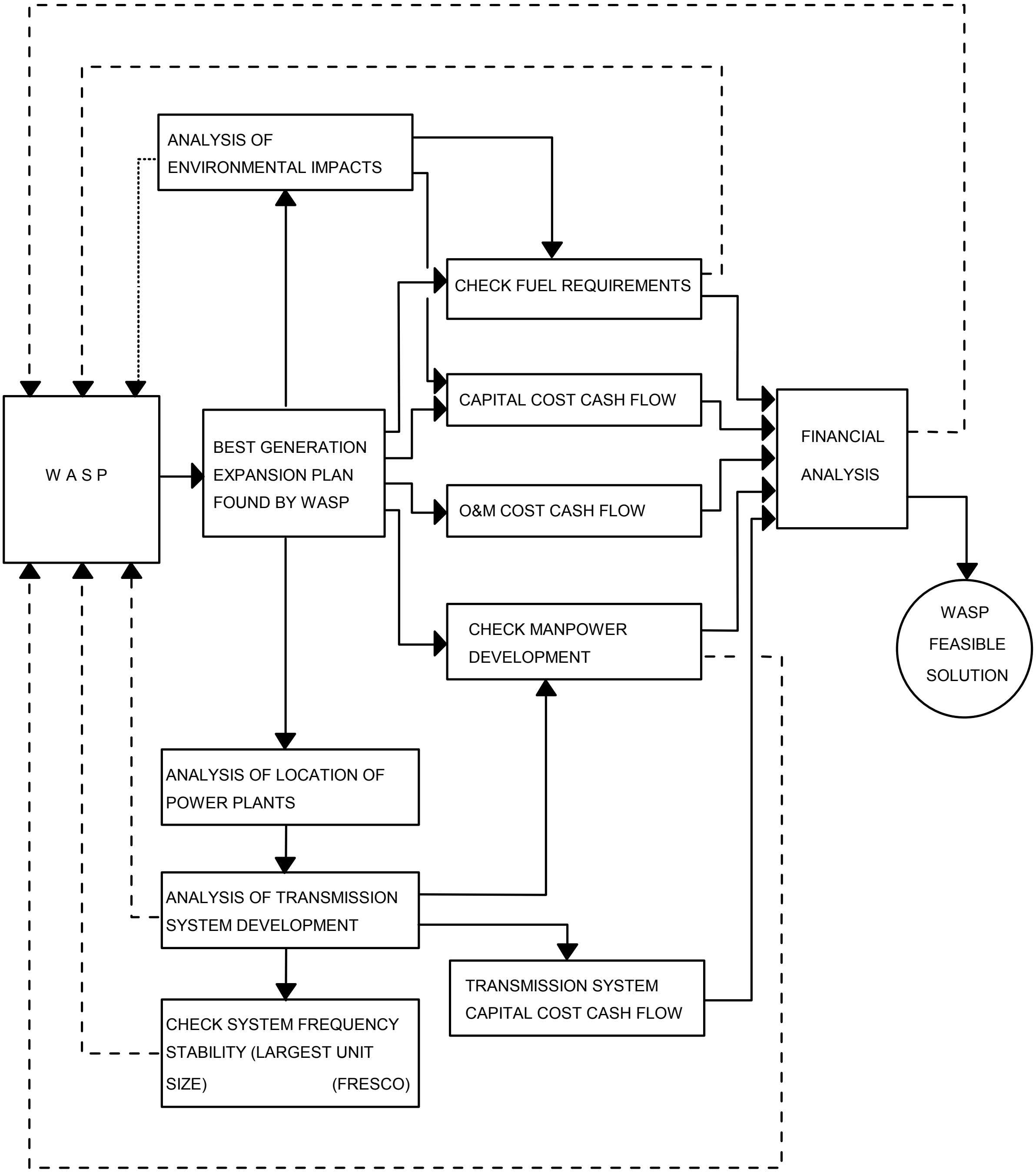


Figure 10.6. Analysis of the WASP output.

Chapter 11
EXECUTION OF SENSITIVITY STUDIES

11.1. NEED TO CONDUCT SENSITIVITY STUDIES

The expansion of electric power generating systems involves the mobilization of large resources of various kinds (financial, manpower, fuel, etc.) which imposes the need for careful planning of this expansion. This is not exclusive of any particular country, but rather of universal nature, and thus applies to industrialized countries and developing countries as well. However, in most developing countries a situation of limited resources is more acute, so that these countries face a more pressing need for adequate allocation of these resources among all sectors of the economy, rather than giving 'unnecessary' advantage in resource allocation to any particular sector (i.e., the electricity supply sector) instead of using these resources for solving other, and perhaps more immediate, social problems (housing, health, education, food, etc.).

The above ideas encompass a major concept, i.e. the need for *integrated energy planning* whereby the demand and supply of energy in all its forms is examined within the larger context of the overall requirements of a country for products and services in order to satisfy the socio-economic and technical development goals established by the society (its government and leaders) and the possibilities to achieve these objectives. The WASP analysis should be considered only as a part of the overall planning process for a country or region. In order to integrate the results of WASP analysis with overall energy planning and economic development planning a number of iterations would be required to capture interactions between electric sector and overall energy sector and the national economy.

Concentrating now on the system expansion analysis alone, all planners are well aware of the uncertainties connected to the basic information being used in the planning studies. Uncertainties arise not only from lack of knowledge about the present value of the input information (forcing the planner to make assumptions), but even if this information can be considered very reliable, the future evolution of the related parameters is rather uncertain. These involve important aspects such as the demand forecast, the technical characteristics of the power plants (days of maintenance, heat rates, FOR, etc.), the economic information related to these plants (fuel prices, O&M costs, investment costs, etc.), up to the very basic information on the future value of some economic parameters (discount and escalation rates) or the required level of the quality of supply to be achieved by the resulting power system configurations (reserve margins, LOLP constraint, cost of unserved energy).

Needles to say that many of these values may be altered in the future and that some of them may interact with one another (discount rate and investment cost are a perfect example) and the range of variation in the future may be unpredictable. This is why that the planners MUST do is to complement the results of the expansion studies, carried out by means of WASP or similar capacity expansion optimization models, with sufficient information on the possible variations of the optimal schedule of plant additions as a consequence of changes in the basic information and hypotheses used to determine the reference optimal solution(s), or in other words, the range of validity of the reference solution. This explains why sensitivity analyses are inseparable from system expansion studies.

Another reason to conduct sensitivity studies is to serve as a feedback for decision making purpose on energy matters. An example of this could be when considering development of a certain type of fuel for which only scarce information is available regarding the future costs connected with mining, refining, transporting and distributing this fuel for electricity production or other end-uses. By making some assumptions for the determination of the reference optimal solution and varying these assumptions during sensitivity analysis, the planner can provide a range of the associated fuel cost that would make this 'fuel" type attractive or otherwise for system expansion.

The results of the sensitivity analyses should be included as part of the report of the system expansion optimization study. This part of the report should be basically addressed to the decision maker in terms of making some recommendations arising from the execution of sensitivity analyses. Hence, the presentation of the results is an important phase of the preparation of a WASP study report, and should include above all a discussion about why the studied parameters (and not others) were selected. In addition, the results of sensitivity studies presented alone would have no meaning without an adequate discussion of their implications in order to alert the decision makers about any potential risks connected with decisions which they will have to make in the near and medium term future.

11.2. WHAT SENSITIVITY STUDIES TO CONDUCT

Judging from the above discussion, the general rule for conducting sensitivity analysis would be to consider all type of information for which large uncertainties are recognized at the outset of the optimization study, either because of lack of knowledge on their statistical or current value (e.g., acceptable LOLP for the system, forced outage rates and O&M cost of existing units, etc.) or because their future evolution is difficult to predict (fuel costs, load forecast, etc.).

Naturally when looking at this general rule, the tendency would be to conduct a large number of sensitivity studies to cover all possible uncertainties in the basic data used and the hypotheses made. Fortunately, the number is generally reduced because of practical considerations regarding the power system characteristics and the economic environment that can be reasonably foreseen at the outset of the study (put aside any unforeseeable changes such as natural catastrophes, an oil embargo, a war, a breakthrough for a new technology, etc.). In addition, the present technology for electricity generation is already well known and its characteristics can vary within certain range because of site conditions (slight variations in power output and heat rate can exist due to differences of temperature of cooling water, the outside temperature or the altitude as compared to the design conditions), but the range of variation is rather limited and its effect on the optimization is also small (e.g. heat rate variation of a candidate power plant from 2140 kcal/kWh to say 2160 kcal/kWh would basically alter the annual operating costs of the optimal solution, but without changing the configurations included in the optimal solution, unless the given plant is marginally optimal, which could be easily detected when changing any other more critical parameters such as for example the investment cost or the related fuel costs).

Moreover, carrying out too many sensitivity analyses and including them as part of the report of the optimization study will tend to diminish the credibility of the study, as well as leading to confusion in terms of the interpretation of the results and of the study recommendations. Both will have a negative effect on the perception by the decision maker. Consequently it is necessary to concentrate in a few sensitivity analyses to study the variation of the optimal solution to the most important parameters for which the planner(s) and sometimes the decision makers accord the highest degree of uncertainty. Some of the sensitivity studies most frequently considered are:

- demand forecast,
- fuel cost,
- investment cost of new power plants,
- discount rate,
- year in which certain plants can be added to the system,
- special considerations related to plant site,
- quality of supply (reserve margin, LOLP limit, cost of unserved energy),
- environmental issues/constraints.

11.3. HOW WASP CAN BE USED TO CONDUCT SENSITIVITY STUDIES

Owing to the modular structure of WASP, sensitivity studies can be performed to evaluate the effects of the various economic parameters on the “reference” optimal solution, by simply rerunning the DYNPRO module. These studies are easy to conduct, particularly if the new values of the parameters do not cause the optimal solution to move against the tunnel boundaries of CONGEN (signs + or - in the DYNPRO output). If the solution does hit the tunnel boundaries of CONGEN, a few additional iterations of CONGEN-MERSIM-DYNPRO may be required to find a new unconstrained 'optimal' solution. The process, however, may take rather limited computation time since most of the configurations may have already been simulated.

The *economic* parameters that may be studied include:

(1) Plant capital cost (range, environmental protection equipment, etc.);

(2) Capital cost escalation ratios;

(3) Discount rates;

(4) System reliability requirement (critical LOLP);

(5) Additional (DYNPRO) constraints on expansion schedule; and

(6) Energy not served costs.

The economic parameter affecting fuel prices may also be varied in sensitivity studies. However, some care must be taken to ensure that the changes in these parameters would not produce a change in the loading order used for the simulation of system operation (MERSIM). Hence, sensitivity studies can be made for reasonable perturbations of the following variables:

(1) Fuel cost escalation factors;

(2) Penalty factor on foreign expenditures.

If it is desired to make large changes in the above variables, particularly fuel costs (e.g. the cost of a given fuel changing by 3 times its reference value) which would cause a change in the loading order, sensitivity studies could still be made. In this case, however, the operating costs for all states are no longer valid and would have to be recalculated for the new loading order.

Sensitivity studies involving modifications such as the load forecast (LOADSY), committed schedule of plant additions and retirements (FIXSYS), the preferred sequence of installation of hydroelectric or pumped storage projects (VARSYS), to name a few, would require to process a complete new WASP study.

Concerning the load forecast, a new WASP study should be conducted based on a different development scenario (refer again to integrated energy planning).

Sensitivity analysis of committed schedule of plant additions and retirements could be conducted if the associated plants were introduced as part of the VARSYS description and maintained as fixed (minimum number of units on record type 2 of CONGEN equal to the number of units in the plant with zero tunnel widths) during the search of the reference optimal solution. Then, while conducting sensitivity studies, the corresponding plants could be postponed or advanced by one or several years, as deemed necessary, in order to determine the impact of this change on the optimal solution.

11.4. PRACTICAL STEPS FOR CONDUCTING SENSITIVITY STUDIES

Before proceeding with the execution of sensitivity — analyses, find the unconstrained optimal solution for the power system under study (i.e. the DYNPRO solution showing no signs + or -, unless these signs are unavoidable: e.g. a + sign connected with a hydro plant for which all projects of this type have been exhausted in the given year, or when reaching the limit of capacity additions for a certain thermal power plant, for example lignite fired units associated to a given mine. Although, in principle, a minus (-) sign could be accepted for a certain candidate which for various reasons must be added to the system in a given year, this situation should be avoided for the 'reference optimal solution’).

Copy all files of the reference optimal expansion case into a new sub-directory within the WASP main directory. If the REMERSIM run for the reference case was done, then execute RESFILES.BAT to restore (reassign) the appropriate name of the simulation file containing results of all configurations.

Decide which sensitivity analyses are of interest for your case study in the light of the results of the optimization phase. For example, if the reference optimal solution shows a marked preference for one type of 'fuel', it is obviously interesting to find the range of validity of such preference for changes in the fuel costs of the related candidate plants. Similarly, if the preference refers to a particular candidate, sensitivity analysis could be conducted on its capital investment cost, or inversely on the capital costs of the second, third, etc. most preferred candidate. Likewise, if there is interest in a particular technology which in the end is not included in the reference optimal solution, sensitivity analysis on its capital investment cost and associated fuel cost may be necessary.

Several other sensitivity studies should be decided based on general considerations about the uncertainties of the input information (e.g. critical LOLP, cost of unserved energy, etc.).

Make a choice of what input data needs to be altered to achieve the intended sensitivity analysis. Examples are:

when increasing fuel prices, changes can be affected either as escalation factors or multiplication factors;

if a certain "fuel" is chosen by the reference solution the same sensitivity study could be conducted by either increasing the fuel cost of the preferred fuel or by decreasing the fuel cost of the next favoured fuel type.

Apply logical judgement of the required studies, what is required to be accomplished and the range of analysis. In the same example of the preferred fuel for system expansion mentioned above, it would probably make no sense to conduct a sensitivity analysis that considers a further decrease of the price of this fuel, since the effect on the solution would be to reduce the total system operating costs and probably increase the number of units of this fuel type in the solution. Sometimes, however, such a study may be required for decision making on energy matters (setting up the price of a certain fuel not yet developed in the country and for which price information is rather unknown).

Make some logical guesses about the anticipated results of the sensitivity analysis before proceeding to prepare the required CONGEN run (if needed). For example, if it is expected that the changes considered would lead to different number of units, provision should be made as to allow in CONGEN more units of the candidate that would become more favoured after changing the parameter(s) being analysed at each time.

Prepare a new CONGEN allowing competition among all VARSYS candidates expected to be changed in the number of accepted units (reference solution) as a result of the variation in the selected parameter under study, making sure that the optimal solution can always be retrieved in DYNPRO using the reference values of the parameter. By careful production of a CONGEN run (using records type 2 and 3), it may be possible to cover a wide range of sensitivity analyses.

Before starting to make changes in the selected parameters, re-run MERSIM and DYNPRO to make sure that the optimal solution can be reproduced with the new CONGEN.

Select the range of variation for each parameter to be studied and start varying the value of each parameter at a time while maintaining the value of the other parameters constant from their reference values. Each parameter change should be made in a stepwise manner and the DYNPRO results analyzed before proceeding to the next run.

In some cases, if the new best solution starts showing signs (+ or -) or even divert from the reference solution in terms of the number of units added, some new iterations of CONGEN-MERSIM-DYNPRO may be needed in order to find a new unconstrained solution (e.g. discount rate being changed from the reference value of 10%/a to 8%/a).

In other cases, specially when examining a wide range of variation for the parameter under study, it is not necessary to re-optimize at each stage of variation, since it suffices to observe the tendency of the new best solution and continue changing the value of the parameter in the same direction until the solution diverts from the reference one. This level or perhaps one step of variation less would represent the break-even point for the parameter being considered. If desired, re-optimize again at this break-even point. It is recommended to save the input and output files corresponding to each sensitivity study with some comments added to keep record of all the analyses.

Chapter 12

TECHNICAL DETAILS OF NEW FEATURES OF WASP-IV

12.1. MULTIPLE GROUP-LIMITATIONS

12.1.1. Introduction

It is very often in the practice that the electric power utilities have to operate the power plants taking into account some constraints limiting the generations of the units. The limitations can be arising from several causes, e.g. limited energy available for hydro electric plants, constraints on the amount of some fuel(s) available, etc. In recent years, environmental concerns have led to regulations that may also limit operation of power plants. These considerations require taking into account, at the time of planning for expansion of the electric system, the practical problems faced by the utility operators. The production costing methods employed for system operation simulation should, therefore, be able to handle such situations.

WASP-IV offers the option to take into consideration several types of external constraints which may limit generation of some of the units. The probabilistic simulation method utilised by WASP for production costing has been combined with a linear programming model to simulate the operation of system under such constraints, which are named as multiple group limitations. Here the group-limitation means that for a group of units, the weighted sum of the unit generations is limited. The weights, called here coefficients, may be of course different. For energy-limited units, the group consists of the single unit and the coefficient is 1. For fuel-limited groups, the coefficients are the average fuel consumption rates. For emission-limited groups, the coefficients are the emission rates, etc. Several group-limitations can be considered, and a unit can take part in any number of these group-limitations, hence the name multiple group-limitations. For example, a coal-fired unit may occur both in a coal-limitation and in an emission-limitation.

The next sections describe the linear programming model for determining an optimal dispatch policy subject to multiple group limitations and a methodology for generating the linear programming problem.

12.1.2. A linear programming model

Let the inverted load duration curve with normalized duration axis be denoted by $L(x)$. Let the generating system consist of N units. For the sake of simplicity, it is assumed here that the units have single-block representation. The extensions relating to the multi-block representation will be treated in section 12.1.4. For Unit i, the following notations are used:

G_i = expected energy generation (MW(h)),
c_i = cost of generating 1 MW(h) energy.

Let M be the number of the group-limitations. For Group j, let I_j denote the index set of the units being elements of the group. A unit can relate to an arbitrary number of groups including zero. Let the positive numbers $LIMIT_j$, j=1,...,M, denote the quantities of the limitations.

Consider a Unit i and a Group j such that $i \in I_j$. Let the positive real $COEF_{ij}$ denote the quantity used from $LIMIT_j$ if Unit i generates 1 MW(h) energy. For example, $COEF_{ij}$ may be the SO_2 emission, measured in kilograms, caused by generating 1 MW(h) energy by Unit i. Generally, the unit of measurement of $COEF_{ij}$ is the ratio of that of $LIMIT_j$ to MW(h). Assuming linearity here, the group-limitations mean

$$\sum_{i \in I_j} COEF_{ij} \times G_i \leq LIMIT_j \qquad \text{for } j=1,\ldots,M. \qquad (1)$$

The cost of these generations is $\sum_{i=1}^{N} c_i G_i$.

Since it may occur that there exists no such loading order that the generation values G_i, obtained by the relating production costing simulation algorithm, would satisfy (1), several loading orders should be used during the period.

A loading order of the units is called strategy if it is considered as an acceptable loading order during a part of the period. Although the number of the loading orders is $N!$, a great part of them can be omitted at once. For example, a nuclear unit should not be in a peaking position.

Let $S_1,\ldots,S_K$ denote strategies to be considered, where K is their number. For every strategy S_k , $k=1,\ldots,K$, perform the production costing simulation using the loading order of S_k. Of course, the group-limitations are not taken into account during the simulations. Let $\overline{G}_{ki}$ be the expected generations of the units obtained in this way for $i=1,\ldots,N$ and $k=1,\ldots,K$. Let $COST_k$ denote the production cost of generation using S_k in the whole period.

$$COST_k = \sum_{i=1}^{N} c_i \times \overline{G}_{ki} \qquad \text{for } k=1,\ldots,K.$$

Let R_{kj} denote the quantity consumed from the resource relating to Group J by using strategy S_k in the whole period. Then

$$R_{kj} = \sum_{i \in I_j} COEF_{ij} \times \overline{G}_{ki} \qquad \text{for } k=1,\ldots,K \text{ and } j=1,\ldots,M.$$

For every strategy S_k, a weight w_k representing the ratio of the duration of using S_k to the whole period has to be determined. Of course, they should be determined in such a way that the total generation cost be minimal subject to the group-limitations. This can be done by solving the linear programming problem

$$\text{minimize} \quad \sum_{k=1}^{K} COST_k w_k \qquad (2)$$

$$\text{subject to} \quad \sum_{k=1}^{K} R_{kj} \cdot w_k \leq LIMIT_j , \qquad j=1,\ldots,M, \qquad (3)$$

$$\sum_{k=1}^{K} w_k = 1 \;, \qquad (4)$$

$$w_k \geq 0, \qquad k=1,...,K. \qquad (5)$$

Constraints (4)–(5) mean the evidences that the sum of the time-fractions used for the strategies must be just the length of the period, in addition, any fraction cannot be negative.
The following statements come from the theory of linear programming. If (2)–(5) has a feasible solution, then it has also a finite optimum since the feasible set is bounded. Moreover, one can obtain an optimal solution such that at most M+1 of the variables are positive. This means that an optimal solution can be mixed from at most M+1 strategies.

Using the optimal solution of (2)–(5), the average loss-of-load probability (LOLP) and energy not served (ENS) values relating to the whole period can be obtained simply by

$$ENS = \sum_{k=1}^{K} ENS_k \cdot w_k \qquad (6)$$

and

$$LOLP = \sum_{k=1}^{K} LOLP_k \cdot w_k \qquad (7)$$

where ENS_k and $LOLP_k$ are the corresponding values of the strategies relating also to the whole period. Similarly, the expected generations of the units are obtained as

$$G_i = \sum_{k=1}^{K} \overline{E}_{ki} \cdot w_k \quad \text{for } i=1,...,N. \qquad (8)$$

Of course, if the group-limitations are too low, problem (2)–(5) may have no feasible solution. Then either the limitations should be reconsidered or further strategies should be introduced. In extreme case, it may however occur that a feasible solution can be obtained only by introducing such strategies where the capacities of some units taking role in a group of exceeded limitation are derated or some of these units are omitted from the loading order. This latter is equivalent to derate the capacities of some units to zero. A possible by-effect of derating or omitting some units is that the generation of some other units may increase. This entails that meanwhile one introduces and mixes new strategies in order to fulfill a group-limitation, other group-limitations may be damaged. At the very worst, one can however introduce the extreme strategy where every unit taking role in any group-limitation is omitted. The introduction of this strategy ensures always that (2)–(5) has feasible solution.

If the capacity of some units is derated or some units are omitted from the loading order, the generation cost of this strategy decreases but the relating LOLP and ENS values increase. If the linear programming model (2)–(5) is also used in this case, one would obtain false result. Since the unserved consumer demand is not penalized, the linear programming model (2)–(5) strives for mixing the optimal solution from the cheap strategies with derated or omitted units. The average ENS and LOLP values (6)–(7) may be so unreal.

Two approaches can be proposed to avoid this phenomenon. Both approaches use nonnegative penalty factors α and ß for LOLP and ENS, respectively. For example, ß can be the real cost of the unserved energy. The first approach adds a penalty term

$$\sum_{k=1}^{K} (\alpha \cdot LOLP_k + \beta \cdot ENS_k) \cdot w_k \qquad (9)$$

to (2), i.e. the linear program

$$\text{minimize} \quad \sum_{k=1}^{K} (COST_k + \alpha \cdot LOLP_k + \beta \cdot ENS_k) \cdot w_k \tag{10}$$

$$\text{subject to} \quad \sum_{k=1}^{K} R_{kj} \cdot w_k \leq LIMIT_j \ , \qquad j=1,...,M, \tag{11}$$

$$\sum_{k=1}^{K} w_k = 1 \ , \tag{12}$$

$$w_k \geq 0, \qquad k=1,...,K. \tag{13}$$

is to be solved. It is easy to see that if there exists no strategy with derated or omitted units among those used in (2)–(5) and (10)–(13), then the optimal solutions of these two problems are the same. This follows immediately since (9) is now constant under (4).

The second approach consists of two steps. In the first step, the minimal penalized average values of LOLP and ENS are searched for, i.e. the linear program

$$\text{minimize} \quad \sum_{k=1}^{K} (\alpha \cdot LOLP_k + \beta \cdot ENS_k) \cdot w_k \tag{14}$$

$$\text{subject to} \quad \sum_{k=1}^{K} R_{kj} \cdot w_k \leq LIMIT_j \ , \qquad j=1,...,M, \tag{15}$$

$$\sum_{k=1}^{K} w_k = 1 \ , \tag{16}$$

$$w_k \geq 0, \qquad k=1,...,K. \tag{17}$$

is to be solved. Let μ denote the optimal value of (14)–(17). In the second step, the linear program

$$\text{minimize} \quad \sum_{k=1}^{K} COST_k \cdot w_k \tag{18}$$

$$\text{subject to} \quad \sum_{k=1}^{K} R_{kj} \cdot w_k \leq LIMIT_j \ , \qquad j=1,...,M, \tag{19}$$

$$\sum_{k=1}^{K} w_k = 1 \ , \tag{20}$$

$$\sum_{k=1}^{K} (\alpha \cdot LOLP_k + \beta \cdot ENS_k) = \mu \tag{21}$$

$$w_k \geq 0, \qquad k=1,...,K. \tag{22}$$

is to be solved. Problem (18)–(22) is obtained by adding (21) to (2)–(5). Constraint (21) ensures the choice among the feasible solutions with the minimal weighted sum of the penalized LOLP and ENS. Of course, the optimal solutions of (2)–(5) and (18)–(22) are again the same if we have no strategy with derated or omitted unit.

Concerning the choice between these two approaches, the first approach can only be used in such cases when true values for factors α and ß can be given. For this reason, the second approach has been implemented in WASP- IV.

The crucial point of the implementation of the methodology proposed here is the way in which the strategies are selected for the linear programming problem. Too few strategies may not ensure the feasibility. The mere increase of the number of strategies entails, of course, the increase of computational time but does not guarantee obtaining the feasibility unconditionally. The choice of the strategies to be introduced should be performed in an efficient way. The heuristic method presented in the next section serves for this purpose.

12.1.3. A heuristic method for generating the linear programming model

The heuristic method presented here is inspired by two aims. On the one hand, feasible solution should be found for the linear program as soon as possible, i.e. by performing as few production costing simulation as possible. On the other hand, the strategies selected for mixing a production plan should have values of production cost, LOLP and ENS as low as possible. The heuristic method makes a compromise between these two objectives.

The production costing simulations, without taking the group-limitations into account, can be performed by subroutine SIMUL of WASP. The first strategy S_1 to be introduced is selected in the same way as in subroutine ANSIM, i.e. S_1 is the loading order submitted by the user or that generated by subroutine MILORD. Subroutine SIMUL is performed and having now K=1, the values for $LOLP_1$, ENS_1 and R_{1j} for j=1,...,M are determined. These are used for the constraint system (3)–(5) of the linear programs. If,

$$R_{1j} \leq LIMIT_j \qquad \text{for } j=1,...,M, \qquad (23)$$

then the starting loading order is an optimal strategy, i.e. $w_1 = 1$ is an optimal solution. Otherwise, the linear program has no feasible solution and new strategy has to be introduced.

Choose an index j_1 such that $R_{1j_1} > LIMIT_{j_1}$. Consider the strategy where the units belonging to the j_1-th group-limitation are moved to the end of the loading order. The relative order among the moved units is however kept. Let this strategy be denoted by S_2 and perform the production costing simulation for it by SIMUL. From the results of SIMUL, the data relevant to strategy S_2 are determined and strategy S_2 is introduced into the linear program.

The production costing simulation performed for strategy S_2 furnishes data, as by-products, also for further strategies. Let S_3 denote the strategy obtained from S_2 by omitting the last unit. The generations of the remaining units are the same in both strategies S_2 and S_3. The value of ENS_3 and $LOLP_3$ can be obtained from the last but one equivalent load duration curve determined by the simulation executed for S_2.

Similarly, if the last but one unit of S_4 belongs also to the j-th group-limitation, a strategy S_4 can be generated by omitting the last two units from S_2. The corresponding values of ENS_4 and $LOLP_4$ can be obtained from the last but two equivalent load duration curve.

Generally, by moving the units of the j_1-th group-limitation to the end of the loading order and performing one production costing simulation, $\left|I_{j_1}\right| + 1$ strategies can be introduced into the linear program. Here, I_{j_1} is the index set of the units belonging to the j_1-th group-limitation and $\left|I_{j_1}\right|$ denotes the number of the elements of I_{j_1}. Of course, subroutine SIMUL has been modified in such a way that the relevant data are stored in the convolution steps and are retrievable when the simulation has been completed.

To illustrate the construction of the strategies, consider the simple example below. Let N=12 and M=2, i.e. there are 12 units and 2 group-limitations. Let the units be denoted by U1,...,U12. Assume that units U2, U5, U7 and U9 belong to the first group-limitation, and units U4, U7, U9 and U11 belong to the second group-limitation. Suppose that the starting loading order submitted by the user or determined by subroutine MILORD is U1, U2,..., U12. Then, strategy S_1 is as follows:

L I M I T A T I O N 1

		↓			↓		↓		↓			
S1:	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12
				↑			↑		↑		↑	

L I M I T A T I O N 2

Assume that (23) does not hold and let j_1=1. The five strategies introduced by the second production costing simulation are depicted below.

L I M I T A T I O N 1

									↓	↓	↓	↓
S2:	U1	U3	U4	U6	U8	U10	U11	U12	U2	U5	U7	U9
			↑				↑				↑	↑

L I M I T A T I O N 2

L I M I T A T I O N 1

									↓	↓	↓
S3:	U1	U3	U4	U6	U8	U10	U11	U12	U2	U5	U7
			↑				↑				↑

L I M I T A T I O N 2

LIMITATION 1

									↓	↓
S4:	U1	U3	U4	U6	U8	U10	U11	U12	U2	U5
			↑				↑			

LIMITATION 2

LIMITATION 1

									↓
S5:	U1	U3	U4	U6	U8	U10	U11	U12	U2
			↑				↑		

LIMITATION 2

S6:	U1	U3	U4	U6	U8	U10	U11	U12
			↑				↑	

LIMITATION 2

Having now 6 strategies, or K strategies generally, it has to be tested that whether a feasible solution can be mixed from the introduced strategies. For K=1, this test means simply to check the validity of relations (23). For K>1, the well-known first phase procedure of linear programming can be used. Consider the linear program

$$\text{minimize} \quad \sum_{j=1}^{M} y_j \tag{24}$$

$$\text{subject to} \quad -y_j + \sum_{k=1}^{K} R_{kj} \cdot w_k \le LIMIT_j \ , \qquad j=1,\dots,M, \tag{25}$$

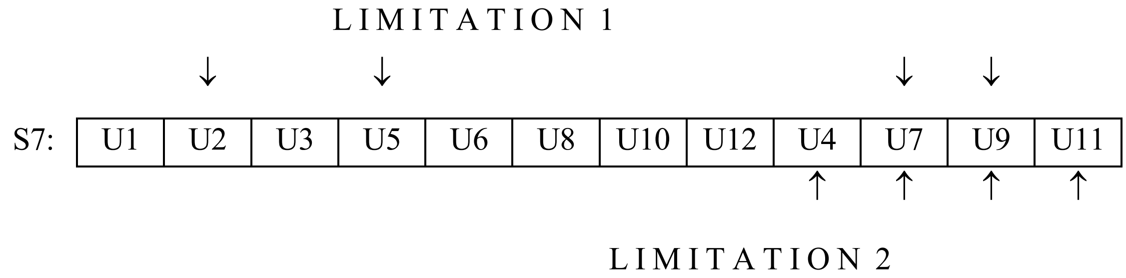
$$\sum_{k=1}^{K} w_k = 1 \ , \tag{26}$$

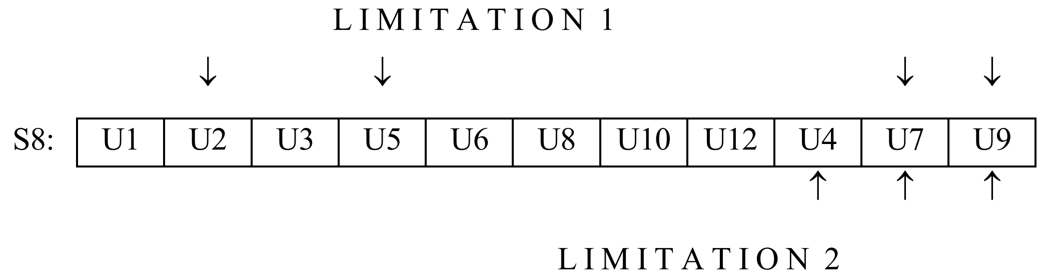
$$y_j \ge 0, \qquad j=1,\dots,M, \quad w_k \ge 0, \quad k=1,\dots,K. \tag{27}$$

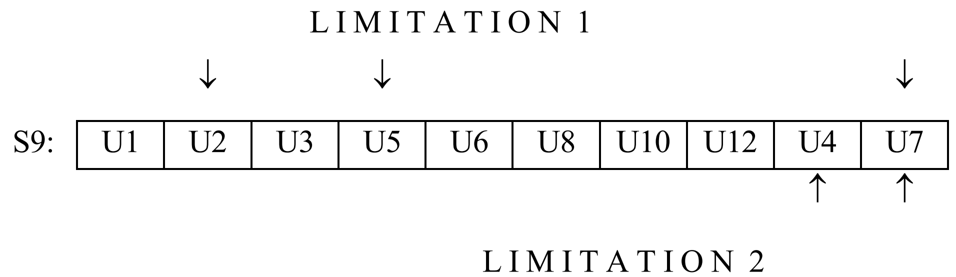
Problem (24)–(27) has always optimal solution and a nonnegative optimal value. Moreover, system (3)–(5) has a feasible solution if and only if the optimal value of (24)–(27) is zero. In this case, the second phase of the procedure can be started, i.e. one can solve the selected linear program presented in the previous section.

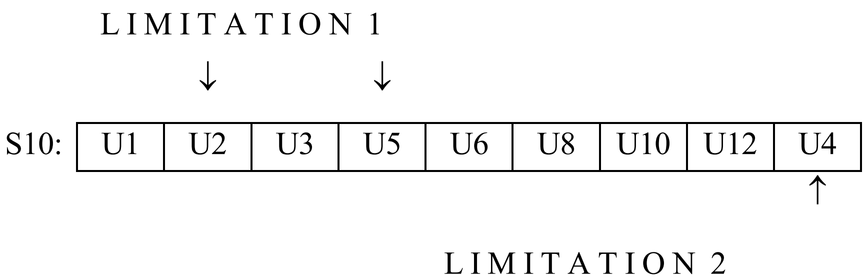
If the optimal value of (24)–(27) is positive, further strategy is to be introduced. Consider those indices $j \in \{1,\dots,M\}$ for which $y_j>0$ in the optimal solution of (24)–(27). If there exists an index, say j_2, among them such that the matter described above for the units of the j_1-th group-limitation has not been performed yet for the units of the j_2-th group-limitation, select this j_2. Perform the matter above now with j_2 instead of j_1. This means that the units taking role in the j_2-th group-limitation are moved to the end in the initial loading order. Subroutine SIMUL is called again to perform the production costing simulation and $\left|I_{j_2}\right|+1$ new strategies are generated for the linear program.

In the context of the example presented above, let j_2=2. The 5 new strategies are depicted below.









LIMITATION 1

		↓		↓				
S11:	U1	U2	U3	U5	U6	U8	U10	U12

The new strategies are added to (24)–(27) and the LP problem is solved. If the optimal value is now zero, the first phase procedure is complete. Otherwise, it is checked that whether there exists an index j_3 with the same property as j_2 above. If the answer is positive, the matter above is now repeated with j_3.

If no such a j_3 has been found, the loading order of S_1 is selected again. Every unit taking role in any group-limitation is moved now to the end of the loading order in such a way that the relative order among the moved units is kept. Subroutine SIMUL is called again to perform the production costing simulation for this new strategy. As by-products, the data of the strategies obtained by omitting the last, last two, etc. units are also generated. Altogether, $\left|\bigcup_{j=1}^{M} I_j\right| + 1$ new strategies are generated by this single call of SIMUL. The 7 new strategies obtained in this way for the example are depicted below.

LIMITATION 1

							↓		↓	↓	↓	
S12:	U1	U3	U6	U8	U10	U12	U2	U4	U5	U7	U9	U11
								↑		↑	↑	↑

LIMITATION 2

LIMITATION 1

							↓		↓	↓	↓
S13:	U1	U3	U6	U8	U10	U12	U2	U4	U5	U7	U9
								↑		↑	↑

LIMITATION 2

LIMITATION 1

							↓		↓	↓
S14:	U1	U3	U6	U8	U10	U12	U2	U4	U5	U7
								↑		↑

LIMITATION 2

L I M I T A T I O N 1

↓ ↓

S15:	U1	U3	U6	U8	U10	U12	U2	U4	U5

↑

L I M I T A T I O N 2

L I M I T A T I O N 1

↓

S16:	U1	U3	U6	U8	U10	U12	U2	U4

↑

L I M I T A T I O N 2

L I M I T A T I O N 1

↓

S17:	U1	U3	U6	U8	U10	U12	U2

S18:	U1	U3	U6	U8	U10	U12

Add the new strategies to (24)–(27). Notice that the special strategy obtained by omitting every unit taking role in any group-limitation is also among them. Since

$$R_{kj} = 0,\ j=1,...,M,$$

for this special strategy, the optimal value of (24)–(27) is now zero. Consequently, one can proceed with the second phase procedure, i.e. solving problem (10)–(13) or problems (14)–(17) and (18)–(22).

The heuristic method presented above requires to call subroutine SIMUL at most M+2 times and generates at most $M + 2 + \sum_{j=1}^{M} \left| I_j \right| + \left| \bigcup_{j=1}^{M} I_j \right|$ strategies for the linear programs. This heuristic method may seem to be too primitive and unreal because of moving the whole set of the units of an exceeded group-limitation to the end of the loading order. It would be more sophisticated to select only a subset of these units and to move them only some positions higher. The introduction of such strategies would be more realistic and may further decrease the production cost obtained by the optimal solution of the linear programs presented in the previous section. The expense of the introduction of such strategies may be however the drastic increase of the computational time. This is why the simpler version has been implemented in the WASP-IV.

12.1.4. The case of multi-block representation of units

In WASP, in order to better simulate the economic dispatch procedure, two-block representation of the units is also allowed. Although, for facilitating comprehension, only the single-block representation was used in the previous sections. Nevertheless, the heuristic method works in the same way for the two-block representation. The role of the units is taken now over by the blocks. In the initial loading order, every base block precedes the corresponding peak block. The two blocks of a unit take part simultaneously in a group-limitation. Moving all blocks of a group-limitation into higher positions, the relative order among the moved blocks is kept.

12.1.5. Allocation of annual limits for periods

Among the input data, the annual values of the limits are to be given along with (optional) the period distribution of these limits. If the period distribution is not given, the annual limits are then divided into period limits by the program. For this purpose the new subroutine DIVLIM is called by ANSIM. The annual limits relating to regulations of environmental pollution are simply divided into equal period limits, i.e. the annual value is divided by the number of periods. For the other limitations (e.g. limited fuel amount), the sums of block capacities weighed by their availability and coefficients are determined for every period. Then the annual limit is divided into period limits proportionally to these weighed sums.

12.2. REPRESENTATION OF PUMPED STORAGE PLANTS

The option for representation of pumped storage plants WASP has been included in view of the importance of energy storage technologies, particularly the hydro pumped storage plants. Pumped storage units save fuel costs by serving the peak load demand, usually served by high fuel cost units, with hydro energy that was pumped to a higher level reservoir during periods of low demand (evening, weekends) when more economic units can be utilized.

The pumped storage plants are limited both in capacity and energy. Their economic evaluation depends on:

- characteristics of the load duration curve (LDC),
- composition of the generating system,
- reliability of each unit , and
- running cost (i.e., fuel and variable O&M) of all types of units.

The characteristics of a pumped storage plant j is described in WASP-IV by the following parameters:

P_j = Pumping capacity (MW)

G_j = Generating capacity (MW)

E_j = Maximum feasible energy generation (storage capacity, GW(h))

n_{pj} = Pumping efficiency (%)

n_{gj} = Generating efficiency (%)

$n_j = n_{pj} \cdot n_{gj}$ = Cycle efficiency (%)

When more than one pumped storage project exists in the system, the projects are aggregated to form an equivalent composite pumped storage project as follows:

$$P = \sum_j P_j$$

$$G = \sum_j G_j$$

$$E = \sum_j E_j$$

$$n_p = \sum_j n_{pj} \cdot \frac{P_j}{P}$$

$$n_g = \sum_j n_{gj} \cdot \frac{G_j}{G}$$

$$n = n_p \cdot n_g$$

where:

P	=	Composite P-S plant pumping capacity (MW)
G	=	Composite P-S plant generating capacity (MW)
E	=	Composite P-S plant storage capacity (GW(h))
n_p	=	Composite P-S plant pumping efficiency (%)
n_g	=	Composite P-S plant generating efficiency (%)
$n = n_p \cdot n_g$	=	Composite P-S plant cycle efficiency (%)

The weighting of the individual efficiencies with the individual capacities assumes that all projects have the same capacity factor and hence is only an approximation.

The pumping (i.e., charging) and generating operations can be considered independently. The generation amount is given by the following equation:

$$E_g = n\, E_p$$

where:

E_g : Generation (GW(h))

E_p : Pumping (GW(h))

To take into account the pumped storage plant operation, modifications were made to several modules (FIXSYS, VARSYS, CONGEN, MERSIM and DYNPRO). The individual pumped storage plants are combined into one equivalent pumping hydro plant described by its pumping potential (pumped storage energy), nominal capacity, cycle efficiency and O&M cost. If a pumped storage plant is active in any year of the study, then the capacity and energy values for the composite hydro plants (HYDA and HYDB) are summed to create a single composite hydro plant which is treated as HYDB and renamed HYDR. The composite hydro plant HYDA is then renamed PUMP and used to represent the generating side of the pumped storage plant. If no pumped storage plant is active, composite plants HYDA and HYDB are treated as in WASP III Plus. The above logic was followed because the same approach of the WASP-II version was applied for the simulation of P-S plant operation in WASP-IV (one composite hydro project and one composite pumped storage project). The operation of pumped storage units is inherently chronological. However, since in the WASP model the load duration oriented simulation is used, this implies an inherent loss of chronological information. The operation of pumped storage plants has, thus, been modelled on period basis.

The pumping process is performed in every period of the year. In order to calculate the potential pumping of the thermal units to fill the "reservoir", the procedure starts from the thermal units which are lower in the loading order and can produce extra energy than that expected (actually produced on the given LDC). For each thermal plant j, the program computes the energy that can be replaced (E_{gj}) by the generation of the pumped storage plant and the energy that is available for pumping (E_{pj}). In the case where the pumped storage plant is able to offset generation from the thermal plant considered (i.e., $E_{gj}>0$), the load is reduced by the generating capacity of the pumped storage plant. In a similar way, when energy is available for pumping purposes (i.e., $E_{pj}>0$), the load for the thermal plant considered is increased by the pumping.

If the thermal block considered shares the place in the loading order with the hydro peaking block, then this complex situation is referred to as the fractional case. The calculation of possible pumped storage plant generation and pumping for the thermal plant considered is in general made by the energy integration in two places: in the actual place and in a displaced position of the thermal plant. This displacement is practically made by the change of the integration limits.

After the energy calculation it is possible to form a complete loading order list of plants, containing energy produced in the system without the pumped storage plant that could be replaced by the pumped storage plant and energy available for pumping purposes at every plant.

The optimal allocation procedure is essentially a search for two power levels which define the pumped storage operation. The largest amount of energy available for pumped storage operation can be determined by summing up generation on a plant by plant basis (pumping from the bottom, generating from the top).

In order to reduce the unserved energy remaining after thermal dispatch and at the same time improve the system reliability, the aggregate pumped storage hydro plant is dispatched in two modes.

- First, the P-S plant is dispatched as though the P-S loading order were a continuation of thermal loading order and P-S generating capacity is to be used for peaking service. This P-S generation is considered compulsory operation and is uneconomical in that it requires additional thermal generation through assignment of pumping duty without any reduction of thermal generation. The pumping duty is assigned to the lowest cost thermal units.

- After the P-S plant is dispatched for compulsory operation it is next considered for economic operation. Economic operation is only possible when the cost of pumping water into the reservoir is cheaper than the cost of thermal generation replaced by the P-S generation. Pumping operation is economic only if:

  $$C_{pi} < n\, C_{gj}$$

  where C_{pi} is the operating cost of thermal unit i participating in pumping operation and C_{gj} is the operating cost of thermal unit j which is being off-loaded by the pumped storage plant. When this inequality is not satisfied the pumping operation stops.

The procedure can result in several different cases:

- First, the available energy may not be sufficient to meet the minimum pumping requirements (for the pumped storage plant as the last plant in the loading order). In this case all the available energy for pumping is used and the procedure stops.
- Second, pumping energy is available but the operation of P-S is not economic because the cost of generation for the thermal plant to be replaced by P-S generation is lower than that of the pumping plant adjusted for P-S efficiency. In this case the P-S operation stops. The procedure also stops when all the P-S generation capability (maximum feasible generation) is exhausted, (the energy not needed is not pumped).

In the procedure presented above, the available energy for pumping in a period considered has to be used in the same period. The procedure does not take into account the possibility of storing energy within one period in order to use it in another subsequent period so to optimise the generation from pumped storage.

12.3. MAINTENANCE SCHEDULING

In the power sector, the scheduling of annual preventive maintenance for generating units is required to ensure the reliable supply of electricity. Removing baseload generating units for maintenance raises the operating cost of the system due to increased production from more expensive units located higher in the loading (merit) order. Withdrawing units would also increase the risk of load shedding; in other words, there is an associated decrease in the level of generating system reliability.

There are several different techniques for allocating the annual maintenance of the generating units within the annual subperiods (months, weeks, etc.). In general the techniques fall into the following two categories:

- levelling the reserve capacity
- levelling the risk

It is necessary to perform the scheduling of annual maintenance for generating units, before proceeding to the production simulation, in order to obtain realistic estimations of the fuel and O & M costs. While the forced outage rate (FOR) of units is captured by the probabilistic production costing methodology, the planned outage of units for maintenance is scheduled in advance in order to minimize generation shortages. The maintenance scheduling of thermal units is performed in the WASP model by applying a technique of “levelling the reserve capacity". In this approach maintenance of a group of units is scheduled so as to level the reserve capacity by placing planned outage of the units into periods of low demands.

While performing annual calculations, the production simulation algorithm (i.e. MERSIM) computes the amount of capacity that will be on maintenance based on the required days of scheduled outage for each unit. In WASP-III Plus, the user is not able to specify a predetermined “fixed” maintenance schedule for a particular generating unit or set of units. In order to make the maintenance scheduling more flexible MERSIM has been modified, in WASP-IV, to allow the user to specify the period(s) within the year (month, season, etc.) to schedule maintenance for a particular unit, set of units, or for all units of the power system. The main characteristics of the improved maintenance scheduling algorithm in WASP-IV are the following:

- Possibility for "fixed" scheduling of maintenance for thermal units,
- Possibility to modify the maintenance schedule of generating units in any year of the study,
- Possibility to cancel the "fixed" maintenance during the planning horizon,
- Possibility to split the total planned outage days of the annual maintenance of the power plants into different subperiods within the annual simulation, and
- Possibility to print a maintenance outage table when the maximum output option is selected in MERSIM.

It should be empasized that to activate the fixed maintenance schedule of the model, additional information is required as input to MERSIM as explained in chapter 7.

Chapter 13

ERROR AND WARNING MESSAGES IN THE WASP-IV CODE

13.1. INTRODUCTION

As mentioned in Chapters 3 to 9, some of the input information to the various WASP-IV modules is checked internally by the programs in order to detect errors in the inputs read from input data files or inconsistencies between information read from the files provided by preceding modules. These checks have been introduced in the various modules for the following purposes:

(1) To avoid upsetting the logic of the program and wasting of time in carrying out calculations (and producing output files) using erroneous data.

(2) To warn the user about the potential sources of errors in the input data which may affect the computations to be carried out by subsequent modules.

(3) To inform the user about errors in the input data which have been corrected by the program in an attempt to complete the current run.

Detection of an error or inconsistency in input information by the respective module, leads to printing of a message in the report of the module and, according to the "severity" of the error or inconsistency detected, two types of messages can be identified:

Error messages: are included for purposes falling under category (1) listed above. They apply in case the error or inconsistency detected affects the execution of the same module such as using a wrong sequence in the input data; exceeding the capabilities of the module for handling and storing information; inconsistencies in input information coming from other modules; etc. This type of error message will normally lead to stop the execution of the program.

Warning messages: are included for purposes listed under categories (2) and (3) above. Since they do not endanger the internal execution of the module considered, the message is printed and the program continues executing.

From the above classification, it is obvious that "error messages" appearing in the printout of a WASP-IV module imply that the corresponding input data have to be revised and corrected in order to remove the error signalized in the report and that the applicable module (or modules) has (have) to be run again until execution of the module considered is completed without errors.

On the other hand, "warning messages" (though less severe) appearing in the report of any WASP-IV module should not be overlooked by the user since removal of the error (or inconsistency) might require correcting input data and re-running the same module before proceeding with the execution of subsequent modules.

Input information is checked more or less sequentially as these data are read by the program. In an attempt to reduce, as much as possible, the number of times the WASP-IV module considered has to be re-run to remove the message(s) and proceed to the subsequent module, some of the checks are carried out in a combined way so that the execution of the program is stopped after all combined checks have been performed, only if one of these ‘validity’ checks is not fulfilled. This is particularly important for the initial phase of input data validation and debugging of programs of a WASP study (see Section 10.2) when several errors in input data are likely to be detected.

The following sections describe the error and warning messages of the WASP-IV modules. Tables 13.1 to 13.7 summarize these messages for modules LOADSY through REPROBAT in the same order as they are described in the manual.

These tables show: the general form of the messages, description of each message, and which actions should be taken by the user for further runs. The general form for most messages (shown at the top of each table) is:

***** A IE ***** EC TEXT

According to this, an error (or warning) message starts (in column 1 of the line) with five asterisks (*), followed by a letter (A) identifying the module involved (L for LOADSY, F for FIXSYS, etc.) and a number (IE) corresponding to the code number assigned to the message (see Tables 13.1 to 13.7). This is followed by five asterisks, a number (EC) corresponding to the counter of accumulated errors and finally, the message (TEXT). Depending on the error involved, the message may occupy one or several lines of the printout as shown in the tables and in the sample of Fig.13.1.

Regarding the instructions for the user given in the tables, it should be noted that they correspond to those runs when an error or inconsistency exists in the data and when the case under study respects the capabilities of the WASP-IV code as summarized in Table 1.1. Case studies not respecting these capabilities (for example considering more than 12 periods per year or more than 14 expansion candidate plants, etc.) cannot be analyzed by WASP-IV, unless the code is modified for appropriate dimensioning of the applicable variables in the various modules.

13.2. MESSAGES IN LOADSY

Table 13.1 shows the messages in LOADSY connected with erroneous input data. This table starts with the general form for all messages (as described in the introduction), followed by a description of each message containing: the *code number* (IE) assigned to the message; the *text* to be printed by the computer; the *type* of message; and the *instructions* for the user how to overcome the problem in case the message appears in the LOADSY printout.

Everything in the TEXT (characters, blanks, periods, etc.) as shown in Table 13.1 corresponds, as close as possible, to the printing formats in the program, except that characters (#) are used here to identify digits to be printed by the computer. It can also be seen in the table that all messages are of the error type; thus, leading to stop the program execution. All other information in Table 13.1 (complemented with the indications given in Section 3.2 and Table 3.1) is considered to be self-explanatory.

Table 13.1. Messages in the LOADSY Module of WASP-IV

GENERAL FORM FOR ALL MESSAGES: ******* L IE ***** EC TEXT**			
DESCRIPTION OF MESSAGES			
IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
1	NO. OF PERIODS =#### (MAX PERMISSIBLE = 12)	Error	Correct value of NPER in record type-A and rerun the program
2	NO. OF FOURIER COEFFICIENTS =#### (MAX. PERMISSIBLE = 100)	Error	Correct value of NOCOF in record type-A and rerun the program
3	CHECK VALUE ON INDEX RECORD####	Error	Revise the sequence and INDEX values in the input data, correct and rerun
4	NP MUST BE EQUAL NPER FOR FIRST YEAR OF STUDY, NP =#### NPER=####	Error	Correct value of NP in record type-4 of first year and rerun the program
5	NP EXCEEDS MAXIMUM OF NPER, NP =#### NPER =####	Error	Correct value of NP in record type-4 of applicable year and rerun the program
6	SEQUENCE OF PERIODS TO BE CHANGED IS WRONG, IPER (###) =####	Error	Correct values of IPER in record type-4 and rerun the program
7	NO. OF LDC POINTS (NPTS) OF PERIOD TO BE ASSIGNED (IPER) AND PERIOD TO BE COPIED (IO) INCONSISTENT, IPER =#### NPTS =#### IO =#### NPTS =####	Error	Correct value of NPTS in record type-4a for period IPER and rerun the program
8	PERIOD TO BE COPIED (IO) EXCEEDS PERIOD TO BE ASSIGNED (IPER), IO =#### IPER =####	Error	Correct value of IO in record type-4a for period IPER and rerun the program
99	ERROR(S) ACCUMULATED THROUGH THIS RUN	Error	Correct the indicated errors as instructed above

Figure 13.1 shows a sample of a LOADSY run of the case example (DEMOCASE) in which some erroneous data have been deliberately used. In this case 14 periods per year and 150 Fourier coefficients were specified in the data record type-A for the run (as shown in the upper part of the figure). Hence, error messages (IE=) 1 and (IE=) 2 of LOADSY are shown in the report. Before the program stops executing, the error message (IE=) 99 is also printed to show the accumulated number of errors in the run.

Part of LOADSY input with erroneous data

```
 DEMOCASE: CASE STUDY FOR THE WASP-IV USERS MANUAL
14 150  1
 6000. 1997
 2
 0.90  0.87  0.93  1.00
 3
  1.0000   -3.6000   16.6000   -36.8000   36.0000  -12.800
  1.0000   -3.0000   13.8500   -31.2000   31.0000  -11.200
  1.0000   -3.0000   13.8500   -31.2000   31.0000  -11.200
  1.0000   -3.6000   16.6000   -36.8000   36.0000  -12.800
 1      (END OF 1997)
6333.0 1998
 1      (END OF 1998)
```

Printout of LOADSY run with erroneous data

```
***** L 1 *****  1  NO. OF PERIODS = 14 (MAX. PERMISSIBLE = 12)

***** L 2 *****  2  NO. OF FOURIER COEFFICIENTS =150 (MAX. PERMISSIBLE=100)


                  WASP COMPUTER PROGRAM PACKAGE

                       LOADSY MODULE

                       CASE STUDY

             DEMOCASE: CASE STUDY FOR THE WASP-IV USERS MANUAL

             **********************************************************
             *                             *
             *      NUMBER OF PERIODS PER YEAR = 14       *
             *                             *
             *      HOURS IN EACH PERIOD =  625.71       *
             *                             *
             *   NUMBER OF COEFFICIENTS OF COSINE TERMS      *
             *   IN FOURIER APPROXIMATION OF THE L.D.C. = 150   *
             *                             *
             **********************************************************

     ***** L 99 *****  2  ERROR(S) ACCUMULATED THROUGH THIS RUN
```

Figure 13.1. Sample of a LOADSY run for DEMOCASE using erroneous data.

13.3. MESSAGES IN FIXSYS

The FIXSYS error messages are listed and described in Table 13.2 which is also self-explanatory (complemented with the respective explanations given in Section 4.2 and Table 4.1).

In addition to the comments made in Section 13.2, also valid in this case, the following remarks can be made about Table 13.2:

- The TEXT of some messages includes characters (AAAA) to identify alphanumeric variables to be printed by the program.

- *Message (IE=) 6* may affect thermal plants or hydroelectric projects. It occurs when any of the following conditions are encountered for the indicated thermal power plant (or hydro project) AAAA:

  (a) for thermal plants, when the input data for plant AAAA specifies the plant with either MWB = 0.0 or MWB > MWC of the same plant.

  (b) for hydro projects, when project AAAA (for the period and hydro condition involved) has inflow energy equal to, or greater than, the total generating capacity of the project (i.e. leading to printing of error message IE=11 as described below) and the resulting base block of capacity (MWB) calculated by HYRUN is greater than the total available capacity (HMWC) specified for the same project. In this case, the resulting peak capacity block (MWP) of the project would be negative and consequently the characteristics of the composite hydro plant that includes this project would be wrong.

Detection of this condition does not lead to stop the program execution, i.e. it is treated by FIXSYS as a warning message, so as to allow checking of more input data in the same run. However, this message has been classified as an "error" message in Table 13.2 in order to warn the user that the message should be removed from the FIXSYS report (correcting the applicable input data and re-running FIXSYS) before proceeding to execute subsequent modules. In particular, if the message affects some hydro projects, the results of CONGEN and MERSIM would be wrong since erroneous values of the composite hydro plant characteristics would be used. Furthermore, in MERSIM whenever the condition MWB = 0.0 or MWB > MWC is encountered for a thermal plant, this is treated by MERSIM as an error message.

- *Messages (IE=) 11, 12* appear in the FIXSYS printout when the respective condition explained in the TEXT (see Table 13.2) occurs for the associated hydro project. Similar to message (IE=6), these messages are also treated as warning messages (i.e., execution of the program continues) to permit checking of more input data in the same run, but they have been classified as "warning" messages to indicate that the user should verify the input data and try to remove the message before proceeding to run subsequent modules. It should be noted that, depending on the specific characteristics of the hydro project, it may not be possible to remove the message for all hydro conditions and periods involved. If so, neglect the message and proceed with subsequent WASP modules.

Table 13.2. (page 1) Messages in the FIXSYS Module of WASP-IV

GENERAL FORM FOR ALL MESSAGES: ****** F IE ***** EC TEXT**

DESCRIPTION OF THE MESSAGES:

IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
1	NO. OF PERIODS =#### (MAX. PERMISSIBLE =12)	Error	Correct value of NPER in data record type-A and rerun the program
2	TOTAL NO. OF THERMAL PLANTS =#### (MIN. = 1, MAX. PERMISSIBLE = 88)	Error	Correct value of NTHPL on data record type-A and rerun the program
3	NO. OF HYDRO CONDITIONS = ## (MAX. PERMISSIBLE =5)	Error	Correct value of IHYDIS on data record type-A and rerun the program
4	ERROR IN HYDROPROBABILITY VALUE NO.## (MUST BE > 0.0)	Error	Correct value of PROBH(##) on data record type-A and rerun the program
5	ERROR IN HYDROPROBABILITIES SUM = ##.### (TOTAL MUST BE = 1.0)	Error	Correct values of PROBH on data record type-A and rerun the program
6	CHECK MWB AGAINST MWC OF PLANT AAAA	Error	Correct applicable values on: record type-B for thermal plant AAAA, or record type-2b for hydroelectric project AAAA and rerun the program
7	NAME OF HYDRO PROJECT AAAA INCONSISTENT WITH HYDRO TYPE NAMES	Error	Correct value of TNAME on record type-2a for hydro project AAAA and rerun the program
8	CHECK VALUE ON INDEX RECORD####	Error	Revise sequence and INDEX values of the input data, correct and rerun the program
9	RECORD(S) FOLLOWING INDEX ## IS/ ARE MISSING	Error	Include missing input data for hydro project (or pumped storage project) and rerun the program

Table 13.2 (page 2) Messages in the FIXSYS Module of WASP-IV

GENERAL FORM FOR ALL MESSAGES: ****** F IE ***** EC TEXT**			
DESCRIPTION OF THE MESSAGES:			
IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
10	INDEX OF THERMAL PLANT ### CONSIDERED FOR ADDITION OR RETIREMENT OR # OF RETIRED UNITS IS WRONG	Error	Check index (NS) on applicable data record type-3, correct and rerun the program
11	WARNING INFLOW ENERGY EXCEEDS MAX. GEN. CAPABILITY IN ## HYDRO CONDITIONS (KEY = 5); RED. BY PROGRAM	Warning	Check and correct input data on record type-2b for associated hydro project in period and hydro condition indicated with KEY=5 or KEY=6 and rerun the program. If, owing to the project characteristics, the message cannot be removed neglect the message and proceed to other WASP modules.
12	WARNING MINIMUM REQUIRED ENERGY EXCEEDS INFLOW ENERGY IN ## HYDRO CONDITIONS (KEY = 6)	Warning	
13	PLANT AAAA SPECIFIED AS SINGLE BLOCK WITH ISPIN > 0	Warning	Verify ISPIN and capacities of plant AAAA if L.O. is to be calculated by MERSIM. If data incorrect, modify it and rerun the program. If data correct, or L.O. is given by the user, neglect this message and proceed to other modules.
14	CHECK VALUE OF NID = ### ON RECORD TYPE - X (PERMISS. 0 TO 9)	Error	Correct the value on record type -X and rerun the program.
15	NUMBER OF GROUP-LIMITATIONS = ## (MAX. PERMISSIBLE =5)	Error	Correct the value of NGROUPLM on record type-C and rerun the program
16	INDEX OF GROUP LIMITATIONS WRONG = ## (MUST BE 1 TO 5)	Error	Check the values of MEASIND, correct and rerun the program

Table 13.2 (page 3) Messages in the FIXSYS Module of WASP-IV

GENERAL FORM FOR ALL MESSAGES: ****** F IE ***** EC TEXT**

DESCRIPTION OF THE MESSAGES:

IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
17	PLANT INDEX #### OF REAL EMISSION ## IS WRONG	Error	Check the plant index, correct and rerun the program (range, descending order)
18	PLANT INDEX #### OF GROUP LIMITATION ## IS WRONG	Error	Check the plant index, correct and rerun the program (range, descending order)
19	COMPOSITE INSTALLED CAP. OF HYDRO TYPE AAAA IS #### MW	Error	Check the installed capacities of hydro projects retired, correct and rerun the program
20	COMPOSITE INSTALLED CAP. OF P-S PLANT PUMP IS #### MW	Error	Check the installed capacities of P-S projects retired, correct and rerun the program
21	MAX. FEASIBLE ENERGY GEN. OF PERIOD ## EXCEEDS MAX. INSTALLED GEN. CAPABILITY, RED BY PROGRAM	Warning	Check the period max. feasible generation by pumped storage plant against installed cap.
22	MAX. FEASIBLE ENERGY GEN. OF PERIOD ## EXCEEDS MAX. PERIOD GEN. CAPABILITY, RED BY PROGRAM	Warning	Check the period max. feasible generation by pumped storage plant against period generation
24	GEN. CAPACITY IN PERIOD ##GREATER THAN INSTALLED CAPACITY	Warning	Check the input data for hydro project
25	AVAILABLE CAP. IN PERIOD ## FOR HYDROCOND. ## GREATER THAN INSTALLED CAPACITY	Warning	Check the input data for P-S project
26	CHECK SUM OR IND. PERIOD RATIO OF GROUP LIMITATION ##	Error	Correct the values and rerun the program
98	ERROR(S) ACCUMULATED THROUGH THIS YEAR ####	Error	Follow the instructions according to the errors encountered
99	ERROR(S) ACCUMULATED THROUGH THIS RUN	Error	Correct the indicated errors as instructed above

- *Message (IE=) 13* occurs when the indicated thermal plant AAAA has been specified as a single block unit (MWB=MWC) but with spinning reserve (ISPIN) not equal 0. This is to warn the user of the possible consequence that such a definition may have on the calculations to be performed later by the MERSIM module and more specifically, if MERSIM is requested to generate the loading order (L.O.) to be used in the simulation of system operation. If, on the contrary, the L.O. to be used by MERSIM is completely specified by the user (fixed L.O.), neglect this message and proceed to subsequent modules.

- *Messages (IE=) 15–18* are related to Group Limitation and Real Emission inputs. These errors can be rectified following the instructions in Table 13.2.

- *Messages (IE=) 19 and 20* occur when the indicated composite hydro (or pumped storage) plant AAAA has negative installed capacity due to wrong retirements. The inputs of all hydro (pumped storage) projects should be checked to remove the message.

- *Messages (IE=) 21–25* are warnings and would occur when there is some unusual input for energies or capacities of hydro (or pumped storage) projects. The results should be reviewed carefully and if found acceptable these warning messages may be ignored.

Other messages from the Table 13.2 are self-explanatory.

13.4. MESSAGES IN VARSYS

Table 13.3 summarizes the error messages in the VARSYS module. The remarks made in Section 13.3 (concerning Table 13.2) for similar error messages in FIXSYS module are also applicable to the information presented in Table 13.3. Other messages, e.g. Messages (IE=) 26 and 27 are self-explanatory and can be removed by following the instructions given in Table 13.3. See also the indications given in Section 5.2 and Table 5.1 which complement the information presented in Table 13.3.

Table 13.3. Messages in the VARSYS Module of WASP-IV

GENERAL FORM FOR ALL MESSAGES: ****** V IE ***** EC TEXT**			
DESCRIPTION OF THE MESSAGES:			
IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
1	NO. OF PERIODS =#### (MAX. PERMISSIBLE =12)	Error	Correct value of NPER in record type-A and rerun the program
2	TOTAL NO. OF THERMAL ALTERNATIVE PLANTS =#### (MAX. PERMISSIBLE =12, OR 11 WHEN P-S IS USED)	Error	Correct value of NTHPL in record type-A and rerun the program
3	NO. OF HYDRO CONDITIONS = ## (MAX. PERMISSIBLE =5)	Error	Correct value of IHYDIS on record type-A and rerun the program
4	ERROR IN HYDROPROBABILITY VALUE NO. ## (MUST BE > 0.0)	Error	Correct value of PROBH(##) on record type-A and rerun the program
5	ERROR IN HYDROPROBABILITIES SUM = ##.### (TOTAL MUST BE = 1.0)	Error	Correct values of PROBH on record type-A and rerun the program
6	CHECK MWB AGAINST MWC OF PLANT AAAA	Error	Correct applicable values on: record type-B for thermal plant AAAA, or record type-2b for hydro project AAAA, and rerun the program
7	NAME OF HYDRO PROJECT AAAA INCONSISTENT WITH HYDRO TYPE NAMES	Error	Correct value of TNAME on record type-2a for hydro project AAAA and rerun the program
11	WARNING INFLOW ENERGY EXCEEDS MAX. GEN. CAPABILITY IN ## HYDRO CONDITIONS (KEY =5); RED. BY PROGRAM	Warning	Check and correct appropriate data on record type-2b for the associated hydro project in period and hydro condition indicated with KEY=5 or KEY=6 and rerun the program. Otherwise neglect the message and proceed to other WASP modules (see Section 13.3 for details)
12	WARNING MINIMUM REQUIRED ENERGY EXCEEDS INFLOW ENERGY IN ## HYDRO CONDITIONS (KEY =6)	Warning	

Table 13.3. (page 2) Messages in the VARSYS Module of WASP-IV

GENERAL FORM FOR ALL MESSAGES: ****** F IE ***** EC TEXT**			
DESCRIPTION OF THE MESSAGES:			
IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
13	PLANT AAAA SPECIFIED AS SINGLE BLOCK WITH ISPIN > 0	Warning	Verify ISPIN and capacities of plant AAAA if L.O. is to be calculated by MERSIM. If incorrect, modify and rerun VARSYS. If data correct or L.O. is given by the user, neglect the message, and proceed to other modules
14	CHECK NO. OF AAAA PROJECTS = ####, AGAINST INPUT OF MAXIMUM= ####	Error	Correct the number of hydro projects of type AAAA included in the VARSYS and rerun the program
15	NUMBER OF GROUP-LIMITATIONS = ## (MAX. PERMISSIBLE =5)	Error	Correct the value of NGROUPLM on record type-C and rerun the program
16	INDEX OF GROUP LIMITATIONS WRONG = ## (MUST BE 1 TO 5)	Error	Check the values of MEASIND, correct and rerun the program
17	PLANT INDEX #### OF REAL EMISSION ## IS WRONG	Error	Check the plant index, correct and rerun the program (range, descending order)
18	PLANT INDEX #### OF GROUP LIMITATION ## IS WRONG	Error	Check the plant index, correct and rerun the program (range, descending order)

Table 13.3. (page 3) Messages in the VARSYS Module of WASP-IV

GENERAL FORM FOR ALL MESSAGES: ****** F IE ***** EC TEXT**			
DESCRIPTION OF THE MESSAGES:			
IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
19	INSTALLED CAP. OF PROJECT #### OF HYDRO TYPE AAAA IS #### MW	Error	Check the installed capacity of hydro project, correct and rerun the program
20	INSTALLED CAP. OF PROJECT #### OF P-S PLANT PUMP IS #### MW	Error	Check the installed capacity of P-S project, correct and rerun the program
21	MAX. FEASIBLE ENERGY GEN. OF PERIOD ## EXCEEDS MAX. INSTALLED GEN. CAPABILITY, RED BY PROGRAM	Warning	Check the period max. feasible generation by pumped storage plant against installed capability
22	MAX. FEASIBLE ENERGY GEN. OF PERIOD ## EXCEEDS MAX. PERIOD GEN. CAPABILITY, RED BY PROGRAM	Warning	Check the period max. feasible generation by pumped storage plant against period generation
24	GEN. CAPACITY IN PERIOD ## GREATER THAN INSTALLED CAPACITY	Warning	Check the input data for P-S project
25	AVAILABLE CAP. IN PERIOD ## FOR HYDROCOND. #### GREATER THAN INSTALLED CAPACITY	Warning	Check the input data for hydro project
26	CHECK NO. OF AAAA PROJECTS = ###, AGAINST POSSIBLE MAXIMUM OF 30	Error	A maximum of 30 projects for each of the two hydro types can be included in VARSYS. Correct the input and rerun the program
27	CHECK NO. OF P-S PROJECTS = ###, AGAINST POSSIBLE MAXIMUM OF 30	Error	A maximum of 30 P-S projects can be included in VARSYS. Correct the input and rerun the program
99	ERROR(S) ACCUMULATED THROUGH THIS RUN	Error	Correct the indicated errors as instructed above

13.5. MESSAGES IN CONGEN

The error and warning messages in CONGEN are summarized in Table 13.4 in the same way as for the previous WASP-IV modules but differentiating the messages produced by MAIN from those coming from subroutines of the program.

13.5.1. Messages coming from MAIN

These messages follow the general form shown at the top of Table 13.4. The following comments can be made about these messages:

- *Messages (IE=) 1 to 8* are self-explanatory.

- *Message (IE=) 9* is printed along with the information of capacity range and committed capacity for the year (see Fig. 6.2, page 3) when the condition explained in the TEXT occurs. If some of the accepted configurations for the respective year appear in the printout marked with *message (IE=) 12*, the user should modify the value of RSVMX (data record type-4) applicable for the year and re-run CONGEN before proceeding to execute the corresponding MERSIM run. In some cases, however, this situation cannot be avoided without eliminating configurations of interest for the user and, if so, the user should be aware of the possible inaccuracy in the calculations of LOLP and energy not served carried out by the MERSIM module.

- *Message (IE=) 10*: If the CONGEN run has been successfully completed and the accepted configurations for each year are satisfactory, the user may ignore this message and proceed to subsequent modules. For further CONGEN runs (or if the current run is not satisfactory), correct the applicable constraints on the maximum reserve margin before rerunning the program.

- *Message (IE=) 11:* This message is self-explanatory. The total number of plants in a system may be reduced to fit the maximum number that can be handled in WASP by lumping together some of the similar plants in FIXSYS.

- *Message (IE=) 13* is also self-explanatory. Although it corresponds to a warning message (execution continues), the program should be re-run with corrected data before proceeding to subsequent modules. The execution of MERSIM and DYNPRO is controlled by the latest CONGEN file so that their execution is stopped if no states are defined in the CONGEN file for a given year.

- *Message (IE=) 14* tells the user that some of the possible configurations for the applicable year could not be examined by the program. In principle, it is suggested to revise and modify the constraints on number of units (or projects) of each candidate plant, and/or reserve margins, and re-run the program before proceeding to MERSIM.

- *Message (IE=) 15* is also a warning message which requires correction of input data and re-running CONGEN before proceeding to MERSIM/DYNPRO, particularly since DYNPRO cannot handle more than 5000 configurations (states) of the system in a single run.

Table 13.4. (page 1) Messages in the CONGEN Module of WASP-IV

GENERAL FORM FOR ALL MESSAGES: ***** C IE ***** EC TEXT			
DESCRIPTION OF THE MESSAGES COMING FROM MAIN			
IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
1	FIXED SYSTEM & VARIABLE ALTERNATIVE FILES INCOMPATIBLE NUMBER OF SEASONS IN FIXSYS = ## IN VARSYS = ##	Error	Correct input data of FIXSYS or VARSYS, rerun applicable program and rerun CONGEN
2	FIXED SYSTEM & VARIABLE ALTERNATIVE FILES INCOMPATIBLE NO. OF HYDRO CONDITIONS IN FIXSYS = ## IN VARSYS =##	Error	Same instruction as for error 1 above
3	FIXED SYSTEM & VARIABLE ALTERNATIVE FILES INCOMPATIBLE NAME OF HYDRO TYPE ## IN FIXSYS = AAAA IN VARSYS = AAAA	Error	Same instructions as for error 1 above
4	LOAD FILE INCOMPATIBLE WITH FIXED AND VARIABLE SYSTEM FILES NO. OF SEASONS IN LOADSY = ## IN VARSYS = ##	Error	Correct input data of LOADSY or FIXSYS/VARSYS, rerun applicable program(s) and resubmit CONGEN
5	FIXED SYSTEM & LOAD DESCRIPTION FILES INCOMPATIBLE CURRENT YEAR IN FIXSYS = #### IN LOADSY = ####	Error	Correct input data of LOADSY or FIXSYS, rerun applicable program and rerun CONGEN
6	CHECK VALUE ON INDEX RECORD ####	Error	Check and correct CONGEN input data and rerun the program
7	NO. OF H-PROJ.#### OF HYDRO TYPE AAAA GREATER THAN MAX NO. OF ALTERN PROJ.###	Error	Correct No. of Hydro projects (records type-2 and 3) of indicated type in the applicable year and rerun CONGEN
8	HYDRO PROJECT#### OF HYDRO TYPE AAAA VIOLATES AVAILABLE YEAR	Error	Correct No. of Hydro project of indicated type respecting the year of availability in VARSYS and rerun the program
9	MAX RES MARGIN PERMITS INSTALLED CAPACITIES ABOVE CAPACITY CRITICAL TO FOURIER METHOD (PEAK + 2 * MIN. LOAD)	Warning	See Section 13.5.1 for instructions

Table 13.4. (page 2) Messages in the CONGEN Module of WASP-IV

DESCRIPTION OF THE MESSAGES COMING FROM MAIN (cont.)			
IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
10	CAPACITY OF CONFIGURATION ABOVE CAPACITY RANGE, BUT WILL BE ACCEPTED	Warning	This message apply when the minimum configuration in the first year of study exceeds indicated constraints. It may also occur in any subsequent year of study provided that related configuration is identical to an accepted configuration in preceding year. See Section 13.5.1 for instructions.
11	TOTAL NUMBER OF PLANTS IN FIXSYS AND VARSYS = ####; (THERMAL + HYDRO + PUMP); MAX. PERMISSIBLE FOR THERMAL + HYDRO + PUMP = 90	Error	Correct the input data and rerun the relevant modules. See section 13.5.1 for instructions
12	INSTALLED CAPACITY EXCEEDS CRITICAL CAP.	Warning	See Section 13.5.1 for instructions
13	***NO STATES DEFINED***	Warning	Correct constraints for applicable year and rerun the program
14	***EXCEEDS 500***	Warning	See Section 13.5.1 for instructions
15	TOTAL NO. OF CONFIGURATIONS =##### (MAX. PERMISSIBLE = 5000)	Warning	Modify constraints and rerun the program
16	***** WARNING: IF APPLICABLE, EITHER 1 INCREASE NUMBER OF FOURIER COEFF. TO MINIMUM REQUIRED FOR IMPROVING THE LOLP CALCULATION AND/OR 2 THE INSTALLED CAPACITY OF THE MARKED CONFIGURATION(S) IS EQUAL OR GREATER THAN THE CAPACITY CRITICAL TO FOURIER METHOD (PEAK + 2*MIN. LOAD). LOLP IS SET TO ZERO (AS IS ALSO UNSERVED ENERGY IN MERSIM) NUMBER OF MARKED CONFIGURATION(S) FOR BOTH CASES:#####	Warning	This applies when error message IE=12 and IE=17 are encountered. The text is self-explanatory. See Section 13.5.1 for more details
17	MINIMUM OF NOCOF MUST BE#####	Warning	See Section 13.5.1 for instructions

Table 13.4. (page 3) Messages in the CONGEN Module of WASP-IV

DESCRIPTION OF THE MESSAGES COMING FROM MAIN (cont.)			
IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
18	FIXED SYSTEM AND SIMULOLD FILES INCOMPATIBLE CURRENT YEAR IN FIXSYS = #### IN MERSIM = ####	Error	Check status of SIMULOLD file and if it was renamed after last iteration, or the name of FIXSYS file.
19	GIVEN CRITICAL HYDRO CONDITION = ## EXCEEDS POSSIBLE NUMBER OF H.C. DEFINED IN FIXSYS OR VARSYS = ##. RESET TO 1 BY PROGRAM	Warning	Correct the value of IHCRIT in record type-8 and rerun the program.
20	NO. OF P-S PLANT #### GREATER THAT MAX. NO. OF ALTERN P-S PLANTS	Error	Correct the number of P-S projects (records 2 and 3) in the applicable year and rerun the program
21	P-S PLANT #### VIOLATER AVAILABLE YEAR ####	Error	Correct the number of P-S projects respecting the year of availability in VARSYS and rerun the program
98	ERROR(S) AND/OR WARNING(S) ACCUMULATED THROUGH THIS YEAR	- - -	Follow instructions according to message in the printout
99	ERROR(S) AND/OR WARNING(S) ACCUMULATED THROUGH THIS RUN	- - -	Same instructions as for error 98 above

FORM AND DESCRIPTION OF SPECIAL ERROR MESSAGES COMING FROM SUB-ROUTINES			
OF SUBROUTINE	ERROR MESSAGE	TYPE	ACTIONS TO BE TAKEN BY THE USER
READFC	ERROR ON FILE ## COMING FROM READFC, IR-###	Error	See Section 13.5.2 for instructions

- *Message (IE=) 16* is printed by CONGEN at the end of the report and if either of the messages (IE=) 12 or 17 is also included in the printout. The last line of the text (see Table 13.4) gives the cumulative number of times (#####) that messages 12 or 17 are encountered in the printout.

- *Message (IE=) 17*: This message appears connected to a given configuration to tell the user that the number of Fourier coefficients defined in LOADSY is less than the minimum required (NOCOF) for accurate calculation of LOLP for this configuration. If the same message applies to several configurations of interest for the user and if the value of NOCOF is considerably lower than (or eventually equal to) 100, correct the LOADSY input data and re-run LOADSY and then CONGEN. High values of NOCOF (> 100) normally occur when the installed capacity of the configurations exceeds the critical capacity for the Fourier method and they should be treated as explained for the error message (IE=) 12.

- *Messages (IE=) 18–21* are self-explanatory.

- *Messages (IE=) 98, 99*: The description in Table 13.4 is self-explanatory; however, no TYPE has been indicated for any of these messages since their classification is dependent on the type of other messages appearing in the printout for the run.

13.5.2. Special message coming from subroutine READFC

This is listed at the bottom of Table 13.4 (page 3) and corresponds to errors detected by subroutine READFC while reading the files created by FIXSYS and VARSYS. The message identifies the respective file by its number (10 for FIXSYS and 11 for VARSYS), the subroutine where the error was detected, and the number of the record involved.

This type of error occurs when the first record expected to be read (from the applicable file) by the corresponding subroutine does not contain the right information. Since they are normally connected with the system control of the file, it is suggested to contact the WASP analyst to solve the problem.

13.6. MESSAGES IN MERSIM

Table 13.5 lists the messages in MERSIM connected with erroneous input data in the same fashion as presented for module CONGEN in Section 13.5.

13.6.1. Messages coming from MAIN

Although the descriptions of these messages as given in Table 13.5 are considered self-explanatory, some additional comments are necessary since correction of the errors at this stage may involve more than one module.

- *Messages (IE=) 1 to 6, 8 to 10* normally occur when any of the LOADSY, FIXSYS or VARSYS modules has been re-run after successful execution of CONGEN (in which some of these validity checks are equally performed) and new values for the applicable variables are used in the run. Removal of these error messages from the MERSIM printout usually requires correcting input data and re-running the applicable program(s) and then resubmitting MERSIM for execution. As stated in Table 13.5, it may be necessary to re-run CONGEN before executing the new MERSIM run.

- *Message (IE=) 7*: In principle the maximum number of plants to define in FIXSYS is: 90 minus the total number of VARSYS plants, but it is recommended to reduce the number to be used in a case study in order to decrease the computer time required for the simulation of system operation and the length of printouts.

- *Message (IE=) 13* occurs when in the loading order (record type-2a) the peak block of the given plant (the plant number appears in the message) is considered before the corresponding base block or when a peak block appears in the loading order although MWB=MWC for the given plant (single block plants must be specified in the L.O. by the base block only).

- *Message (IE=) 16*: If this message appears in the MERSIM printout, the user should verify that the number of Fourier coefficients used for the simulations carried out in the current run corresponds to the intended value and that it is the same for simulations previously performed (stored in SIMULOLD file).

- *Message (IE=) 17* informs the user that the current EXPANALT file does not contain any configuration for the indicated year and that the user should rerun CONGEN before executing MERSIM again.

- *Message (IE=) 18, 19* indicate to the user that the loading order instructions are inconsistent; i.e. that the variable NOLO has been specified with a value of "1", but no basic economic loading order is included in the input data (for IE=18), or that the values of NOLO and SPNVAL are inconsistent as indicated by the text of this message (for IE=19).

- *Messages (IE=) 98, 99*: Same remarks as in Section 13.5.1.

13.6.2. Special message coming from subroutine READFM and DIVLIM

Same remarks as in Section 13.5.2 for similar errors in CONGEN.

Message (IE=) 25 see description in Table 13.5

Table 13.5. (page 1) Messages in the MERSIM Module of WASP-IV

GENERAL FORM FOR ALL MESSAGES: ***** **M IE** ***** **EC TEXT**			
DESCRIPTION OF THE MESSAGES COMING FROM MAIN			
IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
1	FIXED SYSTEM & VARIABLE ALTERNATIVE FILES INCOMPATIBLE NUMBER OF SEASONS IN FIXSYS = ## IN VARSYS = ##	Error	Correct input data to FIXSYS or VARSYS, rerun applicable program. Rerun first CONGEN and then MERSIM
2	FIXED SYSTEM & VARIABLE ALTERNATIVE FILES INCOMPATIBLE NO. OF HYDRO CONDITIONS IN FIXSYS = ## IN VARSYS = ##	Error	Same instructions as for error message 1 above
3	FIXED SYSTEM & VARIABLE ALTERNATIVE FILES INCOMPATIBLE PROBABILITY OF HYDRO CONDITION ## IN FIXSYS = #.### IN VARSYS = #.###	Error	Same instructions as for error message 1 above
4	FIXED SYSTEM & VARIABLE ALTERNATIVE FILES INCOMPATIBLE NAME OF HYDRO TYPE ## IN FIXSYS = AAAA IN VARSYS = AAAA	Error	Same instructions as for error message 1 above
5	FIXED SYSTEM & VARIABLE ALTERNATIVE FILES INCOMPATIBLE OPER AND MAINT COSTS OF HYDRO PLANT ## IN FIXSYS = #.### IN VARSYS = #.###	Error	Same instructions as for error message 1 above
6	LOAD FILE INCOMPATIBLE WITH FIXED & VARIABLE SYSTEM FILES NO. OF SEASONS IN LOADSY = ## IN VARSYS = ##	Error	Correct data in LOADSY or FIXSYS/VARSYS, rerun applicable program(s). Rerun CONGEN and then MERSIM
7	FIXED + VARIABLE SYSTEMS INCLUDE: ### PLANTS (MAX. PERMISSIBLE = ###	Error	Reduce No. of FIXSYS plants (MAX = 90 - VARSYS plants) Rerun FIXSYS, then CONGEN and finally MERSIM

Table 13.5. (page 2) Messages in the MERSIM Module of WASP-IV

DESCRIPTION OF THE MESSAGES COMING FROM MAIN (cont.)			
IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
8	CONFIGURATION GENERATOR FILE & SYSTEM DESCRIPTION FILES INCOMPATIBLE NUMBER OF SEASONS IN CONGEN = ## IN VARSYS = ##	Error	Check number of seasons in data of LOADSY/FIXSYS/ VARSYS. If incorrect rerun all modules up to MERSIM inclusive. If correct rerun first CONGEN and then MERSIM
9	CONFIGURATION GENERATOR FILE & SYSTEM DESCRIPTION FILES INCOMPATIBLE NUMBER OF EXPANSION CANDIDATES IN CONGEN= ## IN VARSYS= ##	Error	Check No. of VARSYS plants. If incorrect rerun VARSYS, CONGEN, MERSIM. If correct rerun CONGEN/MERSIM
10	FIXED SYSTEM & LOAD DESCRIPTION FILES INCOMPATIBLE CURRENT YEAR IN FIXSYS = #### IN LOADSY = ####	Error	Check input data to LOADSY or FIXSYS, correct and rerun applicable program. Rerun CONGEN and MERSIM
11	CHECK VALUE ON INDEX RECORD ###	Error	Revise record sequence and INDEX values in MERSIM input data, correct and rerun the program
12	CHECK MWB AGAINST MWC OF PLANT AAAA	Error	Correct capacity data of plant AAAA in FIXSYS or VARSYS. Rerun applicable program. If new value of MWC for plant AAAA is used, rerun CONGEN and MERSIM
13	PLANT NO.### IS WRONG IN POSITION NO.### OF LOADING ORDER	Error	Correct L.O. (data record type-2a) and rerun the program
14	HYDRO PLANT### APPEARS IN LOADING ORDER	Error	Same instructions as for error message 13 above
15	PLANT NO.#### IS NOT INCLUDED IN LOADING ORDER	Error	Same instructions as for error message 13 above
16	NEW NUMBER OF FOURIER COEFF. EXCEEDS MAXIMUM PERMITTED, WILL BE SET TO MAXIMUM	Warning	Correct value of NOCOF (data record type-5) for further MERSIM runs. If no other error, proceed to DYNPRO

Table 13.5. (page 3) Messages in the MERSIM Module of WASP-IV

DESCRIPTION OF THE MESSAGES COMING FROM MAIN (cont.)			
IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
17	*** NO STATES DEFINED IN YEAR:##### ***	Error	Modify constraints in CONGEN, rerun the program and verify that all years contain at least one configuration in the printout. Rerun MERSIM.
18	BASIC ECONOMIC LOADING ORDER MUST BE DEFINED IN FIRST YEAR! NOLO = ##	Error	Correct record type-2 with (NOLO cannot be specified as 1 in the first year) and rerun MERSIM.
19	CHECK CONFLICTING VALUES OF SPNVAL = #.# AND NOLO = #.#	Error	Correct record type-2 (SPNVAL cannot have values < 0.0 if NOLO = -1) and rerun MERSIM
20	PLANT NO. #### FIXED MAINTENANCE DAYS : #### DIFFERENT THAN IN FIXED OR VARIABLE SYSTEM : ####	Error	Correct the input and rerun the program.
21	THE NUMBER OF GROUP LIMITATIONS ARE DIFFERENT IN FIXSYS #### AND VARSYS #### INPUT	Error	Check the FIXSYS and VARSYS inputs and rerun the relevant module before resubmitting the MERSIM
22	THE NAME OF REAL EMISSION ## IS DIFFERENT IN FIXSYS (AAAA) AND VARSYS (AAAA) INPUT	Error	Check the FIXSYS and VARSYS inputs and rerun the relevant module before resubmitting the MERSIM
23	THE INDEX OF GROUP LIMITATION ## IS DIFFERENT IN FIXSYS (AAAA) AND VARSYS (AAAA) INPUT	Error	Check the FIXSYS and VARSYS inputs and rerun the relevant module before resubmitting the MERSIM
24	THE TEXT OF GROUP LIMITATION ## IS DIFFERENT IN FIXSYS (AAAA) AND VARSYS (AAAA) INPUT	Error	Check the FIXSYS and VARSYS inputs and rerun the relevant module before resubmitting the MERSIM

Table 13.5. (page 4) Messages in the MERSIM Module of WASP-IV

DESCRIPTION OF THE MESSAGES COMING FROM MAIN (cont.)			
IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
26	INDEX OF THERMAL PLANT #### CONSIDERED FOR FIXED MAINTENANCE IS WRONG	Error	Check the input, correct and rerun the program
98	ERROR(S) AND/OR WARNING(S) ACCUMULATED THROUGH YEAR#####	---	Follow instructions according to messages in the printout
99	ERROR(S) AND/OR WARNING(S) ACCUMULATED THROUGH THIS RUN	---	Same instructions as for error message 98 above

FORM AND DESCRIPTION OF SPECIAL ERROR MESSAGES COMING FROM SUB-ROUTINES			
OF SUBROUTINE	ERROR MESSAGE	TYPE	ACTIONS TO BE TAKEN BY THE USER
READFM	ERROR ON FILE ## COMING FROM READFC, IR-###	Error	See Section 13.6.2 for instructions
DIVLIM, IE=25	THE SUM OF GROUP-LIMIT RATIOS MUST BE POSITIVE, IT IS: ####	Error	Correct the input and rerun the program

13.7. MESSAGES IN DYNPRO

The error and warning messages in module DYNPRO are listed and described in Table 13.6, which follows the same format considered for CONGEN and MERSIM in the preceding sections.

13.7.1. Messages coming from MAIN

- *Messages (IE=) 1 and 2* normally occur when the VARSYS module has been re-run after successful execution of MERSIM, and new values for the indicated variables were used in the input data of the latest VARSYS run. To remove these messages from the DYNPRO report, it may be sufficient to re-run the VARSYS module with corrected data and then re-run DYNPRO. If the new values of the variables used in the latest VARSYS run are the intended ones, it is also necessary to re-run CONGEN and re-initialize the MERSIM files with the correct information before proceeding to run the DYNPRO module.

- *Messages (IE=) 3* are applicable to the input data used in the current DYNPRO run and their description in Table 13.6 are self-explanatory.

- *Messages (IE=) 5 and 6* are similar in nature to messages 1 and 2 and usually occur when the CONGEN module has been re-run after successful execution of MERSIM, using new values for the indicated variables. If the data used in the latest CONGEN run are incorrect, simply modify it, rerun CONGEN and proceed with a new execution of DYNPRO. If the data of the latest CONGEN run are the ones to be retained in the study, it will also be necessary to rerun VARSYS with the new values and re-initialize the MERSIM files with the correct information, before proceeding to run the DYNPRO module.

- *Messages (IE=) 7 and 8* are also applicable to the input data given to DYNPRO and their description in Table 13.6 are self-explanatory.

- *Messages (IE=) 9 to 11* as described in Table 13.6 are also self-explanatory. Message (IE=) 11, however, requires verification of the additional constraints given in DYNPRO for the system LOLP and allowable number of units or projects of each expansion candidate per year to be respected by the configurations of the system. If these additional constraints are not to be changed, the user should proceed to execute a new run of CONGEN/MERSIM allowing appropriate patterns of system development according to these constraints.

- *Messages (IE=) 12 and 13* (same description as for messages 3 and 7–8 above).

- *Messages (IE=) 98, 99*: Same remarks as in Section 13.5.1.

13.7.2. Messages coming from subroutine READFD

Same comments made in Section 13.5.2 for similar messages in CONGEN are also valid here, except that in DYNPRO these messages apply only to file 11 (VARSYS) since file 10 (FIXSYS) is not used by this module.

Table 13.6. (page 1) Messages in the DYNPRO Module of WASP-IV

IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
GENERAL FORM FOR ALL MESSAGES COMING FROM MAIN: ***** **D IE** ***** **EC TEXT**			
DESCRIPTION OF THE MESSAGES COMING FROM MAIN			
1	VARIABLE SYSTEM & SIMULATION FILE INCOMPATIBLE NUMBER OF EXPANSION ALTERNATIVES IN VARSYS = ### IN SIMULATION FILES =###	Error	Check VARSYS input data and rerun applicable modules from VARSYS through MERSIM. Resubmit DYNPRO
2	VARIABLE SYSTEM & SIMULATION FILES INCOMPATIBLE NUMBER OF SEASONS IN VARSYS = ## IN SIMULATION FILES =##	Error	Same instructions as for error message 1 above
3	NO. OF YEARS IN STUDY PERIOD: ### (MAX. PERMISSIBLE = 30)	Error	Correct NJHRS in record type-A and rerun the program
5	VARIABLE SYSTEM & SIMULATION FILES INCOMPATIBLE WITH CONFIGURATION GENERATOR FILE NUMBER OF SEASONS IN VARSYS AND MERSIM = ## IN CONGEN = ##	Error	Check and correct input data to CONGEN, rerun it or, if necessary, rerun VARSYS and MERSIM. Rerun DYNPRO
6	VARIABLE SYSTEM & SIMULATION FILES INCOMPATIBLE WITH CONFIGURATION GENERATOR FILE NUMBER OF EXPANSION ALTERNATIVES IN VARSYS AND MERSIM =## IN CONGEN = ##	Error	Same instructions as for error message 5 above
7	CHECK VALUE ON INDEX RECORD ###	Error	Check and correct DYNPRO input data and rerun the program
8	INPUT VALUE OF NBEST ### IS WRONG, IT WILL BE CHANGED TO DEFAULT	Warning	Correct NBEST in data record type-13. See Section 13.7
9	CONFIGURATION NOT IN SIMULATION FILE IFEEZP = ####........	Error	Check whether MERSIM was run after CONGEN; rerun it and check if printout is complete. Rerun DYNPRO.

Table 13.6. (page 2) Messages in the DYNPRO Module of WASP-IV

<table>
<tr><th colspan="4">DESCRIPTION OF THE MESSAGES COMING FROM MAIN (cont.)</th></tr>
<tr><th>IE</th><th>TEXT</th><th>TYPE</th><th>ACTIONS TO BE TAKEN BY THE USER</th></tr>
<tr><td>10</td><td>NUMBER OF STATES IN THIS RUN =###### (MAX. PERMISSIBLE = 5000)</td><td>Error</td><td>Modify constraints in CONGEN; rerun CONGEN through DYNPRO</td></tr>
<tr><td>11</td><td>NO ACCESSIBLE TRANSITION FROM PREVIOUS YEAR</td><td>Error</td><td>Modify constraints in DYNPRO and rerun it.</td></tr>
<tr><td>12</td><td>VALUE OF RTESLO (##) IS 0.0 OR BLANK, RESET TO 1.0 BY PROGRAM</td><td>Warning</td><td rowspan="2">Correct value of RTESLO or RTESFO on type-9 record for the indicated fuel type index (##) and rerun DYNPRO. (Fuel type index is 1, 2, ..., 13 for "fuel" type code 0, 1, ..., 12, respectively)</td></tr>
<tr><td>13</td><td>VALUE OF RTESFO (##) IS 0.0 OR BLANK, RESET TO 1.0 BY PROGRAM</td><td>Warning</td></tr>
<tr><td>14</td><td>VALUE OF EOPL (##) IS 0.0 OR BLANK, RESET TO 1.0 BY PROGRAM</td><td>Warning</td><td rowspan="2">Correct value of EOPL or EOPF on type-17 record for the indicated fuel type index (##) and rerun DYNPRO. (Fuel type index is 1, 2, ..., 13 for "fuel" type code 0, 1, ..., 12, respectively)</td></tr>
<tr><td>15</td><td>VALUE OF EOPF (##) IS 0.0 OR BLANK, RESET TO 1.0 BY PROGRAM</td><td>Warning</td></tr>
<tr><td>98</td><td>ERROR(S) AND/OR WARNING(S) ACCUMULATED THROUGH THIS YEAR</td><td>---</td><td>Follow instructions according to messages in printout</td></tr>
<tr><td>99</td><td>ERROR(S) AND/OR WARNING(S) ACCUMULATED THROUGH THIS RUN</td><td>---</td><td>Same as for error message 98 above</td></tr>
</table>

<table>
<tr><th colspan="4">FORM AND DESCRIPTION OF SPECIAL ERROR MESSAGES COMING FROM SUB-ROUTINES</th></tr>
<tr><th>OF SUBROUTINE</th><th>ERROR MESSAGE</th><th>TYPE</th><th>ACTIONS TO BE TAKEN BY THE USER</th></tr>
<tr><td>READFD</td><td>ERROR ON FILE ## COMING FROM READFC, IR-###</td><td>Error</td><td>See Section 13.7.2 for instructions</td></tr>
</table>

13.8. MESSAGES IN REPROBAT

The error messages in REPROBAT are summarized in Table 13.7 including similar information as in the tables (13.1 to 13.6) for the preceding modules. In addition, this table indicates the subroutine where the respective message is originated from. The information presented in Table 13.7 is considered self-explanatory.

It should be borne in mind that REPROBAT uses the current information existing in the various files created by the preceding modules according to the report options specified for the run. This information is simply read by REPROBAT without repeating the validity checks of consistency which were already performed by CONGEN, MERSIM and DYNPRO. The program, however, does perform validity checks of the input data used for the run against the information retrieved from files and against the program capabilities. Therefore, the user should verify that the REPROBAT printout does not include any error message and, in addition, that it contains the intended information in the various reports. If this is not the case, the applicable module(s) have to be re-run to recreate the respective files.

13.8.1. Messages coming from MAIN, INIT, INIT2, FIXPLT, NULED1 or CONCOS

These messages are printed following the general form shown at the top of Table 13.7. Removal of these messages from the REPROBAT printout is simply done following the instructions indicated in this table.

Table 13.7. (page 1) Messages in the REPROBAT Module of WASP-IV

GENERAL FORM FOR MESSAGES COMING FROM SUBROUTINES INDICATED BELOW: ******* R IE ***** IEC TEXT**				
DESCRIPTION OF THE MESSAGES				
SUB-ROUTINE	IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
INIT	1	NUMBER OF YEARS IN STUDY PERIOD : ### (MAX PERMISSIBLE = 30)	Error	Correct record type-A. Rerun program
INIT	2	CHECK VALUE ON INDEX RECORD ###	Error	Check and correct REPROBAT input data and rerun the program
INIT	3	PLANNING PERIOD: #### - #### IS NOT EMBEDDED IN STUDY PERIOD	Error	Correct planning period (data record type-4) and rerun the program
INIT	4	DATE AND/OR -CARRIED OUT BY- INFORMATION IS WRONG OR MISSING	Error	Check that records type-6 are correct and in the proper sequence. Rerun program
INIT	5	NUMBER OF LEGEND RECORDS EXCEEDS 60	Error	Reduce number of data records type-7 to at least 60 and rerun the program
INIT	6	CHECK LAST RECORD OF/AFTER LEGEND. IS IT INDEX ?	Error	Check and correct sequence of input data and rerun the program
FIXPLT	7	INCREASE DIMENSION OF IPOTHS(500) IN SUBROUTINE FIXPLT, TOO MANY ADDITIONS OR RETIREMENTS	Error	Try to reduce number of additions or retirements. Otherwise, contact the WASP analyst
FIXPLT	8	GIVEN STUDY PERIOD IS INCOMPATIBLE WITH FIXED SYSTEM	Error	Make study period (record type-A) match FIXSYS information. Rerun program
CONCOS/ INIT2	9	NUMBER OF YEARS OF CONSTRUCTION TO BE CONSIDERED IN CASH FLOW CALCULATION IS ### YEARS (MAX. PERMISSIBLE = 40)	Error	Correct total range of construction period of all candidates (not to exceed 40 years) in the corresponding record type-2 (or 2a) of DYNPRO.
CONCOS/ INIT2	10	TIME OF CONSTRUCTION OF PLANT AAAA IS ###.##	Error	Rerun DYNPRO - REPROBAT

Table 13.7. (page 2) Messages in the REPROBAT Module of WASP-IV

GENERAL FORM FOR MESSAGES COMING FROM SUBROUTINES INDICATED BELOW: ******* R IE ***** IEC TEXT**				
DESCRIPTION OF THE MESSAGES				
SUB-ROUTINE	IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
CONCOS	11	NUMBER OF PLANTS TO BE BUILT EXCEEDS 200, INCREASE DIMENSION OF ARRAYS MINYC & MINYF IN SUBROUTINE CONCOS	Error	Try to reduce number of plants to be built. Otherwise, contact the WASP analyst
NULED1	12	INCREASE DIMENSION OF NADD(99) AND DATA ASSIGNMENT IN SUBROUTINE NULED1, TOO MANY ADDITIONS (=####)	Error	Try to reduce number of additions or retirements. Otherwise, contact the WASP analyst
NULED1	13	INCREASE DIMENSION OF NRET(99) AND DATA ASSIGNMENT IN SUBROUTINE NULED1, TOO MANY RETIREMENTS (=####)	Error	
INIT	14	IF INDEX = 7 THE PRINTOUT OPTION IOPLST (8) AND ITS SUBOPTIONS (IOPCON) MUST BE >0 (RESET BY PROGRAM)	Warning	Correct appropriate values on record type-2 and 3 and rerun the program.
INIT2	15	NAME OF CANDIDATE ## IN DYNPRO = AAAA IS INCOMPATIBLE WITH INPUT = AAAA	Error	Check and correct REPROBAT input data and rerun the program.
INIT2	16	SUM OF % DOM./FOR. CONSTR. COST IS NOT 100.0 IN SET ## (DYNPRO) FOR THERMAL CANDIDATE AAAA (SUM % = ###.##)	Error	See Error 15.
INIT2	17	SUM OF % DOM./FOR. FUEL INVENTORY COST IS NOT 100.0 IN SET ## (DYNPRO) FOR THERMAL CANDIDATE AAAA (SUM % = ###.##)	Error	See Error 15
INIT2	18	NAME OF HYDRO PROJECT ## IN DYNPRO = AAAA IS INCOMPATIBLE WITH INPUT = AAAA	Error	See Error 15

Table 13.7. (page 3) Messages in the REPROBAT Module of WASP-IV

GENERAL FORM FOR MESSAGES COMING FROM SUBROUTINES INDICATED BELOW: ***** **R IE** ***** **IEC TEXT**				
DESCRIPTION OF THE MESSAGES				
SUB-ROUTINE	IE	TEXT	TYPE	ACTIONS TO BE TAKEN BY THE USER
INIT2	19	SUM OF % DOM./FOR. CONSTR. COST IS NOT 100.0 IN SET ## (DYNPRO) FOR HYDRO PROJECT AAAA OF TYPE AAAA (SUM % = ###.##)	Error	See error 79
INIT2	20	SUM OF % DOM./FOR. CONSTR. COST IS NOT 100.0 FOR COMMITTED PLANT AAAA (SUM % = ###.##)	Error	See error 79
INIT2	21	SUM OF % DOM./FOR. FUEL INVENTORY COST IS NOT 100.0 FOR COMMITTED PLANT AAAA (SUM % = ###.##)	Error	See error 79
INIT2	22	SUM OF % DOM./FOR. INTEREST DURING CONSTR. IS NOT 100.0 FOR COMMITTED PLANT AAAA (SUM % = ###.##)	Error	See error 79
MAIN	23	SUBOPTION IOPSIM CAN ONLY BE ACTIVE AFTER RESIMULATION (RESET BY PROGRAM)	Warning	See error 79
INIT	24	NUMBER OF INDEX = 7 RECORDS EXCEEDS MAXIMUM OF 20	Error	See error 79
MAIN	99	ERROR(S) AND/OR WARNING(S) ACCUMULATED THROUGH THIS RUN	Error	Follow instructions for errors above

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