A UNIT COMMITMENT PROGRAM USING FUEL COST ESTIMATION

by

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LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviations

UCP: Unit Commitment Program

MWH: megawatt hours

CT: combustion turbine

MW: megawatts

Symbols

P_L: total transmission losses (MWH)

P_i: power generated by unit i (MW)

B_{nm}, B_{no}, K_{1o}: loss equation coefficients

S_o: initial state

S_{ij}: the i^{th} state to be considered at hour j

H_i: heat rate of unit i (MBTU/MWH)

a_i, b_i, c_i: coefficients for the heat rate expression

C_i: cost of generator i ($/hour)

F_i: incremental fuel cost of generator i ($/MBTU)

CS: start-up cost of a unit ($)

CSC: cold start cost of a unit ($)

τ: the boiler cooling time constant (hours)

K: cost of starting a turbine ($)

t: the amount of time a unit has been off-line (hours)

a: constant in start-up cost model

CS^o: minimum start-up cost ($)

λ: incremental cost of system ($/MWH)

B: slope of start-up cost model for a banked unit

T: value of t at which a unit may be considered cold

T': value of t at which the banking and exponential start-up cost models intersect

P_G: total system generation (MWH)

P_D: load demand (MWH)

n: number of generators in the system

λ_i: incremental cost of unit i ($/MWH); the value of λ when the i^{th} megawatt has been removed ($/MWH)

C: cost of a state ($/hour)

C^o: cost of base state ($/hour)

ΔC: change in cost of a state ($/hour)

λ_{est}: average λ over a change in λ; i.e., $\lambda_{est} = (\lambda_{min}+\lambda_{max})/2$ ($/MWH)

λ^o: incremental cost of base state ($/MWH)

λ_o: incremental cost of maximum capacity state ($/MWH)

P_{off}: generation taken off-line with respect to the base state (MWH)

p_i: the i^{th} megawatt taken off-line with respect to the base state

ΔP_{Li}: change in total transmission losses (MWH)

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CHAPTER I

INTRODUCTION

The primary objective of the power industry is to provide electrical energy to the consumer on demand. For most power systems, this demand follows a pattern exhibiting substantial variation between the peak and valley hours. If the same generation required to meet the peak demand is kept on-line during the valley hours, many of the generating units would be forced to operate near their minimum generating limits. Not only is this costly due to the increased inefficiency of the units at their lower limit, but the ability to regulate the system's generation may be hampered. This is especially true when much of the load demand is being met with large super-critical steam or nuclear units which cannot be used for regulation. The problem is growing due to the fact that the variation between the peak and valley load conditions is increasing. Hydro generation used for "peak shaving" has helped in the past, but most of the potential hydro sites have been developed and cannot be depended on to handle the increased load differentials. Unless they are cycled, steam units will be forced to operate at lower efficiency levels during the valley hours. The solution to this problem is to take units off-line enabling the other units to generate at levels well above their minimum limits.

The problem now becomes how many units should be taken off-line, which units should be taken off-line, when should they be taken off-line, and how long should they remain off-line. One approach to solving this problem is unit commitment, which is the determination of the most economical set of generating units to be on-line each hour to meet the forecasted system load demand and reserve requirements over a given period of time. Much study has been conducted on the problem of unit commitment and various methods have been developed to solve the problem [1, 2, 3]. However, due to the relatively large size of today's power systems and to their many operational constraints, these methods have not achieved the desired accuracy.

It is the intent of this author to describe the development of a Unit Commitment Program (UCP). This program schedules the units of a large power system in such a way that the resulting commitment is an excellent approximation of the optimal solution. The approach of this paper will be three-fold:

1. A system description is given to acquaint the reader with the various aspects of the unit commitment problem.

2. A description of a computer program which was developed to solve the unit commitment problem is presented. Certain features of this program proved to be undesirable due to the large computer time and storage requirements.

3. The problem of large computer requirements was greatly diminished by replacing the slow, "exact" method of calculating fuel costs with a quicker estimation method. The development of this estimation method, called fuel cost estimation, is presented.

Chapters II, III, and IV will accomplish the above objectives. A final chapter giving conclusions and recommendations will also be included.

CHAPTER II

SYSTEM DESCRIPTION

Several models or descriptions of power systems have been developed and used. One of the most popular is the single-line diagram. This chapter will begin with a simplified form of this model and will develop from it the model to be used by the UCP.

Fig. II-1 shows the single-line model. A system is confined to some geographical area, which is connected to other power systems via tie lines. Within the power system itself is an interconnected network of loads, transmission lines, and generators. The author realizes that this is a somewhat limited model, but it will suffice for the stated purpose of developing a suitable unit commitment model.

LOAD DEMAND

Fig. II-2 shows a typical load curve for a summer day. Note, as would be expected, the load is at a minimum during the early morning hours. As daily activity begins and the temperature rises, the load increases. In the late afternoon as businesses and factories shut down and the temperature decreases, the load starts declining. The decline is not as rapid as the earlier increases due to evening and night activities. Finally, sometime after midnight, the load decreases toward its minimum. The minimum load is termed the valley load or the valley condition; the maximum load is known as the peak load or peak

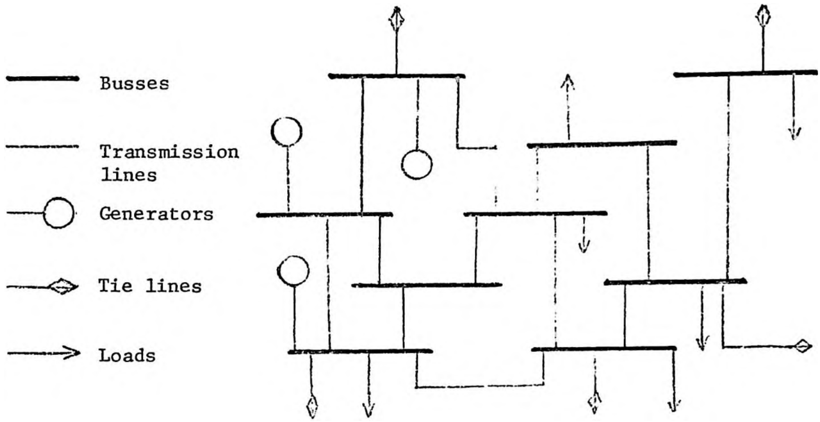

Figure II-1. A typical single-line diagram of a power system

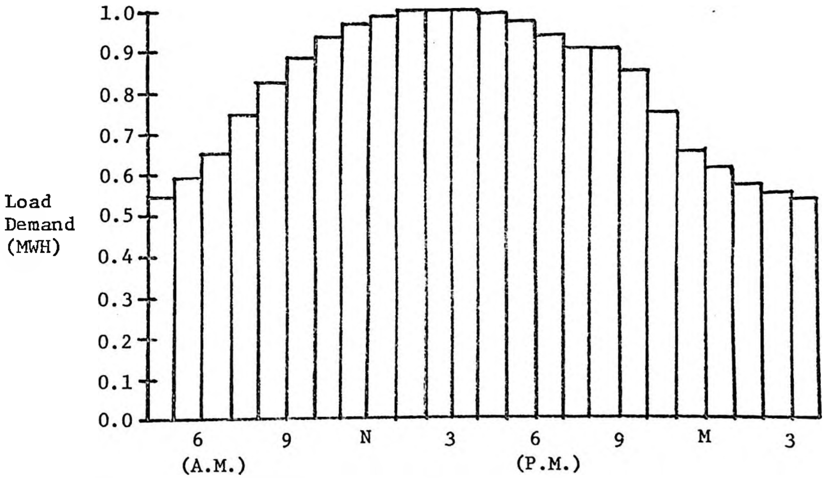

Figure II-2. A typical normalized summer load demand curve condition. The cyclic nature of loads enhances unit commitment since one needs to optimize the operation over only one cycle.

TRANSMISSION LINES AND LOSSES

The transmission line is the means by which the electrical energy travels from the generation source to the load. There are, of course, losses due to the lines. This paper will make use of the loss formula developed by Early, Watson, and Smith [4].

$$P_L = K_{1o} + \Sigma_n B_{no} P_n + \Sigma\Sigma_{nm} P_m B_{mn} P_n \qquad \text{(II-1)}$$

GENERATION

The generators, or units, are the chief source of electrical power. There are several different types of units in operation today. These various types may be considered to fall into two basic categories when related to unit commtiment: dispatchable and scheduled.

The dispatchable units are essentially those units whose loading depends on the system economics. Most fossil-fuel steam units fall into this category.

The scheduled units are those units whose loading is firmly scheduled on a basis other than economics. Hydro and combustion turbine generators are usually scheduled. Usually hydro units are used to their full capacity and are scheduled during the peak hours. Combustion turbines are usually scheduled when other forms of generation are unable to meet the load.

There are several other various types of generation which are considered scheduled. Nuclear generation is usually considered as base load generation. The fuel costs are such that the best operating strategy, economically, is to run the unit constantly at or near its peak rating. Because of this feature, nuclear generators are considered scheduled. Tie points (although not actually generating units) are also considered scheduled units since interchange is contracted and thus scheduled between power systems. Another type of scheduled generation is pumped-storage hydro. This type is relatively new, and studies are still being made to determine its most economical operating scheme. For the purposes of this paper, it will be assumed that the pumping and generating cycles of these units are predetermined. Some fossil-fuel units may be considered as scheduled units. This is the case when the unit is scheduled to generate a fixed amount of power each hour of a commitment period.

Each of the various types of units is considered to be operating in one of four statuses. Various modes may be associated with each status. The four statuses may be termed as economically up, economically down, must-run, and must-down. Each status takes on a slightly different interpretation depending on the unit's type. The various statuses are numbered and defined as follows:

Status 0: Economically up

Status 1: Must-run

Status 2: Must-down

Status 3: Economically down

The numbering scheme is chosen to begin with zero for the convenience of implementation on a digital computer.

A description of the various statuses for each unit type is as follows:

Steam Units:

Status 0 - A steam unit is economically up when it is on-line but may be shut-down at the discretion of the UCP. There are a couple of modes associated with this status. A unit is in a dispatched mode if its loading is determined economically. A unit is in the fixed mode if its loading is predetermined.

Status 1 - A steam unit is considered must-run if the unit is on-line and may not be shut-down at the program's discretion. The same modes exist for this status as for the economically up status.

Status 2 - A steam unit is considered must-down if it is down and may not be started at the program's discretion. There are no modes associated with this status. The unit cannot be considered as operating reserve.

Status 3 - A steam unit is economically down if the unit is off-line but may be started at the program's discretion. One mode is the dispatchable mode where if the unit is started, it will assume its generation level economically. The fixed mode exists when the unit is to have a predetermined generation level if it is started.

Hydro and Combustion Turbine Units:

Status 0 - Since these units are scheduled on-line, the program cannot bring them off. Therefore, this status is not allowed for hydro or combustion turbine (CT) units.

Status 1 - If a hydro or CT unit is on-line, it will have this status. There are no modes associated with this status for a CT unit. However, a hydro unit which is motoring will have this status and zero generation. Its capacity may then be considered as spinning reserve.

Status 2 - A hydro or CT unit having this status is off-line and may not be considered as operating reserve.

Status 3 - A hydro or CT unit having this status is off-line but may be considered as operating reserve.

Tie Points:

Status 0 - This status is not allowed for a tie point because all interchange is scheduled.

Status 1 - A tie point has this status when scheduled flows are in effect.

Status 2 - This status refers to no interchange scheduled at the tie point.

Status 3 - This status has no meaning for a tie point and therefore is not allowed.

No attempt has been made to define the statuses for nuclear or pumped-storage hydro units. The reason for this is the relative newness of these types of generators. The UCP looks at a unit's number instead of its type to determine how it is to be modeled. Therefore, nuclear and pumped-storage hydro units may be included in the commitment scheme by treating them as any one of the previously mentioned types.

GENERATION STATE-SPACE

Using the concepts developed, the state of a system as used for unit commitment is defined by the status of each generating unit as given above. The state must be such that the load demand is met using the existing transmission network. Using this idea of the state of a system, unit commitment can be defined as the problem of determining the sequence of system states which will minimize the total production costs. Fig. II-3 is a diagram of what is termed the state-space of the power system. The state-space is two-dimensional with a time dimension and a system state dimension. The state-space could be thought of in terms of a plot of x and f(x), where x is time and f(x) is the state at time x. The purpose of unit commitment is to find the path, or f(x), such that the cost of the path is minimal. The practical aspects of this problem prevent a continuous solution to unit commitment; therefore, the time dimension is quantized into discrete time segments. The most convenient length of a time segment for a power system is one hour. This is due to load forecasts usually being expressed in integrated hourly loads and to the hourly nature of the heat rate dimensions.

PRODUCTION COSTS

Since the desire is to minimize the production costs over the commitment period, it is important that the production costs be defined as a function of a system state. The production cost of the system is equal to the sum of the production costs of the individual units. Since some of the individual units are scheduled, their contribution to the system cost is constant and does not affect the commitment solution.

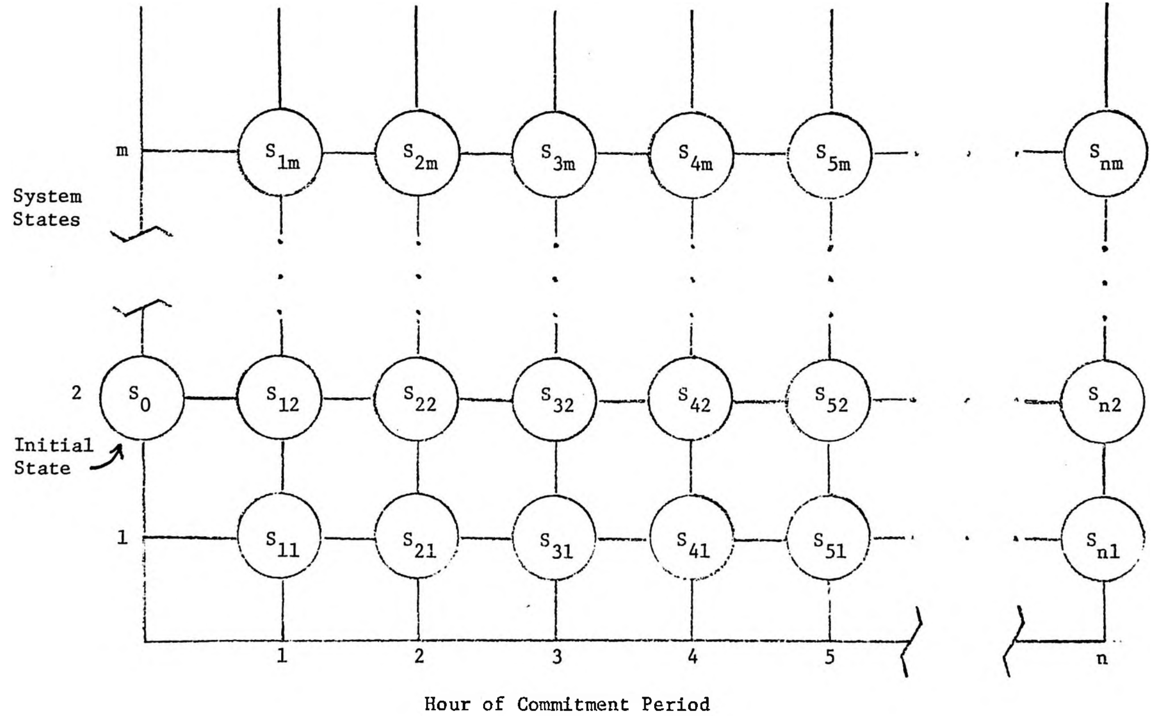

Figure II-3. State-space of a power system

Therefore, only the dispatchable units need to be considered. These units are usually made up of fossil-fuel steam units; although, nuclear and combustion turbine units may fall into this category. If so, they must be modeled similarly to the fossil-fuel steam units. Since the models are the same, only one model needs to be considered for the calculation of the production cost of a dispatchable unit.

The production cost of a unit consists of two parts: the fuel cost and the start-up cost. The cost of energy, F, for a steam unit can be expressed as the cost of the fuel in dollars per MBTU of heat energy it produces. This cost is unique for each unit due to the type and quality of the fuel and the transportation costs of getting the fuel to the plant.

Each unit has associated with it a heat rate curve, which is usually approximated by a second-order expression. The heat rate equation gives the amount of heat required to produce an amount of electrical energy. The heat rate, H, may be expressed as

$$H = a + bP + cP^2 \qquad \text{(II-2)}$$

where P is the power generated and a, b, and c are the heat rate coefficients of the unit determined from empirical data or manufacturers' design data. H has dimensions of MBTU per hour. Since each unit has a unique set of heat rate coefficients, a subscript notation will be adopted. For unit i,

$$H_i = a_i + b_iP_i + c_iP_i^{\,2} \qquad \text{(II-3)}$$

Therefore, the fuel cost (C_i) of a unit per hour can be expressed as a function of the power generated; i.e.,

$$C_i = F_iH_i = F_i(a_i + b_iP_i + c_iP_i^2) \qquad \text{(II-4)}$$

where C_i has dimensions of dollars per MWH.

If the fuel cost were the only cost to be considered, to realize the optimum commitment schedule, one would only need to determine the lowest cost state for each hour of the commitment period. This would be true because the fuel cost of a state is not dependent on any past or future system states. This leads to the second part of production costs; i.e., the cost of starting-up a unit. Start-up costs are dependent on the transition between the system states of two consecutive hours. Therefore, the lowest cost state for a certain hour may not be the state that would minimize the total production cost for the commitment period.

Several models have been used to relate the cost of starting-up a unit to its down-time [1, 3, 5, 6]. Fig. II-4 is a graphical description of a few of these models. Perhaps, the simplest of the models is shown by curve A of Fig. II-4, where the start-up cost (CS) is equal to the sum of the cold start cost (CSC) and the cost of starting the turbine (K), regardless of how long the unit has been down.

A more elaborate model, which is popularly used, is the exponential model, curve B. This model is based on the approximation that a boiler's temperature will decrease exponentially with a cooling time constant, τ. The start-up cost is given by the equation

$$CS = CSC[1 - \exp(-t/\tau)] + K \qquad \text{(II-5)}$$

where t is the number of hours the unit has been down and K is the cost of starting the turbine alone. K should also contain the additional operation and maintenance costs due to cycling. Sometimes t is

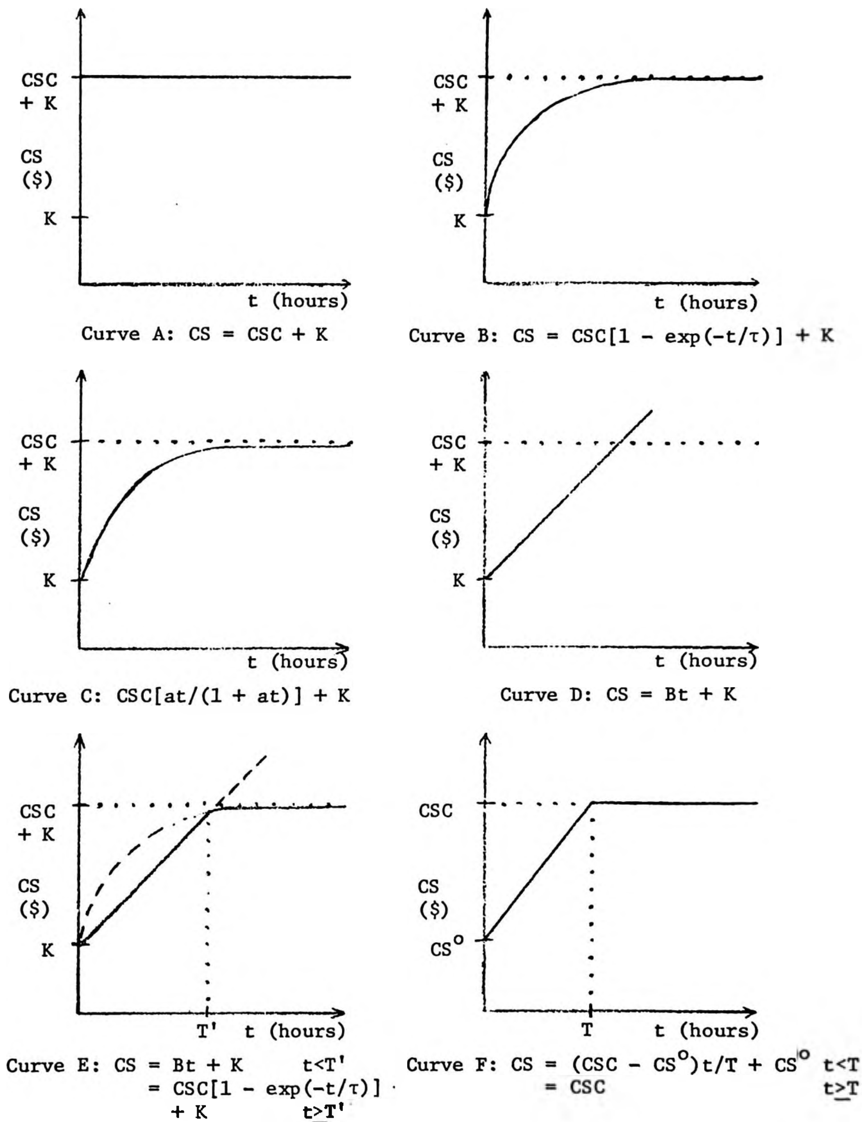

Figure II-4. Various start-up cost models replaced by t-1 to allow an hour for the start-up of the unit. Because of the excessive computer time required in evaluating exponentials, this model is often approximated by the equation

$$CS = CSC[at/(1 + at)] + K \qquad \text{(II-6)}$$

where a is a predetermined constant. This equation corresponds to curve C in Fig. II-4.

A further refinement to the exponential model is made by superimposing a curve, curve D of Fig. II-4, which represents the start-up cost of a boiler that has been banked; i.e., the temperature and pressure have been maintained while the unit is down. This cost is of the form

$$CS = Bt + K \qquad \text{(II-7)}$$

where B is the cost of banking the boiler in dollars per hour. Since banking is more economical for short down-times, a model is constructed such that the banking model is used until it intersects the exponential model, after which the exponential model is used. This model is shown by curve E of Fig. II-4.

The model adopted by this paper for the use of unit commitment is shown by curve F of Fig. II-4. The start-up cost is assumed to begin at a minimum start cost and increase linearly with time until it reaches the intersection of CSC and T. The time, T, will be termed the boiler's cooling time and is specified here as $\tau/.632$. If a unit is started after T, its cold start cost will be used for its start-up cost. Note that with the use of this model, the operator can tell if it is more economical to bank a unit or shut it down completely by looking at how long the unit is scheduled to be down. Mathematically, the start-up cost may be expressed by the equation:

$$CS = \begin{cases} CS^o + \frac{CSC - CS^o}{T} \cdot t, & t < T \\ CSC, & t > T \end{cases} \qquad \text{(II-8)}$$

where CS^o is the minimum start-up cost.

To evaluate the fuel cost of a system state, the determination of the loading of each individual unit must be made. The basic requirement which must be met is that the total power generated must be equal to the system load plus the transmission losses, or

$$P_G = \sum_{i=1}^{n} P_i = P_D + P_L \qquad \text{(II-9)}$$

where P_G = total power generated

n = number of units in the system

P_i = power generated by unit i

P_D = system load demand

P_L = transmission losses.

To determine the loading of each generator, the system load demand must first be determined. This is done by means of load forecasting.

LOAD FORECASTING

Several methods of load forecasting have been developed. [7, 8, 9]. Some of these methods take into account such factors as weather conditions, seasonal trends, special days (such as holidays), and other conditions that affect the amount of power demanded.

For purposes of developing a unit commitment algorithm, a simple method of load forecasting was adopted. After all, any unit commitment algorithm developed should not depend on the method of load forecasting, only on the load forecast itself. The observation was made that for a given season, the general shape of the actual daily load curves was about the same. The demand differed only in relative magnitude. Using actual load data, several normalized load models were constructed. With this information, one needs only to supply the peak load demand of the day and the load demands for each hour may be calculated.

ECONOMIC DISPATCHING

The process of determining the optimal loading for the individual on-line generators is known as economic dispatching [10]. A system is considered economically dispatched when each unit in the system has the same incremental cost, λ, where λ is given by the equation

$$\lambda = \lambda_i = \frac{\partial F_i/\partial P_i}{1 - \partial P_L/\partial P_i} , \quad i = 1, 2, 3, \ldots, n \qquad \text{(II-10)}$$

where n is the number of units, F_i is given by Eq. II-4, and P_L is given by Eq. II-1.

The numerator is the incremental cost of the unit i and the denominator is a penalty term due to losses. For each unit there exists an equation of the form of Eq. II-10; therefore, there are a total of n equations. The generation levels of each unit and lambda are the unknowns in the equations. Since there are n+1 unknowns and only n equations, one more equation is needed. The remaining equation needed to solve for the generating levels of each unit is provided by the generation-load-loss relationship of Eq. II-9.

A special economic dispatching subroutine was developed for the UCP. Given the system state, the units are dispatched such that the economic dispatch equations and the generation-load-loss equation are satisfied. To accomplish this, Eq. II-10 must be solved for P_i. From Eq. II-4,

$$\partial F_i/\partial P_i = F_i(b_i + 2c_iP_i) \tag{II-11}$$

and from Eq. II-1,

$$\partial P_L/\partial P_i = B_{io} + 2\sum_m B_{im}P_m \tag{II-12}$$

Eq. II-12 follows from the fact that the B matrix is symmetric; i.e., $B_{ij}=B_{ji}$. The second term of Eq. II-12 may be written as

$$2\sum_{\substack{m\\m\neq i}} B_{im}P_m + 2B_{ii}P_i$$

Substituting this, Eq. II-11, and Eq. II-12 into Eq. II-10, the expression obtained is

$$\lambda = \frac{F_i(b_i + 2c_iP_i)}{1 - B_{io} - 2\sum\limits_{\substack{m\\m\neq i}} B_{im}P_m - 2B_{ii}P_i} \tag{II-13}$$

and then solving for P_i

$$P_i = \frac{1 - B_{io} - 2\sum\limits_{\substack{m\\m\neq i}} B_{im}P_m - F_ib_i/\lambda}{2B_{ii} + 2F_ic_i/\lambda} \tag{II-14}$$

The algorithm begins by estimating a value of λ, solving for the P_i's, and summing them to obtain the total generation. After calculating losses, a correction to λ is made based on the difference between the generated power and the system load plus losses. This procedure is repeated until the optimum loading is obtained. The reader is referred to Appendix A.14 for a source listing of the economic dispatch subroutine.

RESERVE REQUIREMENTS

Most power systems have policies which require that a certain amount of spare generation be kept available. These policies are adopted to insure that the system can meet its demands in the event of forced outages, unexpected load demands, or any other conditions which could prevent the system from meeting its demands. Such policies are called reserve requirements.

Reserves may take on two forms, spinning and operating. Spinning reserves refer to the spare generation which is on-line. This type of reserve may have associated with it a time requirement such that in Y minutes, X MW must be available. The calculation of this type of reserve requires the response rates of the units. These values indicate how fast a unit can pick up load. Operating reserves refer to the available generation which is off-line. The operating reserve requirement is usually a fixed value, often a function of the capacity of the largest unit in the system.

Starting with the concepts presented in this chapter, an algorithm can be constructed to obtain a solution to the unit commitment problem. The next chapter deals with one such algorithm.

CHAPTER III

A UNIT COMMITMENT ALGORITHM

The overall purpose of the unit commitment algorithm is to search through the state-space (defined in Chapter II, page 9) and find the least cost path from the initial to the final hour of the commitment period. The magnitude of this problem is so great that only a digital solution is feasible. A complete solution is one that considers all possibilities and constraints with detailed accuracy. However, even with the highest speed digital computers of today, this is virtually impossible. Therefore, the problem must be reduced using a combination of sound engineering judgment, accurate and acceptable approximations, and special programming methods.

STATE-SPACE REDUCTION

There are several aspects of the unit commitment problem which causes it to be so voluminous. One is the number of possible paths that exist through the state-space. Consider a state-space which consists of only ten states per hour and is twenty-four hours long. The number of possible paths is 10^{24}. In general, for a commitment period of n hours and considering x states each hour, the total number of possible paths is given by the equation:

$$\text{total number of paths} = x^n \qquad \text{(III-1)}$$

Another aspect of the unit commitment problem has to do with the large number of units in today's power systems. How many states should be considered each hour? For a system with m generating units, each hour there are $\sum_{i=1}^{m} \binom{m}{i}$ possible states. For a system consisting of 100 units, this number is on the order of 10^{30}. Later, it will be shown that many of these states are not feasible. Even if only half of the total possible states were considered each hour, the number of paths to be considered over a commitment period of twenty-four hours would be on the order of 10^{715}. Even if a computer could evaluate each path in one-millionth of a second, it would still take over 10^{700} years to find the least cost path. This, however, is not the whole problem.

To calculate the cost of a single state, the individual loadings of the units must be known; i.e., the state must be economically dispatched. The most commonly used economic dispatch routines usually take a few seconds. The economic dispatch routine used by this unit commitment program takes about two seconds to run on a UNIVAC 1110 computer. Going back to the earlier example of 100 units and a commitment period of twenty-four hours, the total number of states to be considered would be 1.5×10^{31}. At two seconds per state, 1×10^{18} years would be needed to just calculate the fuel costs.

Using special programming techniques and system approximations, the problem can be reduced such that an acceptable solution may be obtained. The basic problems are the large number of states which may be considered for each hour of the commitment period and the large number of paths to be considered. Dynamic programming is the solution to the problem of having so many paths. According to Richard Bellman's Principle of Optimality, an optimal path has the property that at any point on the path, the path is optimal to that point. This can be illustrated by considering Fig. III-1. State S_{ij} may be approached from any of the states of the previous hour. However, the only path which must be remembered past state S_{ij} is the cheapest path through that state. Therefore, instead of having to consider x^n paths, where x is the number of states each hour and n is the number of hours, only $x \cdot n$ paths need to be considered. Referring to the example of ten states each hour for twenty-four hours, this amounts to 240 paths.

It was determined earlier that there may be an extraordinary number of states to be considered each hour. To reduce the number of states to be considered each hour, an approximating constraint is placed on the problem. This constraint is that units are to be considered for shut-down (or start-up) in a certain order of priority. For example, if two units are available for shut-down, the unit with the lowest priority will be considered first. The priority list removes the randomness from the selection of units for start-up or shut-down. This means that for a system of n units, only $n-\ell$ states need to be considered each hour where ℓ is the minimum number of units which can carry the system load and losses.

At this point, the problem has been reduced from impossibly large to a size that can be handled. One problem still remains. Each state considered must be economically dispatched to determine its fuel cost. For a system of 100 units, 50 of which must be on-line to meet load, and a 24 hour commitment period, a total of (100-50)24 or 1200 states must be considered. If it takes 2 seconds to dispatch each state, 1200 × 2 = 2400 seconds or 40 minutes of computer time would be required just to dispatch the various states. Although this result is

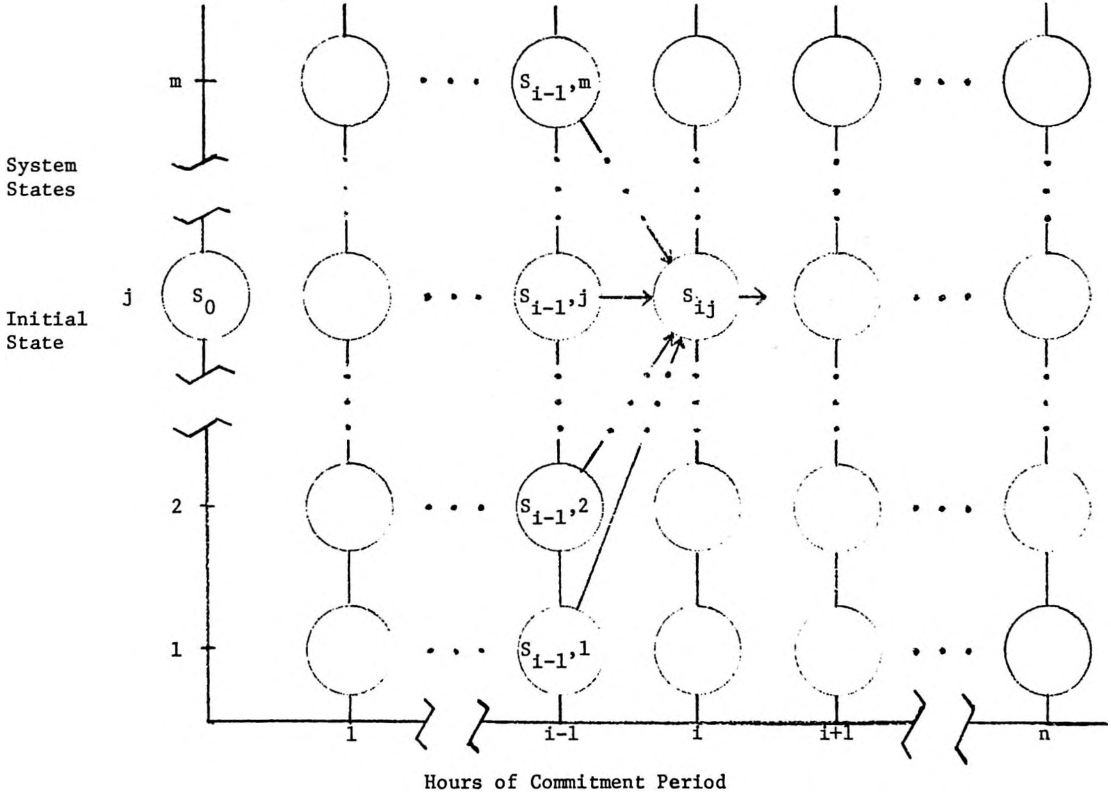

Figure III-1. Illustration of Bellman's Principle of Optimality much better than before, practical considerations require that it still be reduced.

Two methods of reducing the time requirement have been developed. One method is to reduce the time of economically dispatching each state by accurately approximating the fuel costs of the various states considered. This method will be described in more detail in the next chapter.

The other method reduces the number of states considered each hour by making a good guess at where the most economical path should lie and searching the state-space around this guess. The basic problem with this method is obtaining the initial guess. To gain insight into this problem, a study was made using a realistic power system. This system consisted of 119 units, 75 of which were fossil-fired steam units. The remaining 44 units were made up of 12 combustion turbines, 11 hydro units, and 21 tie points.

The approach to the study was to economically dispatch all possible system states, constrained by the priority list, and to compare their costs. Only the steam units were considered for this study, since the UCP is dependent only on their costs. The system was first dispatched in its maximum state; i.e., the state with all the generators on-line. Then the system state was altered by shutting-down the first unit on the priority list. After dispatching this new state, the fuel cost was recalculated and recorded. This procedure was repeated, removing units in order of their priority, until the minimum state was reached. The minimum state is defined as the state where removal of an additional unit would prevent the system from meeting the system load and losses.

The study was repeated for various load conditions. It was evident from the cost data provided by this study that the lowest cost state for a certain load demand was at or near the minimum state. This result logically follows from the fact that if a unit is taken off-line whose average cost per MW is greater than the system average, the system average will decrease. Since the priority list was developed on the basis of the average costs of the units, the effect of removing units in order of their priority approximates this situation. The significant factor is that for the power system studied, the minimum state was usually reached before units whose average cost was less than the system average could be taken off-line.

Since the start-up costs constitute only a small percentage of the total production costs, the optimal path for a commitment period should pass somewhere near the most economical state of each hour (or load). This means that the minimum state for each hourly load qualifies as a good first guess. Therefore, the UCP first determines the minimum state for each hour of the commitment period. Then it creates the other states to be considered each hour by successively adding the next highest priority unit in the priority list. It was found that the consideration of 12 states each hour is about the maximum number which can be handled conveniently. At first, this may seem to be a limiting constraint, but experience has shown that the optimal path is pretty well confined to these boundaries. Fig. III-2 relates the search bounds of the state-space to the load demand.

One aspect of this method is its dependence on the priority list. This list should be updated with any large system change such as new generating units or major transmission line additions.

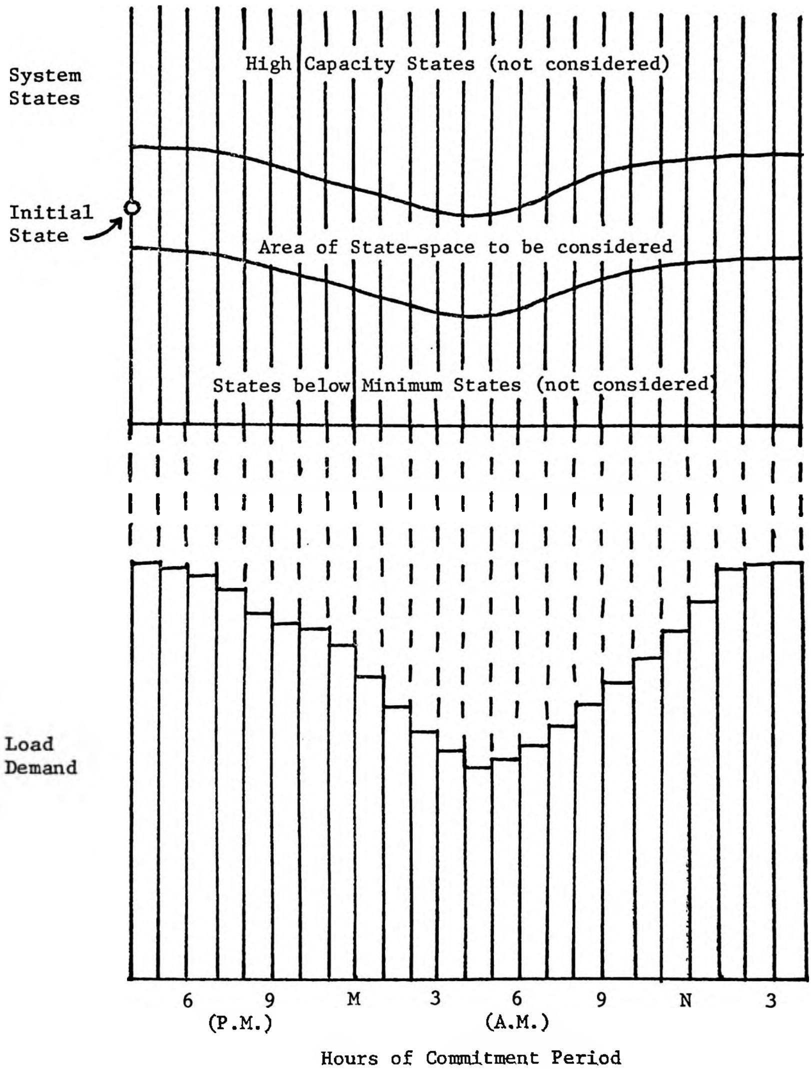

Figure III-2. Relationship of state-space to load demand

PROGRAM DESCRIPTION

The UCP was constructed in the form of a main program which calls various subroutines. These subroutines may also call other subroutines. The purpose of this form is to facilitate changing the various algorithms. For example, if the subroutine which calculates the hourly loads is found to be unsuitable for a particular condition, that subroutine may be replaced by another subroutine, which uses the desired algorithm. Listings of the UCP subroutines are given in Appendix A.

Most of the data required by the UCP are system data which are normally stored for the power systems' application programs. This system data consist of unit data and B constants (for calculation of losses and economic dispatching). Unit data include unit numbers, unit names, entry points, priority numbers, fuel costs, heat rates, minimum and maximum capacity limits, cold start costs, and boiler cooling times. For the method of load forecasting currently used by the UCP, several normalized load models are also input. Other data used by the UCP include reserve requirements, generation mix information, peak loads, tuning parameters, output options, and schedule cards.

There are three tuning parameters. One is a factor which is multiplied by the cold start costs of the various units to specify their minimum start-up cost. Another parameter is used by the economic dispatch subroutine as a convergence criterion. The last parameter is a multiplier on the load and the result is used to insure that ample capacity is on-line to meet the load and the losses.

Over a given commitment period, any unit may be constrained to be in a certain status. This function and the scheduling of scheduled units is accomplished using schedule data. These data consist of the unit's number, the status the unit is to have, and the hours the unit is to have that status. Since a commitment period might start one day and end the next, the program receives schedules for both days, retaining only the portion of the schedules within the commitment period. If the unit is to have a fixed generation level, this information is also included with the schedule data.

If a unit is not scheduled by the schedule data, certain default conditions exist. For a dispatchable unit, the default status is economically up in a dispatch mode. Hydro units are assumed motoring, while CT units are assumed off. Tie flows are assumed zero.

After all the necessary data have been read in by subroutine INPUT, the UCP calls a load modeling subroutine (FLS) to determine the hourly load demand based on the peak demands for both days which are input by the user. Then a subroutine called MAXG is called to calculate the maximum generating capacity available each hour.

In order to guarantee that ample generation will be available for the second day's peak, subroutine PVA is called. One of its functions is to insure that any unit with a minimum down-time greater than twenty hours is not shut-down during the commitment period if it is needed to meet the second day's peak. If such a unit is found, it is placed on a must-run status for the entire commitment period. Subroutine PVA also places on must-run status those units which are required to meet the valley load condition.

Subroutine SIGS determines the minimum state for each hour. Units are removed in order of their priority until the removal of an additional unit would prevent the system from having the capacity to meet the system load and losses.

The heart of the UCP is subroutine OPTO. This subroutine searches through the commitment period for the least cost path. For each hour, the following functions are performed:

1. Subroutine ASC is called to create the states to be considered each hour by starting with the minimum state and adding units according to the priority list.

2. Subroutines EDP and PCOST are called to economically dispatch and determine the fuel cost of each state.

3. Subroutine SUCA calculates the start-up costs due to transitions from each state of the previous hour to each state of the present hour. The production cost for each state is calculated by summing the fuel costs and the start-up costs. A total cost to the present state is determined by adding the production cost of that state to the total costs of reaching the states of the previous hour. Because of Bellman's Principle of Optimality, the only transitions that need to be remembered are those transitions which yield the least total costs to the states of the present hour.

After the final hour has been evaluated, each state of the final hour will have associated with it an optimal path and that path's total cost. The state with the lowest cost path will be the final state of the least cost path for the commitment period.

Subroutine TRACE is called to trace back the path associated with each final state. Although one path will be the least cost path, the other paths may have other advantages that would offset the cost difference. All of the paths traced back are remembered in case the user wishes to examine them.

Finally, subroutine OUTPUT is called to print the results of the unit commitment run. The output from this subroutine consists of two reports. One is an hourly report on the system. Each hourly report is headed by the hour of the day the report addresses. Also, each unit is listed according to its state that hour. A plus sign (+) appears beside a unit's name if that unit is to be started that hour and a minus sign (-) appears if that unit is to be shut-down that hour. The other report is a commitment summary for the entire commitment period. This report lists various system information for each hour of the commitment period. This information includes the system load, losses, number of start-ups, number of shut-downs, the hourly cost, the total cost to that hour, reserves, hydro generation, CT generation, and tie flows. Hourly reports and a commitment summary may be printed for each commitment path.

The user has an option on how many paths are to be reported. If one path is desired, the least cost path is reported. If more than one path is desired, the paths are reported in order of their cost. Appendix B contains sample output from a typical unit commitment run.

CASE STUDIES

In order to test the UCP and determine the potential value of unit commitment, many case studies were conducted. Twelve cases are described in Table III-1. Appendix C gives more detailed descriptions

TABLE III-1

CASE STUDY DESCRIPTIONS

Case Number	Peak Load (MW)	Scheduling Code*	Cycling Code**
1	13,000	A	0
2	13,000	A	1
3	13,000	A	2
4	13,000	B	0
5	13,000	B	1
6	13,000	B	2
7	10,000	A	0
8	10,000	A	1
9	10,000	A	2
10	10,000	B	0
11	10,000	B	1
12	10,000	B	2

*Scheduling Codes:

A. All steam capacity assumed available. No Hydro, CT generation, or interchange scheduled.

B. Typical hydro, maintenance, deslagging, and must-run schedules are included. See Appendix C for details of the schedules.

**Cycling Codes:

0 - No cycling allowed. The system remains in its initial state throughout the commitment period.

1 - All units are given a twenty-four hour minimum down-time. A unit may be shut-down if not needed throughout the commitment period.

2 - Any unit may be cycled unless constrained by the steam schedule.

of those cases where units are scheduled. For every case where alternate states were considered for each hour, the program was run at its maximum capacity; i.e., twelve states were considered each hour of a commitment period which was twenty-four hours long.

The results of these runs (see Table III-2) show that for the cases where cycling was unlimited, the total cost was substantially less than the comparable cases where cycling was limited or not allowed. This indicates that if units could be cycled, a substantial cost savings would be realized.

Using the UCP at its full capacity takes approximately 6 minutes on a UNIVAC 1110 computer. The storage requirements are large as the program must store several large arrays, the largest of which requires 24 K words of storage. The total storage requirement is approximately 65 K words. Both the time and storage requirements are still undesirable. The next chapter will describe a method by which the time may be reduced by using a fuel cost estimation. This method will be tested by using it on the case studies of this chapter and comparing the results to those already obtained.

TABLE III-2

CASE STUDY RESULTS

A. High peak load demand (13,000 MW)

All steam capacity assumed available. No hydro scheduled.		Typical hydro, deslagging, and maintenance schedule	
Case No.	Total Cost ($/day)	Case No.	Total Cost ($/day)
1	1,417,001.70	4	1,559,088.23
2	1,416,640.55	5	1,558,657.08
3	1,407,650.92	6	1,556,088.45

B. Low peak load demand (10,000 MW)

All steam capacity assumed available. No hydro scheduled.		Typical hydro, deslagging, and maintenance schedule*	
Case No.	Total Cost ($/day)	Case No.	Total Cost ($/day)
7	1,040,524.14	10	1,130,394.62
8	1,037,356.70	11	1,125,980.22
9	1,035,475.50	12	1,125,980.80

*Under this schedule, cases 11 and 12 resulted in identical commitment results.

CHAPTER IV

FUEL COST ESTIMATION

The basic source of the large time requirement for a single unit commitment run is the economic dispatching of each system state considered each hour. Up to 95% of the total time is due to this function alone. The reason for dispatching the states is to determine the individual unit loadings so that the fuel cost may be calculated. A substantial savings in computer time could be realized if the fuel costs for the various states could be calculated, or accurately approximated, without the necessity of economic dispatching every state.

This chapter will describe the development of a method for fuel cost estimation. The basic approach of this method is threefold:

1. Economically dispatch and determine the fuel cost (C^o) of one state; call this the base state.

2. Calculate the difference in cost (ΔC) between the base state and the state in question based on the differences between the two states.

3. Calculate the cost of the state in question (C) by summing C^o and ΔC; i.e.,

$$C = C^o + \Delta C \tag{IV-1}$$

The system load demand is assumed the same for the states considered. This implies that at least one economic dispatch is required for each hour of the commitment period in order to calculate the fuel cost for the base state.

Due to the priority constraint, the basic difference between any two states considered each hour lies in how many units are on-line. The state which has the most units on-line is to be taken as the base state. This enables the calculation of the other state costs to be made based on the costs of shutting units down. If any other state was chosen as the base state, difficulties would arise in calculating the cost of the maximum capacity state for reasons which will become evident later.

The increase in cost to a system when a unit is shut-down may be written as

$$\Delta C = \lambda_{est}\Delta P - C_i \qquad \text{(IV-2)}$$

where λ_{est} is the average cost of the system to pick up one megawatt, ΔP is the generation the system must pick up, and C_i is the fuel cost of the unit i before it was taken off-line. C_i is given by Eq. II-4, repeated here,

$$C_i = F_i(a_i + b_iP_i + c_iP_i^2) \qquad \text{(II-4)}$$

ΔP is the sum of the generation taken off-line and the change in losses due to the change in state. This is the reason for choosing the maximum capacity state as the base state. Calculation of ΔP depends on knowing the loading of the generators considered for shut-down. The only way to do this is to economically dispatch the state which has all of these units on-line.

In H. H. Happ's paper [11], a relationship similar to Eq. IV-2 is used to evaluate the change in cost due to taking a unit off-line.

The major differences are that he assumes (1) λ is approximately constant over a change in state, (2) the unit taken off-line is on its minimum limit, and (3) the losses remain unchanged with the change in state. Assumption 2 is not necessary if the base state has been economically dispatched and the loading for unit i determined. Letting λ^o represent the system lambda of the base state, and using assumptions 1 and 3, Eq. IV-2 may be written

$$\Delta C \simeq \lambda^o P_i - C_i \qquad \text{(IV-3)}$$

Extending this to the case where n units are taken off-line, Eq. IV-3 becomes

$$\Delta C \simeq \lambda^o \sum_{i=1}^{n} P_i - \sum_{i=1}^{n} C_i \qquad \text{(IV-4)}$$

This approximation was tested for several different system load demands. In general, the average error incurred using the approximation to calculate the fuel cost of a state was about one percent of the actual fuel cost. For a state costing \$50,000, this amounts to \$500. The error is noticed to be on the same order as the transition costs between states. This implies that the commitment schedule would be sensitive to the error in calculating the fuel costs. In order to decrease this sensitivity, refinements must be made so that the error is much less than the transition costs. This may be done by not making assumptions 1 and 3 made by Happ; i.e., not assuming lambda to be constant over a change in state and not assuming the losses to remain the same.

If λ is not assumed constant, the average λ (λ_{est}) must be determined. To do this, recall that λ is defined as the incremental cost at only one specific operating point. If the system does experience a very small generation increase, say one megawatt, the added cost would be λ, but the system would then take on another value for λ, say λ'. In order to understand more about this relationship, the system was dispatched in the maximum capacity state for a given load and $\lambda = \lambda_o$ was recorded. Also, the generation of each unit (P_i) was recorded for that state. Units were then removed in order of their priority. Each time a unit was removed, the system was redispatched and a new value of λ was obtained. The λ's were plotted as a function of the generation taken off-line (P_{off}). These plots were made for several different load demands and are shown in Fig. IV-1. Note that λ seems to increase almost linearly with the generation taken off-line. However, the slopes are different for the various load conditions. No short-cut method exists at this time to determine the slopes for a given load. However, if the λ's were known for two states under a given load condition, the λ for any state having a capacity between the capacities of the two known states can be approximated using a linear interpolation.

Fig. IV-2 shows a plot similar to those of Fig. IV-1, but using a hypothetical situation where the λ versus P_{off} curve is linear. λ_o represents the base state for which the actual fuel cost is known. p_1 represents the first MW of generation taken off-line, p_2 the second, and on up to p_n. (To evaluate λ_{est}, it will be assumed that the change in losses is negligible.) The cost of adding the first megawatt is λ_o, the cost of adding the second is λ_1, etc. Therefore, the total cost of adding n megawatts of generation is $\sum_{i=0}^{n-1} \lambda_i$. Since the λ_i's are linearly related, the average cost per megawatt (λ_{est}) added would be

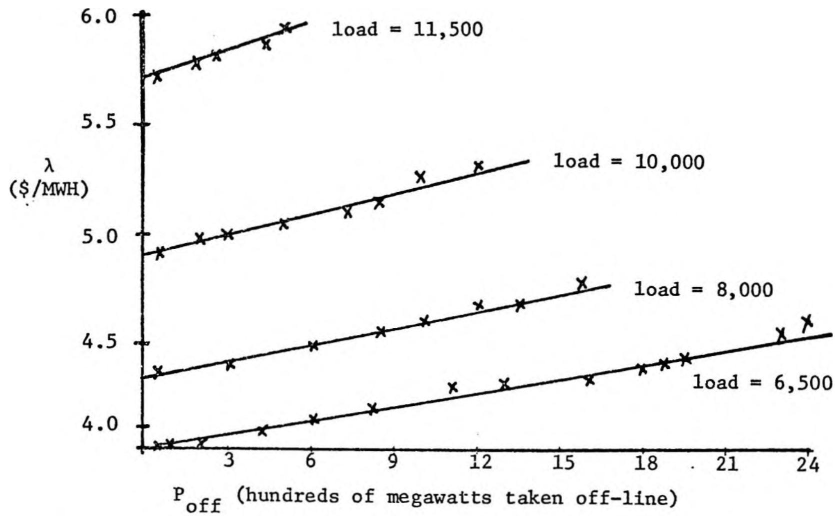

Figure IV-1. Actual λ versus P_{off} plots for various load demands

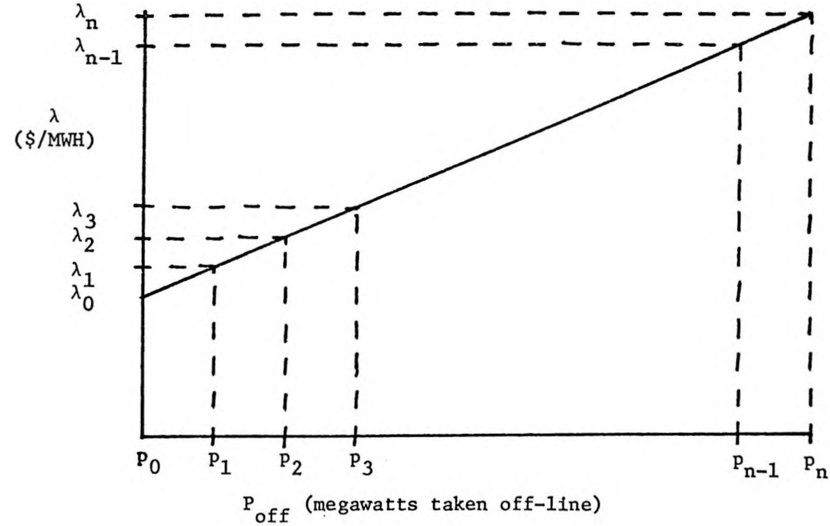

Figure IV-2. λ versus P_{off} plot assuming perfect linearity

$$\lambda_{est} = \sum_{i=0}^{n-1} \lambda_i/(n-1) = \tfrac{1}{2}(\lambda_{n-1} - \lambda_o) \simeq \tfrac{1}{2}(\lambda_n - \lambda_o) \qquad \text{(IV-5)}$$

The approximation can be made since the change in λ over 1 MW is negligible compared to the overall change in lambda for a change in state; i.e., $\lambda_{n-1} \simeq \lambda_n$. Substituting Eq. IV-5 into Eq. IV-2,

$$\Delta C = \frac{(\lambda_n - \lambda_o)\Delta P}{2} - C_i \qquad \text{(IV-6)}$$

The only remaining term to be calculated is ΔP, which is the generation a state must pick-up when a unit is taken off-line. ΔP may be expressed as

$$\Delta P = P_i + \Delta P_{Li} \qquad \text{(IV-7)}$$

where P_i is the power unit i delivered before it was taken off-line, and ΔP_{Li} is the change in the losses due to unit i being taken off-line. P_i is known from the economic dispatching of the base state. ΔP_{Li} is not known. An assumption was made that the losses would change linearly with a change in state. At the time this assumption was made, it was considered a poor approximation, but possibly better than assuming the losses to be constant. Comparison was made between the two assumptions by using both of them to estimate the fuel costs of several states for various load conditions. The results showed that the linear approximation usually increased the error in the cost estimate. This was due to the fact that losses may increase or decrease with a change in state depending on the particular unit taken off-line.

The results of the study comparing the linear and constant approximations of the change in losses also revealed that when $\lambda_{est} = (\lambda_n - \lambda_o)/2$, the magnitude of the error was usually around 0.2%.

Using λ_{est} instead of λ^o improves the approximation substantially, greatly reducing the commitment's sensitivity to the estimating of the fuel costs.

In order to evaluate the concepts presented in this chapter, case studies 3, 6, 9, and 12 from the previous chapter were repeated using fuel cost estimation. The cases were chosen because they allowed unlimited cycling and would provide a good basis for comparison. To further improve the comparison, the schedules resulting from the repeated cases were dispatched to obtain the actual cost of the schedule. Table IV-1 tabulates the total costs obtained for the comparison. Appendix D contains the case summaries. The results show that although the commitment schedules are slightly different, the overall potential savings are about the same.

The computer time required for one unit commitment run is about 2 minutes on a UNIVAC 1110 computer. The time requirements have been reduced over 60%; but what is more important is that more states may be considered each hour with very little added time requirement. The more states considered each hour, the better the probability that the optimal path lies within the search bounds.

TABLE IV-1

TOTAL COSTS USING EXACT COST CALCULATION*

AND FUEL COST ESTIMATION

	Case 3	Case 6	Case 9	Case 12
Exact Cost	1,407,650.92	1,556,088.45	1,035,475.50	1,125,980.80
Estimated Cost	1,407,999.78	1,556,837.47	1,035,380.56	1,128,053.67
Difference	348.86	749.02	-94.94	2,072.87
Percent Error	0.0248	0.0481	-0.0092	0.1836

*Exact calculation refers to calculation of the fuel costs based on the power generated by each unit, their average fuel costs, and heat rates.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The cost figures given in Chapters III and IV indicate that there are potential savings to be gained by scheduling steam units using the unit commitment program described by this paper. Along with this monetary savings, there is also possibly a more important benefit, the actual fuel savings. In a time when the world is experiencing a general fuel shortage, it is imperative that the fuel available be used to its maximum benefit.

Generator manufacturers have designed fossil-fuel steam units for cycling. These units have capacities in the 200 to 400 MW range and their heat rates are comparable to those of conventional steam units of the same size. Their designs have considerably reduced the depreciation costs of cycling. Unfortunately, most of the annual production costing programs commonly used today are not able to evaluate in sufficient detail the economics of cycling. Therefore, units designed for cycling are not often included in generation expansion plans. The results of the case studies made in this paper show that the inclusion of these units in planning considerations may result in potential savings.

The unit commitment program can also be used as a study tool which can help evaluate system operating policies, such as deslagging and maintenance schedules. The program can also be used to evaluate proposed generation expansion plans in greater detail than is possible using most annual production costing programs. By merely observing the results of program runs and comparing them with the real world operations, the user can gain much insight into the system under study. Because of this, the program may be useful as a training tool.

Basically, the program was designed more to aid the system coordinator than to actually control the system. Problems such as forced outages and unexpected demands cannot be foreseen by the program, so the decisions which must be made due to such conditions must be left to the coordinator. If he knows what the best schedule is under the expected situations, he is better equipped to handle any deviations which may occur.

Having used the program to a certain extent, one recognizes its potential usefulness to power systems engineering. However, there are several areas in which more work and research need to be done.

The time requirement has been reduced greatly using fuel cost estimation. Since the program was developed in a research environment several parts could be reprogrammed to reduce the time requirement even further. The economic dispatch subroutine still accounts for much of the time required to run the program, possibly as much as 50%. The heart of this subroutine is the solving of the economic dispatch equations (Eq. II-14) using a Gauss-Seidel iterative technique. Faster convergence may be possible by the determination of a method for obtaining a better initial guess to the solution than is currently used and incorporating the loss evaluation earlier in the algorithm.

As mentioned earlier, the storage requirements are quite large.

It is this problem that now hinders the consideration of more states each hour. This requirement may be reduced by storing only the minimum state each hour and constructing the other states as they are needed, by adding the appropriate units. Other storage requirements can be reduced by storing only the upper half of symmetric matrices and making more efficient use of the storage space.

More research is also needed in priority listing. The method used to create the priority list used in this paper is quite complicated and certainly could not be done for each commitment run. It seems at this time that the actual savings are not extremely sensitive to minor variations within the priority list. This indicates the possibility that a simpler method of priority listing may be sufficient.

In Chapter IV, the decision was made not to include the change in losses due to a change in state because a suitable method had not been found to calculate this term. If a method for approximating the change in the system losses based on a change in state could be developed, its inclusion could increase the accuracy of the fuel cost estimation. It should be noted, however, that the solutions obtained are still quite good, even if the losses are not accounted for.

In order to meet the load demands of the consumer in a most economical way, consideration must be given by the power industry to the selection of generating units to be on-line such that the total production costs be minimized. The program described by this paper accomplishes this task while taking into consideration many constraints which may be imposed on a power system. The program was developed using data from a large power system in the southeastern United States.

The characteristics of this system are typical of most other power systems. For this reason, the algorithms used by the program could be easily adapted to other power systems.

The flexibility of the program enables it to be of value not only to system operation but also to system planning. The program is of sufficient detail and accuracy to evaluate the worth of a single generating unit; yet it is general enough to represent most operational conditions. Using the UCP in a study mode could provide valuable information to the user for evaluating system economics in light of other system characteristics such as reliability and/or security.

APPENDIX A

SOURCE LISTINGS OF SUBROUTINES

Brief descriptions of the various subroutines are given below. The following pages contain the actual Fortran source listings. Comments are included in the listings to further aid the reader.

A.1. MAIN Routine - Calls subroutines

A.2. SB - Initializes variables

A.3. Subroutine INPUT - Reads data

A.4. Subroutine FIX - Expands the B-coefficient matrix

A.5. Subroutine SKED - Reads the scheduling data and performs associated calculations

A.6. Subroutine FLS - Builds a load forecast based on a load model and peak demand

A.7. Subroutine RCA - Calculates steam reserve requirements

A.8. Subroutine MAXG - Calculates hourly system generation capacity

A.9. Subroutine PVA - Constrains twenty-four hour minimum down-time units as necessary to meet the second day's peak load demand

A.10. Subroutine SIGS - Determines the minimum capacity state for each hour

A.11. Subroutine OPTO - Searches the state-space for the optimal path

A.12. Subroutine ASC - Creates and stores the alternate states

A.13. Subroutine FCE - Estimates the fuel costs for each system state

A.14. Subroutine EDP - Economically dispatches a given system state for a given system load

A.15. Subroutine PCOST - Calculates fuel cost for a state given the unit loadings

A.16. Subroutine SUCA - Calculates the start-up cost of a unit

A.17. Subroutine TRACE - Traces and stores the optimal path

A.18. Subroutine OUTPUT - Prints the hourly reports and commitment summary

A.1. MAIN Routine

```
C
C*****************************************************************************
C
C    THIS MAIN ROUTINE ALLOWS NORMAL CYCLING.  THE PRODUCTION COSTS
C    ARE CALCULATED USING FUEL COST ESTIMATION.
C
C*****************************************************************************
C
      COMPILER (XM=1)
      COMMON /COM1/ NA,ND,PMAX(80),PMIN(80),PFIX(125,25)
      COMMON/COM7/ HRES(25),FM(3,25),HLT(25),PEAK1,RMW,M2,IT,MOD1
      COMMON /COM9/ FL(25), REQ(25)
      COMMON /COM10/ DPL(125),PS,PL
      COMMON /COM11/ PEAK2,MOD2
      COMMON /COM14/ DPS,CO
      COMMON /COM15/ MS,NSKED
      COMMON /COM16/ AS(80,25,12)
      COMMON/ COM18/ DF(5,21),N1,N2,N3,N4
      REAL*8 NM(2,125)
          INTEGER*2 S(125,25),NP(80),NFRM(25,12),TR(25,12),AS
      REAL  LAMBDA(25,12)
      DIMENSION R(125),  COST(25,12),GMAX(25),NEXT(12)
      DATA NFRM/300*1/,TR/300*1/
      CALL INPUT(NM,NP,S)
      CALL FLS
      CALL RCA
      CALL MAXG(S,M2,GMAX)
      CALL PVA(GMAX,PEAK2,NP,S)
      CALL SIGS(S,GMAX,NP)
      CALL OPTU(COST,NFRM,LAMBDA,NP,NEXT,LASTST)
      CALL TRACE(M2,NFRM,TR)
      CALL OUTPUT(ND,M2,COST,IT,TR,LAMBDA,NM,LASTST)
      STOP
      END
```

A.2. SB

```
C
C*****************************************************************************
C
C    THIS ROUTINE INITIALIZES THE PFIX,HRES,HLT,HMAX, AND DF ARRAYS.
C
C*****************************************************************************
C
      BLOCK DATA
      COMMON /COM1/ NA,ND,PMAX(80),PMIN(80),PFIX(125,25)
      COMMON /COM7/ HRES(25),FM(3,25),HLT(25),PEAK1,RMW,M2,IT,MOD1
      COMMON/COM8/HMAX(80)
      COMMON/ COM18/ DF(5,21),N1,N2,N3,N4
      REAL PFIX/3125*0.0/,HRES/25*0.0/,HLT/25*0.0/,HMAX/80*0.0/
      REAL DF/105*0.0/
      END
```

A.3. Subroutine INPUT

```
      SUBROUTINE INPUT(/NM/,/NP/,/S/)
C
C*****************************************************************************
C
C    THIS SUBROUTINE READS IN ALL DATA NECESSARY FOR A UNIT COMMITMENT
C    RUN. IT ALSO INITIALIZES THE MASTER STATE MATRIX (S), EXPANDS THE B
C    AND BNO MATRICES, AND CALCULATES HYDRO RESERVES FOR EACH HOUR, AND
C    PREPARES THE PFIX ARRAY.
C
C    THE VARIABLES USED BY THIS SUBPROGRAM ARE DESCRIBED BELOW.
C
C    NAME    DIMENSION   COMBLOCK              DESCIPTION
C
C    NA          1         COM1     # OF ACTIVE UNITS
C    ND          1         COM1     # OF STEAM UNITS
C    PMAX       80         COM1     MAX LIMIT OF UNITS
C    PMIN       80         COM1     MIN LIMIT OF UNITS
C    PFIX     125X25       COM1     FIXED GENERATION VALUES OF EACH UNIT E
C    D         125         COM2     DIAGONAL OF B-MATRIX WRT UNITS
C    C         125         COM2     BNO-CONSTANTS WRT UNITS
C    B       125X125       COM2     B-CONSTANTS WRT UNITS
C    NE        125         COM3     ENTRY POINTS OF UNITS
C    BT       30X300       COM3     B-CONSTANTS WRT ENTRY POINTS
C    BC         30         COM3     BNO-CONSTANTS WRT ENTRY POINTS
C    HC         80         COM4     UNIT HEAT RATE COEFF - C
C    HB         80         COM4     UNIT HEAT RATE COEFF - B
C    FCI        80         COM4     UNIT INCREMENTAL FUEL COSTS
C    RATE      125         COM5     UNIT RESPONSE RATES
C    MUT        80         COM5     UNIT MIN UP TIMES
C    MDT        80         COM5     UNIT MIN DOWN TIMES
C    CSC        80         COM5     UNIT COLD START COSTS
C    STC        80         COM5     UNIT DOWN TIME FOR COLD START
C    HA         80         COM6     UNIT HEAT RATE COEFF - A
C    FCA        80         COM6     UNIT AVERAGE FUEL COSTS
C    HRES       25         COM7     HOURLY HYDRO RESERVES
C    FM        5X21        COM7     HOURLY LOAD MODELS
C    HLT        25         COM7     HOURLY HYDRO-CT-TIE-NUCLEAR GENERATION
C    PEAK1       1         COM7     PEAK LOAD OF FIRST DAY
C    RMW         1         COM7     MW RESERVE CAPACITY REQUIREMENT
C    M2          1         COM7     # HOURS IN COMMITMENT PERIOD
C    IT          1         COM7     INITIAL HOUR OF COMMITMENT PERIOD
C    MOD1        1         COM7     FIRST DAY'S LOAD MODEL TYPE
C    HMAX       80         COM8     HOURLY HYDRO AVAILABILITY
C    DF        5X21        COM18    TIE LINE DISTRIBUTION FACTORS
C    PEAK2       1         COM11    PEAK LOAD FOR SECOND DAY
C    MOD2        1         COM11    SECOND DAY'S LOAD MODEL TYE
C    DPS         1         COM14    CONVERGENCE VALUE FOR EC. DISPATCH
C    CU          1         COM14    MINIMUM START FACTOR
C    MS          1         COM15    NO. OF STATES CONSIDERED EACH HOUR
C    NSKED       1         COM15    NO. OF PATHS TO BE REPORTED
C    AS      80X25X12      COM16    ALTERNATE STATE MATRIX
C    PCTR        1         COM17    PCT RESERVE REQ. IN RT MINUTES
C    RT          1         COM17    TIME REQ. FOR SPINNING RESERVES
C    DF        5X21        COM18    TIE LINE DISTRIBUTION FACTORS
C    N1          1         COM18    NO. OF STEAM UNITS
C    N2          1         COM18    NO. OF CT UNITS
```

```
C    N3          1        COM18     NO. OF HYDRO UNITS
C    N4          1        COM18     NO. OF TIE POINTS
C    GENMIN      1        COM20     LOSS FACTOR
C    NM       2X125       -----     UNIT NAMES
C    S        125X25      -----     MASTER STATE MATRIX
C    NP         80        -----     RELATES PRIORITY NO. TO UNIT NO.
C    NST        40        -----     UNIT STATION NO.
C    NSU        80        -----     UNIT START UP PER STA. PER HOUR LIMIT
C    DIS         5        -----     RELATES TIE POINTS TO NEIGHBOR
C    I           1        -----     DATA CARD TYPE
C
C    DATA CARD TYPES --              1. HEADER CARD
C                                    2. UNIT NAME CARDS
C                                    3. B-CONSTANTS
C                                    4. BNO-CONSTANTS
C                                    5. UNIT DATA CARDS
C                                    6. RESERVE REQ. CARD
C                                    7. LOAD PEAKS CARD
C                                    8. LOAD MODEL DATA CARDS
C                                    9. SCHEDULE CARDS
C                                   10. INITIAL STATE CARDS
C                                   11. TUNING PARAMETERS CARD
C                                   12. OUTPUT OPTIONS CARD
C
C**********************************************************************
C
      COMMON /COM1/ NA,NO,PMAX(80),PMIN(80),PFIX(125,25)
      COMMON /COM2/ D(125),C(125),B(125,125)
      COMMON /COM3/ NE(125),BT(30,30),BC(30)
      COMMON /COM4/ HC(80),HB(80),FCI(80)
      COMMON /COM5/ RATE(125),MUT(80),MDT(80),CSC(80),STC(80)
      COMMON /COM6/ HA(80),FCA(80)
      COMMON /COM7/ HRES(25),FM(3,25),HLT(25),PEAK1,RMW,M2,IT,MOD1
       COMMON /COM8/ HMAX(80)
      COMMON /COM11/ PEAK2,MOD2
      COMMON /COM14/ DPS,CO
      COMMON /COM15/ MS,NSKED
      COMMON /COM16/ AS(80,25,12)
      COMMON /COM17/ PCTR,RT
      COMMON/ COM18/ DF(5,21),N1,N2,N3,N4
      COMMON /COM20/ GENMIN
      REAL*8 NM(2,125),I1,I2
      INTEGER*2 S(125,25),NP(80),NST(40),NSU(80),IS1,AS
      DIMENSION H(3),DIS(5)
C
C**********************************************************************
C
C    READ IN DATA CARD TYPE
C    TRANSFER CONTROL TO APPROPRIATE SECTION FOR SPECIFIC DATA INPUT
C
C**********************************************************************
C
   10 READ(5,8000,END=9500)I
   20 GO TO(100,200,300,400,500,600,700,800,900,1000,1100,1200),I
C
C**********************************************************************
C
```

```
C    READ IN HEADER. CALCULATE NO. OF CARDS PER ROW OF B AND BNO         00010100
C    CONSTANT DATA CARDS. INITIALIZE THE MASRER STATE MATRIX TO THE      00010200
C    FOLLOWING DEFAULT CONDITIONS.                                       00010300
C                                                                        00010400
C                         STEAM UNITS  - 0                               00010500
C                         HYDRO UNITS  - 3                               00010600
C                         CT UNITS     - 2                               00010700
C                         NUC UNITS    - 3                               00010800
C                         TIE POINTS   - 2                               00010900
C                                                                        00011000
C***********************************************************************00011100
C                                                                        00011200
  100 READ(5,6010)I,NA,ND,NC,NH,NT,NN,NB,M2,MS,IT                        00011300
      IF(M2.EQ.0)M2=24                                                   00011400
      IF(MS.EQ.0)MS=12                                                   00011500
      IF(IT.LE.0)IT=1                                                    00011600
      NNB=(NB+7)/8                                                       00011700
      N1=ND+1                                                            00011800
      N2=N1+NC                                                           00011900
      N3=N2+NH                                                           00012000
      N4=N3+NN                                                           00012100
      DO 120 I=1,NA                                                      00012200
      IS1=0                                                              00012300
      IF(I.GE.N1)IS1=2                                                   00012400
      IF(I.GE.N2)IS1=3                                                   00012500
      IF(I.GE.N3)IS1=3                                                   00012600
      IF(I.GE.N4)IS1=2                                                   00012700
      DO 110 J=1,25                                                      00012800
      S(I,J)=IS1                                                         00012900
  110 CONTINUE                                                           00013000
      IF(I.GT.ND) GO TO 120                                              00013100
      AS(I,1,1)=IS1                                                      00013200
  120 CONTINUE                                                           00013300
      GO TO 10                                                           00013400
  200 CONTINUE                                                           00013500
C                                                                        00013600
C***********************************************************************00013700
C                                                                        00013800
C    READ IN UNIT NAME CARD. IF UNIT IS HYDRO, IT WILL HAVE NO STATION   00013900
C    NO., S.U./STA./HR LIMIT, OR PRIORITY NO.. HOWEVER, STORE ITS        00014000
C    CAPACITY IN HMAX. READ IN THE DISTRIBUTION FACTORS FOR EACH TIE     00014100
C    LINE. DF(J,I) = DISTRIBUTION FACTOR FOR COMPANY J AT TIE BUS I.     00014200
C    COMPANY CODES ON THE TYPE 9 CARDS OF 501, 502, 503, 504, AND 505    00014300
C    CORRESPOND RESPECTIVELY TO THE J VALUES.                            00014400
C                                                                        00015100
C***********************************************************************00015200
C                                                                        00015300
      DO 210 L=1,NA                                                      00015400
      READ(5,6020)I,K1,K2,K3,K4,I1,I2,RR,CAP,(DIS(J),J=1,5)              00015500
      NE(I)=K2                                                           00015600
      NM(1,I)=I1                                                         00015700
      NM(2,I)=I2                                                         00015800
      RATE(I)=RR                                                         00015900
      IF(I.GT.ND)GO TO 205                                               00016000
      NP(K1)=I                                                           00016100
C     NST(K3)=I                                                          00016200
C     NSU(K4)=I                                                          00016300
```

```
      GO TO 210
  205 K=I-ND
      KK2=NA-NT
      IF(I.LE.KK2)GO TO 208
      NTIE= I- KK2
      DO 207 J=1,5
      DF(J,NTIE) = DIS(J)
  207 CONTINUE
      GO TO 210
  208 HMAX(K)=CAP
  210 CONTINUE
      GO TO 10
C
C*****************************************************************************
C
C    READ IN B-CONSTANTS WRT ENTRY POINTS
C
C*****************************************************************************
C
  300 DO 320 L=1,NB
      KK=-7
      KK1=0
      DO 310 L1=1,NNB
      KK=KK+8
      KK1=KK1+8
      IF(L1.EQ.NNB)KK1=NB
      READ(5,6030)LINENO,(BT(L,L2),L2=KK,KK1)
  310 CONTINUE
  320 CONTINUE
      GO TO 10
C
C*****************************************************************************
C
C    READ IN BNO-CONSTANTS WRT ENTRY POINTS
C    CALL SUBROUTINE FIXUP TO EXPAND THE B AND BNO MATRICES TO GIVE B
C    AND BNO CONSTANTS WRT EACH UNIT. ALSO, FIXUP WILL FIND AND SAVE THE
C    DIAGONAL ELEMENTS OF THE EXPANDED B MATRIX.
C
C*****************************************************************************
C
  400 KK=-7
      KK1=0
      DO 410 L1=1,NNB
      KK=KK+8
      KK1=KK1+8
      IF(L1.EQ.NNB)KK1=NB
      READ(5,6040)LINENO,(BC(L2),L2=KK,KK1)
  410 CONTINUE
      CALL FIXUP(NA)
      GO TO 10
  500 CONTINUE
C
C*****************************************************************************
C
C    READ IN UNIT DATA CARD
C
C*****************************************************************************
```

```
C
  550 READ(5,8050)I,L,J,K,GN,GX,S1,T,F1,F2,A1,A2,A3
      IF(I.NE.5)GO TO 10
      MUT(L)=J
      MDT(L)=K
      PMIN(L)=GN
      PMAX(L)=GX
      CSC(L)=S1
      STC(L)=T
      FCA(L)=F1
      FCI(L)=F2
      HA(L)=A1
      HB(L)=A2
      HC(L)=A3
      GO TO 550
C
C***********************************************************************
C
C    READ IN RESERVE REQUIREMENTS
C
C***********************************************************************
C
  600 READ(5,8060)RMW,RT,PCTR
      GO TO 10
C
C***********************************************************************
C
C    READ IN LOAD INFORMATION CARD
C    MOD1 AND MOD2 DESIGNATE FIRST AND SECOND DAY MODELS (1,2,OR 3)
C    PEAK1 AND PEAK2 ARE FIRST AND SECOND DAY PEAKS IN MW.
C
C***********************************************************************
C
  700 READ(5,9000)MOD1,PEAK1,MOD2,PEAK2
      GO TO 10
C***********************************************************************
C
C    READ IN LOAD MODEL DATA, ADJUSTING FOR DIFFERENCE IN REAL AND
C    PROGRAM TIME. MODELS ARE FOR WEEKDAYS, SATURDAY, AND SUNDAY (J = 1,
C    2, AND 3 RESPECTIVELY).
C
C***********************************************************************
C
  800 DO 810 L=1,24
      READ(5,8070)(H(J),J=1,3)
      N=L-IT+24
      IF(N.GT.24)N=N-24
      DO 805 J=1,3
      FM(J,N)=H(J)
      IF(N.EQ.1)FM(J,25)=H(J)
  805 CONTINUE
  810 CONTINUE
      GO TO 10
  900 CONTINUE
C
C    CALL SKED TO READ IN AND PROCESS THE SCHEDULES.
C
```

```
      CALL SKED(S,NT)
      GO TO 10
C
C*************************************************************************
C
C    READ IN INITIAL STATE DATA. (SAME FORM AS SCHEDULE CARDS)
C
C*************************************************************************
C
 1000 CONTINUE
      READ(5,6090)I,J,IS,LT,LH,FIX
      IF(I.NE.10)GO TO 20
      AS(J,1,1)=IS
      IF(IS.EQ.1)PFIX(J,L)=FIX
 1040 GO TO 1000
C
C*************************************************************************
C
C    READ IN TUNING PARAMETERS
C
C*************************************************************************
C
 1100 CONTINUE
      READ(5,9010)I,DPS,CO,GENMIN
      WRITE(6,1111)  GENMIN
 1111 FORMAT(//20X,'THE MULTIPLYING FACTOR ON LOAD IS',2X, F5.3)
      WRITE(6,1112)  CO
 1112 FORMAT(//20X,'THE MINIMUM START-UP COST MULTIPLYING FACTOR IS',
     12X, F5.3)
      IF(DPS.LT.1E-6)DPS=1.
      GO TO 10
C
C*************************************************************************
C
C    READ IN OUTPUT OPTIONS
C
C    NSKED = THE NUMBER OF SCHEDULES TO BE PRINTED OUT.
C
C*************************************************************************
C
 1200 READ(5,6010)  NSKED
      IF(NSKED.GT.MS)  NSKED=MS
 6000 FORMAT(I4)
 6010 FORMAT(12I4)
 6020 FORMAT(4X,5I4,2A8,F4.1,F7.1,5F5.1)
 6030 FORMAT(17X,I2,4X,8F7.5)
 6040 FORMAT(20X,I2,1X,-2P8F7.5)
 6050 FORMAT(2I4,2I3,F6.1,F7.1,F6.1,F5.1,2F7.2,F8.3,F7.3,F8.5)
 6060 FORMAT(4X,F6.1,2F5.1)
 6070 FORMAT(5F5.3)
 6080 FORMAT(6I4,F8.1)
 6090 FORMAT(5I4,F8.1)
 9000 FORMAT(2(I4,F8.1))
 9010 FORMAT(I4,F6.2,3F6.3)
 9500 CONTINUE
      RETURN
      END
```

A.4. Subroutine FIX

```
      SUBROUTINE FIXUP(NA)
C
C*****************************************************************************
C
C    THIS SUBROUTINE EXPANDS THE B & BNO MATRICES AND STORES THE DIAGONAL
C    ELEMENTS OF THE EXPANDED B-MATRIX IN VECTOR D.
C
C    I.E.       IF    K IS THE ENTRY POINT OF UNIT I
C               AND   L IS THE ENTRY POINT OF UNIT J
C
C               THEN D(I)=BT(K,K)
C                    C(I)=BC(K)
C                    B(I,J)=BT(K,L)
C
C    WHERE BT AND BC ARE THE B AND BNO MATRICES, RESPECTIVELY, WRT THE
C    ENTRY POINTS. NA IS THE TOTAL NUMBER OF ACTIVE UNITS.
C
C
C*****************************************************************************
C
       COMMON /COM2/ D(125),C(125),B(125,125)
      COMMON /COM3/ NE(125),BT(30,30),BC(30)
      DO 50 I=1,NA
   40 K=NE(I)
      D(I)=BT(K,K)
      C(I)=BC(K)
      DO 45 J=1,NA
      L=NE(J)
      B(I,J)=BT(K,L)
   45 CONTINUE
   50 CONTINUE
      RETURN
      END
```

A.5. Subroutine SKED

```
      SUBROUTINE SKED(/S/,/NT/)
C
C*****************************************************************************
C
C    READ SCHEDULE CARD, PREPARE MASTER STATE AND PFIX MATRICES, CALC. HY
C    CT, TIE, AND NUC GENERATION, AND CALC. HOURLY HYDRO RESERVES
C
C    IH=INITIAL HOUR. DEFAULT VALUE IS 1
C    LT=DURATION OF THIS SCHEDULE.
C    LH=LAST HOUR. DEFAULT VALUE IS LAST HOUR OF COMMITMENT PERIOD
C
C    STATE DEFINITIONS -
C
C         STEAM UNITS -
C                   0 - ON-LINE COMMITABLE (ECONOMIC RUN)
C                   1 - ON-LINE NOT COMMITABLE (MUST RUN)
C                   2 - OFF-LINE NOT COMMITABLE (MUST DOWN)
C                   3 - OFF-LINE COMMITABLE (ECONOMIC DOWN)
C
C                   A VALUE OF 3 OR GREATER INDICATES TIME UNIT HAS BEEN
C                   ECONOMICALLY
C
C                   PFIX HAS VALUE ONLY IF UNIT IS IN STATE 1, OTHERWISE
C                   FOR STEAM UNITS IN STATE 1 - PFIX=0 IMPLIES ECONOMIC
C                                                PFIX>0 IMPLIES FIXED GEN
C
C         HYDRO & CT UNITS -
C                   0 - NOT ALLOWED. DEFAULT TO 3 HYDRO UNITS, 2 FOR FOR
C                   1 - SCHEDULED UP. PFIX GIVES VALUE OF GENERATION
C                   2 - OFF-LINE. NOT RESERVE CAPACITY
C                   3 - OFF-LINE. RESERVE CAPACITY
C
C         TIE POINTS -
C                   0 - NOT ALLOWED. DEFAULT TO 2
C                   1 - SCHEDULED INTECHANGE. PFIX CONTAINS MW VALUE
C                   2 - NO INTERCHANGE SCHEDULED
C                   3 - NOT ALLOWED. DEFAULT TO 2
C
C         NUCLEAR UNITS -
C
C                   ** LOGIC NOT YET DEVELOPED **
C
C*****************************************************************************
C
      COMMON /COM1/ NA,ND,PMAX(80),PMIN(80),PFIX(125,25)
      COMMON /COM7/ HRES(25),FM(3,25),HLT(25),PEAK1,PMW,M2,IT,MOD1
      COMMON/COM8/ HMAX(80)
      COMMON /COM16/ AS(80,25,12)
      COMMON/ COM18/ DF(5,21),N1,N2,N3,N4
      INTEGER*2 S(125,25),AS
      LOGICAL DAY2
C **READ A SCHEDULE CARD
      DAY2=.FALSE.
      WRITE(6,81)
   81 FORMAT(//5X,'TYPE',5X,'UNIT',2X,'START TIME',3X,'END TIME',3X,
     1'STATE',5X,'FIXED MW',//)
```

```
   50 READ(5,80)  I,J,IH,LH,IS,FIX
   80 FORMAT(3I4,4X,2I4,F8.1)
      WRITE(6,82)  I,J,IH,LH,IS,FIX
   82 FORMAT(6X,I2,6X,I4,6X,I2,10X,I2,7X,I3,6X,F8.1)
      IF(I.NE.9)GO TO 700
C **CHECK FOR SECOND DAY SCHEDULE AND TRANSFER************
      IF(J.EQ.2222)  DAY2=.TRUE.
      IF(DAY2)  GO TO 500
C  ****PROCESS FIRST DAY SCHEDULE. IF THE INITIAL TIME IS 2400 GO TO
C        THE SECOND DAY.******
      IF (IT.EQ.24)  GO TO 50
      IF(LH.EQ.0)  GO TO 100
      IF(LH.GT.IT)  GO TO 110
C  ***THIS SCHEDULE ENDS BEFORE THE INITIAL TIME. SKIP IT.****
      GO TO 50
C  ***OBTAIN THE LAST HOUR FROM THE END TIME OF SCHEDULE.****
  100 LH=24-IT
      GO TO 120
  110 LH= LH-IT
C* ***OBTAIN THE START HOUR FROM THE START TIME OF SCHEDULE.******
  120 IF(IH) 121,130,121
  121 IF(IH-IT) 130,130,122
  122 IH= IH-IT
      GO TO 160
  130 IH=1
  160 DO 395 L=IH,LH
C *** IS THIS A STEAM UNIT?  ******************************************
      IF(J.LT.N1)GO TO 250
C    IS THIS A CT?   **************************************************
      IF(J.LT.N2)GO TO 240
C    IS THIS A HYDRO UNIT?   ******************************************
      IF(J.LT.N3)GO TO 230
C    IS THIS A NUCLEAR UNIT?  *****************************************
      IF(J.LT.N4)GO TO 220
      IF(J.GE.500)GO TO 300
  220 CONTINUE
C            ** NUCLEAR LOGIC GOES HERE **
      GO TO 255
  230 IF(IS.EQ.0)GO TO 50
      GO TO 245
  240 IF(IS.EQ.0)GO TO 50
  245 IF(IS-2)246,255,246
  246 RES=HMAX(J-ND) - FIX
      IF(RES.LE.0.0)RES=0.0
      HRES(L)=HRES(L)+RES
      GO TO 255
  250 IF(L.EQ.1)AS(J,1,1)=IS
  255 S(J,L)=IS
      IF(IS.EQ.1)PFIX(J,L)=PFIX(J,L)+FIX
      IF(J.GT.ND)HLT(L)=HLT(L)+FIX
  290 GO TO 395
C  *** PROCESS THE TIE LINES ******
  300 M=J-500
      NFIRST=NA-NT+1
      DO 390 I=NFIRST,NA
      I1 = I+NT-NA
      IF(IS.NE.1)IS=2
```

```
      S(I,L)=IS
      IF(IS.EQ.1)TEMP=-FIX*DF(M,II)/100
      PFIX(I,L)=PFIX(I,L)+TEMP
  390 HLT(L)=HLT(L)+TEMP
  395 CONTINUE
  399 GO TO 50
C  *** PROCESS THE SECOND DAYS SCHEDULE*******
  500 IF(IH.EQ.0)GO TO 600
      IF(IH.LT.IT+2)GO TO 610
C  THIS SCHEDULE STARTS AFTER THE END OF THE COMMITMENT PERIOD
C  THEREFORE SKIP IT
      GO TO 50
C  OBTAIN START HOUR FROM START TIME OF SCHEDULE
  600 IH=25-IT
      GO TO 620
  610 IH=IH+24-IT
C  OBTAIN LAST HOUR FROM END TIME OF SCHEDULE
  620 IF(LH)621,630,621
  621 IF(LH-IT)622,622,630
  622 LH=LH+24-IT
      GO TO 160
  630 LH=25
      GO TO 160
  700 LAST=N3-1
      DO 800 I=N2,LAST
      DO 900 L=1,25
      IF(S(I,L).NE.3)GO TO 900
      HRES(L)=HRES(L)+HMAX(I-ND)
  900 CONTINUE
  800 CONTINUE
      RETURN
      END
```

A.6. Subroutine FLS

```
      SUBROUTINE FLS
C
C*************************************************************************
C
C    THIS SUBROUTINE RECEIVES AN HOURLY, NORMALIZED LOAD MODEL FOR EACH
C    DAY OF THE COMMITMENT PERIOD.  AN HOURLY LOAD FORECAST IS THEN
C    CONSTRUCTED BY MULTIPLYING EACH LOAD FACTOR BY THE PEAK DEMAND.
C
C*************************************************************************
C
      COMMON /COM1/ NA,ND,PMAX(80),PMIN(80),PFIX(125,25)
      COMMON /COM7/ HRES(25),FM(3,25),HLT(25),PEAK1,RMW,M2,IT,MOD1
      COMMON /COM9/ FL(25),REQ(25)
      COMMON /COM11/ PEAK2,MOD2
      DO 20 I=1,25
      IF(IT+I.GT.24)GO TO 10
      FL(I)=PEAK1*FM(MOD1,I)
      GO TO 20
   10 FL(I)=PEAK2*FM(MOD2,I)
   20 CONTINUE
      RETURN
      END
```

A.7. Subroutine RCA

```
      SUBROUTINE RCA
C
C***********************************************************************
C
C   THIS SUBROUTINE CALCULATES THE HOURLY RESERVE REQUIREMENT (REQ) BY
C   SUBTRACTING THE HOURLY HYDRO RESERVE CAPACITY (HRES) FROM THE TOTAL
C   RESERVE CAPACITY REQUIREMENT (RMW).
C
C   M2 IS THE # OF HOURS IN THE COMMITMENT PERIOD.
C
C***********************************************************************
C
      COMMON /COM7/ HRES(25),FM(3,25),HLT(25),PEAK1,RMW,M2,IT,MOD1
      COMMON /COM9/ FL(25),REQ(25)
      DO 10 I=1,M2
       REQ(I)=RMW-HRES(I)
      IF(REQ(I).LT.0.)REQ(I)=0.
   10 CONTINUE
      RETURN
      END
```

A.8. Subroutine MAXG

```
      SUBROUTINE MAXG(/S/,/M2/,/GMAX/)
C
C***********************************************************************
C
C   THIS SUBROUTINE CALCULATES THE MAXIMUM GENERATION AVAILABLE EACH
C   HOUR BASED ON THE MASTER STATE MATRIX (S) AND THE GENERATION
C   SCHEDULE MATRIX (PFIX).
C
C   MAXG = SUM OF STEAM AVAILABLE + HYDRO, CT, TIE, AND NUC SCHEDULED
C
C   THE AVAILABILITY OF A STEAM UNIT =
C                  0     IF UNIT IS OFF-LINE
C              PMAX     IF UNIT IS ECONOMICALLY DISPATCHED
C              PFIX     IF UNIT IS FIXED.
C
C   M2 IS THE # OF HOURS IN A COMMITMENT PERIOD.
C
C***********************************************************************
C
      COMMON /COM1/ NA,NS,PMAX(80),PMIN(80),PFIX(125,25)
      DIMENSION GMAX(25)
      INTEGER*2 S(125,25)
      DO 20 J=1,M2
      GMAX(J)=0.
      DO 10 I=1,NA
      IF(S(I,J).GE.2)GO TO 10
      P=PFIX(I,J)
      IF(I.GT.NS)GO TO 5
      IF(P.LT.1.)P=PMAX(I)
    5 GMAX(J)=GMAX(J)+P
   10 CONTINUE
   20 CONTINUE
      RETURN
      END
```

A.9. Subroutine PVA

```
      SUBROUTINE PVA(/GMAX/,/PEAK2/,/NP/,/S/)
C
C*****************************************************************************
C
C     THIS SUBROUTINE SELECTS CERTAIN UNITS FOR BASE LOAD OPERATION BASED
C     VALLEY LOAD AND THE PEAK LOAD FOR THE NEXT DAY.
C
C*****************************************************************************
C
      COMMON /COM1/ NA,ND,PMAX(80),PMIN(80),PFIX(125,25)
      COMMON /COM5/ RATE(125),MUT(80),MDT(80),CSC(80),STC(80)
      COMMON /COM7/ HRES(25),FM(3,25),HLT(25),PEAK1,RMW,M2,IT,MOD1
      COMMON /COM9/ FL(25),REQ(25)
      COMMON /COM20/ GENMIN
      INTEGER*2 S(125,25),NP(80)
      DIMENSION GMAX(25)
C
C*****************************************************************************
C
C     FIND THE VALLEY AND PEAK STEAM REQUIREMENTS AND THE HOURS AT WHICH
C     THEY OCCUR.
C
C*****************************************************************************
C
      J=24-IT+1
      DSR=FL(J)*GENMIN+REQ(J)-HLT(J)
      DO 25 L=1,ND
      FIX=PFIX(J,L)
      IF(FIX.GT.1.0)DSR=DSR-FIX
   25 CONTINUE
      VL=FL(1)*GENMIN+REQ(1)-HLT(1)
      DO 30 L=1,ND
      FIX=PFIX(L,1)
      IF(FIX.GT.1.)VL=VL-FIX
   30 CONTINUE
      NV=1
      DO 50 I=2,M2
      PK=FL(I)*GENMIN+REQ(I)-HLT(I)
      DO 40 L=1,ND
      FIX=PFIX(L,I)
      IF(FIX.GT.1.)PK=PK-FIX
   40 CONTINUE
      IF(PK.GT.VL)GO TO 45
      VL=PK
      NV=I
      GO TO 50
   45 IF(I+IT.LE.24)GO TO 50
      IF(PK.LT.DSR)GO TO 50
      DSR=PK
      NPK2=I
   50 CONTINUE
C
C*****************************************************************************
C
C     GO DOWN PRIORITY LIST CHECKING EACH UNIT TO SEE IF IT CAN BE TAKEN
C     OFF-LINE AND LOAD AND RESERVE CAPACITY REQUIREMENTS STILL BE MET.
```

```
C
C*************************************************************************
C
      GM=GMAX(NV)
      GM1=GMAX(NPK2)
      DO 100 I=1,ND
      J=NP(I)
      IF(S(J,NV).NE.0) GO TO 100
      IF(FL(NV)*GENMIN+REG(NV).GT.GM-PMAX(J))GO TO 80
C
C*************************************************************************
C
C    IF UNIT CAN BE TAKEN OFF-LINE AND IS A 24-HOUR UNIT, CHECK TO SEE
C    IF IT CAN BE TAKEN OFF-LINE DURING THE NEXT DAY'S PEAK STEAM DEMAND.
C    IF NOT, MAKE IT A MUST-RUN UNIT FOR THE ENTIRE COMMITMENT PERIOD.
C
C*************************************************************************
C
      IF(MUT(J).LT.20)GO TO 70
      IF(FL(NPK2)*GENMIN+REQ(NPK2).GT.GM1-PMAX(J))GO TO 80
      GM1=GM1-PMAX(J)
C
C*************************************************************************
C
C    IF UNIT CAN NOT BE TAKEN OFF-LINE, MAKE IT MUST-RUN FOR THE ENTIRE
C    COMMITMENT PERIOD.
C
C*************************************************************************
C
   70 GM=GM-PMAX(J)
      GO TO 100
   80 DO 90 K=1,M2
      IF(S(J,K).EQ.0) S(J,K)=1
   90 CONTINUE
  100 CONTINUE
      RETURN
      END
```

A.10. Subroutine SIGS

```
      SUBROUTINE SIGS(/S/,/GMAX/,/NP/)
C
C***********************************************************************
C
C    THIS SUBROUTINE CREATES THE MINIMUM STATE FOR EACH HOUR AND STORES
C    IT AS THE FIRST STATE OF EACH HOUR IN THE ALTERNATE STATE MATRIX.
C
C***********************************************************************
C
      COMMON /COM1/ NA,ND,PMAX(80),PMIN(80),PFIX(125,25)
      COMMON /COM7/ HRES(25),FM(3,25),HLT(25),PEAK1,RMW,M2,IT,MOD1
      COMMON /COM9/ FL(25),REQ(25)
      COMMON /COM16/ AS(80,25,12)
      COMMON /COM20/ GENMIN
      INTEGER*2 AS
      INTEGER*2 S(125,25),NP(80)
      DIMENSION GMAX(25)
      LOGICAL*4  MINCAP
      DO 100 I=2,M2
      GM=GMAX(I)
      FLGR= GENMIN*FL(I) + REQ(I)
      MINCAP=.FALSE.
C
C***********************************************************************
C
C    FIND THE NEXT UNIT IN THE PRIORITY LIST. IF IT IS NOT ON-LINE BUT
C    COMMITABLE (STATE = 0), ASSIGN IT WHATEVER STATE IS INDICATED BY
C    THE MASTER STATE MATRIX FOR THAT HOUR. IF IT IS ON-LINE AND MAY BE
C    SHUT DOWN, TAKE IT OFF-LINE IF LOAD AND RESERVE REQUIREMENTS CAN
C    STILL BE MET.
C
C***********************************************************************
C
      DO 50 K=1,ND
      J=NP(K)
 12   IF(MINCAP)GO TO 40
      IF(S(J,1).NE.0) GO TO 40
   10 IF(FLGR.GT.GM-PMAX(J)) GO TO 30
      AS(J,I,1)=3
      GM=GM-PMAX(J)
      GO TO 50
   30 MINCAP= .TRUE.
   40 AS(J,I,1)=S(J,I)
   50 CONTINUE
  100 CONTINUE
      RETURN
      END
```

A.11. Subroutine OPTO

```
      SUBROUTINE OPTO(COST,NFRM,LAMBDA,NP,NEXT,LASTST)
C
C*****************************************************************************
C
C   THIS SUBROUTINE CREATES THE ALTERNATE STATES, CALCULATES THEIR FUEL
C   COSTS, AND SEARCHES THE STATE-SPACE FOR THE LEAST-COST PATH.
C
C*****************************************************************************
C
      COMMON /COM1/ NA,ND,PMAX(80),PMIN(80),PFIX(125,25)
      COMMON /COM5/ RATE(125),MUT(80),MDT(80),CSC(80),STC(80)
      COMMON /COM7/ HRES(25),FM(3,25),HLT(25),PEAK1,RMW,M2,IT,MOD1
      COMMON /COM13/ FCOST(25,12),SCOST(25,12),TCOST(25,12),TLOSS(25,12)
      COMMON /COM15/ MS,NSKED
      COMMON /COM16/ AS(80,25,12)
      INTEGER AS,NFRM(25,12),NP(80)
      DIMENSION COST(25,12),NEXT(12)
      REAL LAMBDA(25,12)
C
C*****************************************************************************
C
C   DO FOR EACH HOUR OF THE COMMITMENT PERIOD
C
C*****************************************************************************
C
      DO 3000 K=2,M2
      LASTST=MS
C
C*****************************************************************************
C
C   CREATE THE ALTERNATE STATES FOR THIS HOUR
C
C*****************************************************************************
C
      CALL ASC(K,NP,NEXT,LASTST)
C
C*****************************************************************************
C
C   CALCULATE THE FUEL COST OF EACH STATE THIS HOUR
C
C***************************************************************************
C
           CALL FCE(LAMBDA,K,NEXT)
           DO 2000 J=1,MS
           IF(AS(1,K,J).GT.50)GO TO 3000
           COST(K,J)=1.0E10
C
C***************************************************************************
C
C   COME FROM EACH STATE OF THE PREVIOUS HOUR CALCULATING START-UP
C   COSTS AND TOTAL PRODUCTION COSTS
C
C*****************************************************************************
C
      DO 1000 M=1,MS
      IF(AS(1,K-1,M).GT.50) GO TO 2000
```

```
      COST1=FCOST(K,J)
      CS1=0.0
      DO 900 I=1,ND
      IF(AS(I,K-1,M).GE.3) GO TO 600
      IF(AS(I,K-1,M).NE.2) GO TO 900
      IF(AS(I,K,J).GT.1) GO TO 900
      CS=CSC(I)
      GO TO 800
  600 IF(AS(I,K,J).GT.2) GO TO 900
      DT=AS(I,K-1,M)+1
      CALL SUCA(CSC(I),STC(I),CO,DT,CS)
  800 COST1=COST1+CS
      CS1=CS1+CS
  900 CONTINUE
C
C**************************************************************************
C
C    CALCULATE THE TOTAL COST TO THIS STATE AND IF IT IS LESS THAN THE
C    TOTAL COST TO THIS STATE SO FAR, SAVE THE FROM STATE AND THE APPROPRIATE
C    COSTS
C
C**************************************************************************
C
      TOTCOS=COST(K-1,M)+COST1
      IF(TOTCOS.GT.COST(K,J)) GO TO 950
      SCOST(K,J)=CS1
      COST(K,J)=TOTCOS
      NFRM(K,J)=M
      TCOST(K,J)=COST1
      IF(K.EQ.2) GO TO 1200
  950 CONTINUE
 1000 CONTINUE
C
C**************************************************************************
C
C    UPDATE THE DOWN-TIMES OF THE UNITS REMAINING IN THE ECONOMICALLY
C    DOWN STATUS
C
C**************************************************************************
C
 1200 NF=NFRM(K,J)
      DO 1500 I=1,ND
      IF(AS(I,K-1,NF).LT.3) GO TO 1500
      IF(AS(I,K,J).NE.3) GO TO 1500
      AS(I,K,J)=AS(I,K-1,NF)+1
 1500 CONTINUE
 2000 CONTINUE
 3000 CONTINUE
      RETURN
      END
```

A.12. Subroutine ASC

```
      SUBROUTINE ASC(K,NP,NEXT,LASTST)
C
C*************************************************************************
C
C   THIS SUBROUTINE CREATES UP TO MS ALTERNATE STATES FOR HOUR K
C
C*************************************************************************
C
      COMMON /COM1/ NA,ND,PMAX(80),PMIN(80),PFIX(125,25)
      COMMON /COM15/ MS,NSKED
      COMMON /COM16/ AS(80,25,12)
      INTEGER AS,NP(80),NEXT(12)
      DO 400 J=2,MS
C
C*************************************************************************
C
C   CREATE THE NEXT STATE FOR THIS HOUR BY COPYING THE PREVIOUS STATE
C   AND BRINGING ON-LINE THE 1ST AVAILABLE UNIT IN THE PRIORITY LIST
C   WHICH WAS NOT ON-LINE IN THE PREVIOUS STATE
C
C*************************************************************************
C
      DO 100 I=1,ND
      AS(I,K,J)=AS(I,K,J-1)
      IF(AS(I,K,J).GT.3) AS(I,K,J)=3
  100 CONTINUE
      N=ND
      L=J-1
  200 M=NP(N)
      NEXT(L)=M
      IF(AS(M,K,J).NE.3) GO TO 300
      AS(M,K,J)=0
      GO TO 400
  300 N=N-1
      IF(N.EQ.0) GO TO 450
      GO TO 200
  400 CONTINUE
      RETURN
C
C*************************************************************************
C
C   IF ALL THE AVAILABLE CAPACITY IS ON-LINE AND MS STATES CAN NOT BE
C   CREATED, KEY THE STATE FOR WHICH NO UNIT CAN BE BROUGHT ON-LINE BY
C   GIVING THE FIRST UNIT OF THAT STATE A STATUS NUMBER = 55
C
C*************************************************************************
C
  450 AS(1,K,J)=55
      LASTST=J-1
      RETURN
      END
```

A.13. Subroutine FCE

```
      SUBROUTINE FCE(LAMBDA,K,NEXT)
C
C**************************************************************************
C
C   THIS SUBROUTINE ESTIMATES THE FUEL COST OF THE STATES OF HOUR K
C
C**************************************************************************
C
      COMMON /COM1/ NA,ND,PMAX(80),PMIN(80),PFIX(125,25)
      COMMON /COM4/ HC(80),HB(80),FCI(80)
      COMMON /COM6/ HA(80),FCA(80)
      COMMON /COM9/ FL(25),REQ(25)
      COMMON /COM10/ UPL(125),PS,PL
      COMMON /COM13/ FCOST(25,12),SCOST(25,12),TCOST(25,12),TLOSS(25,12)
      COMMON /COM15/ MS
      COMMON /COM16/ AS(80,25,12)
      INTEGER AS
      REAL LAMBDA(25,12)
      DIMENSION R(125),DELT(12),SUM(12),NEXT(12)
C
C**************************************************************************
C
C   CALCULATE THE EXACT LAMBDA OF THE MINIMUM-CAPACITY STATE
C
C**************************************************************************
C
      CALL EDP(FL(K),PFIX(1,K),R,AS(1,K,1),A1)
      TLOSS(K,1)=PL
      LAMBDA(K,1)=A1
      J=MS
      DO 100 M=1,MS
      IF(AS(1,K,M).LT.50)GO TO 100
      J=M-1
      GO TO 200
  100 CONTINUE
C
C**************************************************************************
C
C   CALCULATE THE COST AND LAMBDA OF THE MAXIMUM-CAPACITY STATE USING
C   ECONOMIC DISPATCHING AND THE HEAT RATES
C
C**************************************************************************
C
  200 IF(J.EQ.1) GO TO 250
      CALL EDP(FL(K),PFIX(1,K),R,AS(1,K,J),A2)
      TLOSS(K,J)=PL
      LAMBDA(K,J)=A2
  250 CALL PCOST(AS(1,K,J),PFIX(1,K),R,FCOST(K,J))
      IF(J.EQ.1)GO TO 700
C
C**************************************************************************
C
C   USE THE FUEL COST ESTIMATION METHOD TO CALCULATE THE FUEL COSTS
C
C**************************************************************************
C
```

```
      SUM(J)=0.0
      DELT(J)=0.
      I=J-1
  300 N=NEXT(I)
      SUM(I)=SUM(I+1)+R(N)
      X=FCA(N)/100.
      DELT(I)=DELT(I+1)+X*(HA(N)+R(N)*(HB(N)+R(N)*HC(N)))
      IF (I.EQ.1) GO TO 400
      I=I-1
      GO TO 300
  400 CONTINUE
      JJ=J-1
      DO 600 I=1,JJ
      IF(I.EQ.1) GO TO 500
      LAMBDA(K,I)=(SUM(I)/SUM(1))*(A1-A2)+A2
  500 FCOST(K,I)=FCOST(K,J)-DELT(I)+LAMBDA(K,I)*SUM(I)
  600 CONTINUE
  700 CONTINUE
      RETURN
      END
```

A.14. Subroutine EDP

```
      SUBROUTINE EDP(E,PFIX,R,S,A)
C
C*******************************************************************************
C
C   THIS SUBROUTINE ECONOMICALLY DISPATCHES A GIVEN SYSTEN STATE (S AND PFIX
C   MATRICES) TO A GIVEN LOAD FORECAST (E). THE VECTOR (R) CONTAINS THE
C   GENERATION LEVELS FOR EACH DISPATCHED UNIT. (PFIX CONTAINS THE GENERATION
C   VALUES FOR THE FIXED UNITS.)
C
C   THIS ROUTINE  -
C                   1. GUESSES AT LAMBDA BASED ON THE LOAD FORECAST
C                   2. ITERATES ON LAMBDA TO OBTAIN A DISPATCH
C                   3. SUMS THE TOTAL GENERATION FOR THAT LAMBDA
C                   4. CALCULATES LOSSES
C                   5. SUBTRACTS LOSSES FROM TOTAL GEN. TO OBTAIN NET POWER DEL.
C                   6. COMPARES NET POWER DELIVERED TO THE LOAD DEMAND
C                   7. ADJUSTS LAMBDA BASED ON RESULTS OF 6
C                   8. REPEATS 2 THRU 7 UNTIL THE NET PWR DEL. EQUALS THE LOAD
C
C*******************************************************************************
C
      INTEGER*2 S(80)
      DIMENSION PFIX(125)
      DIMENSION R(125),GP(125),BJO(80),DV(80),C1(80)
      COMMON /COM1/ NA,NS,PMAX(80),PMIN(80),FAKE(125,25)
      COMMON /COM2/ D(125),C(125),B(125,125)
      COMMON /COM4/ HC(80),HB(80),FCA(80)
      COMMON /COM6/ HA(80),FCI(80)
      COMMON /COM10/ DPL(125),PS,PL
      COMMON /COM14/ DPS,CO
C
C*******************************************************************************
C
C   GUESS AT LAMBDA BASED ON LOAD FORECAST
C   INITIALIZE SWITCHING CONSTANTS
C
C*******************************************************************************
C
      IF(A.GT.0.1)GO TO 620
  580 A=E*(E*(4.149570E-11*E-9.569339E-07)+7.024765E-03)-12.08984
  620 PT=E
      LCT=1
      LT=0
      IT2=0
C
C*******************************************************************************
C
C   INITIAILIZE R TO 0
C   CALCULATE CONSTANT TERMS WHICH ARE INDEPENDENT OF LAMBDA AND THE DISPATCHED
C   OUTPUTS.
C
C*******************************************************************************
C
  630 DO 650 I=1,NS
      R(I)=0.
      IF(S(I).GE.2)GO TO 850
```

```
      IF(PFIX(I).GT.1.) GO TO 850
  800 Y=0.
      DO 840 J=1,NA
  840 Y=Y+2.*B(I,J)*PFIX(J)
      C1(I)=100.-C(I)-Y
  850 CONTINUE
C
C*****************************************************************************
C
C   CALCULATE TERMS DEPENDENT ON LAMBDA ONLY.
C
C*****************************************************************************
C
  860 DO 870 I=1,NS
      DV(I)=2.*D(I)+FCI(I)*2.*HC(I)/A
      BJO(I)=C1(I)-FCI(I)*HB(I)/A
  870 CONTINUE
      IF(ABS(A).GT.5000)GO TO 1066
C
C*****************************************************************************
C
C   GAUSS-SIEDEL ITERATION ROUTINE TO SOLVE FOR OUTPUT VECTOR (R). WHENEVER A
C   UNIT IS OUTSIDE ITS OPERATING LIMITS, SET IT ON TIS NEAREST LIMIT TO
C   CALCULATE OTHER UNIT OUTPUTS, BUT LET IT BE RECALCULATED EACH ITERATION.
C   ITERATION IS COMPLETE WHEN NO UNIT'S OUTPUT IS CHANGED BY GREATER THAN 1 MW
C   FROM LAST ITERATION. PS IS THE SUM OF THE DISPATCHED OUTPUTS.
C
C*****************************************************************************
C
  880 DP=0.
      PS=0.
      DO 940 I=1,NS
      IF(S(I).GE.2)GO TO 940
      IF(PFIX(I).GT.1.) GO TO 940
  890 Y=BJO(I)
      DO 920 J=1,NS
      IF(S(J).GE.2)GO TO 920
      IF(PFIX(J).GT.1.) GO TO 920
  900 X=2.*B(I,J)
      IF(I.EQ.J) GO TO 920
  910 Y=Y-R(J)*X
  920 CONTINUE
  930 Y=Y/DV(I)
      IF(Y.LT.PMIN(I)) Y=PMIN(I)
      IF(Y.GT.PMAX(I)) Y=PMAX(I)
      DPT=Y-R(I)
      R(I)=Y
      PS=PS+R(I)
      IF(ABS(DPT).GT.ABS(DP)) DP=DPT
  940 CONTINUE
      IF(ABS(DP).GT.1.0) GO TO 880
C
C*****************************************************************************
C
C   SUM THE FIXED OUTPUTS TO THE DISPATCHED OUTPUTS TO FIND THE TOTAL GEN. (PS)
C
C*****************************************************************************
```

```
C
      DO 950 I=1,NA
      PS=PS+PFIX(I)
  950 CONTINUE
C
C*****************************************************************************************
C
C   FIND EACH GENERATOR OUTPUT AND CALCULATE THE TOTAL LOSSES (PL) AND THE
C   PARTIAL DERIVATIVE OF THE TOTAL LOSSES WRT EACH UNIT. (DPL)
C
C*****************************************************************************************
C
      DO 955 I=1,NA
      P=0.
      IF(I.LE.NS)P=R(I)
      GP(I)=P+PFIX(I)
  955 CONTINUE
      PL=109.35
      DO 958 I=1,NA
      PL=PL+C(I)*GP(I)/100.
      DPL(I)=C(I)
      DO 957 J=1,NA
      DPL(I)=DPL(I)+2.*B(I,J)*GP(J)
      PL=PL+B(I,J)*GP(I)*GP(J)/100.
  957 CONTINUE
  958 CONTINUE
C
C*****************************************************************************************
C
C   SUBTRACT LOSSES FROM GENERATION. IF NOT WITHIN 1 MW OF LOAD DEMAND, REGUESS
C   LAMBDA BY -
C
C         1. ON FIRST ITERATION, INCREMENT (OR DECREMENT) LAMBDA BY 0.1 IF FIRST
C            GUESS WAS LOW (OR HIGH).
C
C         2. IF THIS IS NOT THE FIRST ITERATION, AND ALL PREVIOUS GUESSES HAVE
C            BEEN ALL HIGH OR ALL LOW, USE A SLOPE METHOD TO GUESS LAMDA.
C
C         3. IF A GUESS WAS ONCE HIGH, THEN LOW, (OR VISA VERSA) USE A HALVING
C            ROUTINE TO HOME IN ON LAMBDA.
C
C*****************************************************************************************
C
      PS=PS-PL
      IF(ABS(PS-PT).LT.DPS)GO TO 1068
      IT1=0
      IF(PS.GT.PT)IT1=1
      GO TO (960,1061),LCT
  960 LCT=2
      ICT=0
      IF(PS.GT.PT)IT2=1
  970 A1=A
      IF(ICT.GE.5)GO TO 1066
      ICT=ICT+1
      A3=A
      IF(PS.GT.PT) A2=A-0.1
      IF(PS.LT.PT) A2=A+0.1
```

```
      P1=PS
      MM=0
      GO TO 1064
 1061 IF(IT1.NE.IT2) LT=1
      IF(LT.EQ.1) GO TO 1062
      IF(P1.EQ.PS)GO TO 970
      A2=(A*(P1-PT)-A1*(PS-PT))/(P1-PS)
      IF(A2.LE.0.)A2=A-1.
      A1=A
      A3=A
      P1=PS
      GO TO 1064
 1062 IF(PS.GT.PT)GO TO 1063
      A2=(A+A3)/2.
      A1=A
      GO TO 1064
 1063 A2=(A+A1)/2.
      A3=A
 1064 A=A2
C
C*****************************************************************************
C
C    RETURN TO SECTION THAT CALCULATES TERMS DEPENDENT ON LAMBDA ONLY.
C
C*****************************************************************************
C
      GO TO 860
 1066 CONTINUE
      IF(PS.GT.PT)WRITE(6,2000)
      IF(PS.LT.PT)WRITE(6,3000)
      WRITE(6,4000),PS,PT,PL,A
      A=0.
 2000 FORMAT(' TOO MUCH MUST RUN CAPACITY',//)
 3000 FORMAT(' SYSTEM CANNOT MEET LOAD AND LOSSES',//)
 4000 FORMAT(' TOTAL GENERATION = ',F9.2,//' TOTAL DEMAND = ',F13.2,//'
     1TOTAL LOSSES =',F13.2,//' LAST LAMBDA =',F13.5)
      DO 1067 I=1,NA
      WRITE(6,5000)I,S(I),PMIN(I),R(I),PMAX(I),PFIX(I),GP(I),C1(I),BJO(I
     1),DV(I),DPL(I),D(I),FCI(I),HC(I)
 5000 FORMAT(2I4,5F7.2,7F10.3)
      SUM=SUM+R(I)+PFIX(I)
 1067 CONTINUE
      WRITE(6,6000)SUM
 6000 FORMAT('   SUM =',F13.2)
 1068 CONTINUE
      RETURN
      END
```

A.15. Subroutine PCOST

```
      SUBROUTINE PCOST(/S/,/PFIX/,/R/,/TCOST/)
C
C*************************************************************************
C
C    THIS SUBROUTINE CALCULATES THE TOTAL COST PER HOUR (TCOST) FOR A
C    GIVEN SYSTEM DISPATCH BY SUMMING THE UNIT COSTS PER HOUR (COST).
C
C    COST ($/HR) = AVG. FUEL COST ($/MBTU) * HEAT RATE (MBTU/HR) / (100 (
C    1 - DPL))
C
C    ALSO, A UNIT COST RATE (UCR) AND A TOTAL COST RATE (TCR) ARE
C    CALCULATED.
C
C    UCR ($/MWH) = COST ($/HR) / (1.-DPL) (MW)
C
C    TCR ($/MWH) = TCOST ($/HR) / TOTAL GEN (MW)
C
C*************************************************************************
C
      COMMON /COM1/ NA,NS,PMAX(80),PMIN(80),FAKE(125,25)
      COMMON /COM4/ HC(80),HB(80),FCI(80)
      COMMON /COM6/ HA(80),FCA(80)
      COMMON /COM10/ DPL(125),PS,PL
      COMMON /COM12/ COST(80),UCR(80),TCR
      INTEGER*2 S(75)
      DIMENSION R(125),PFIX(125)
      TCOST=0.
      DO 1069 I=1,NS
      COST(I)=0.
      IF(PFIX(I).GT.1.)R(I)=0.
      P=PFIX(I)
      IF(S(I).GE.2)P=0.
      TGEN=(P+R(I))*1.06
      IF(TGEN.LT.1.)GO TO 1069
      COST(I)=FCA(I)*(HA(I)+TGEN*(HB(I)+TGEN*HC(I)))/100.
      UCR(I)=COST(I)/(TGEN*(1.-DPL(I)/100.))
      TCOST=TCOST+COST(I)
 1069 CONTINUE
      TCR=TCOST/PS
      RETURN
      END
```

A.16. Subroutine SUCA

```
      SUBROUTINE SUCA(/CSC/,/STC/,/CO/,/DT/,/CS/)
C
C*************************************************************************
C
C    THIS SUBROUTINE CALCULATES THE START-UP COST (CS) OF A UNIT GIVEN
C    THE UNIT'S COLD-START COST (CSC), BOILER COOLING TIME (STC), DOWN
C    TIME (DT), AND THE MINIMUM START FACTOR (CO). THE FIGURE BELOW
C    ILLUSTRATES THE MODEL USED.
C
C                    S.U. .         *****************
C                    COST .         *               *
C                     ($) .         * UNIT START-UP *
C                         .         *  COST MODEL   *
C                         .         *   C1=CO*CSC   *
C                         .         *               *
C                         .         *****************
C                         .
C                     CSC +-------------------* * * * * * * * * *
C                         .                  * .
C                         .                *   .
C                         .              *     .
C                         .            *       .
C                      CS +----------*         .
C                         .        * .         .
C                         .      *   .         .
C                         .    *     .         .
C                         .  *       .         .
C                      C1 *          .         .
C                         .          .         .
C                         .          .         .
C                         .          .         .
C                         .          .         .
C                        -+----------+---------+-----------------
C                         .
C                                   DT        STC     DOWN TIME (HR)
C
C
C
C*************************************************************************
C
      IF(DT.GT.STC)GO TO 10
      C1=CO*CSC
      CS=DT*(CSC-C1)/STC+ C1
      GO TO 20
   10 CS=CSC
   20 CONTINUE
      RETURN
      END
```

A.17. Subroutine TRACE

```
      SUBROUTINE TRACE(/M2/,/NFRM/,/TR/)
C
C*****************************************************************************
C
C    THIS SUBROUTINE TRACES THE MOST ECONOMICAL PATHS BY STARTING AT THE
C    LAST HOUR AND FOLLOWING EACH PATH BACKWARDS BY EXAMINING THE NFRM
C    MATRIX. WHEN FINISHED, EACH ROW OF THE TRACE MATRIX (TR) CONTAINS
C    THE STATES OF THE PREVIOUS HOUR FROM WHICH ONE PATH CAME.
C
C*****************************************************************************
C
      COMMON /COM15/ MS,NSKED
      INTEGER*2 NFRM(25,12),TR(25,12)
      DO 200 J=1,MS
      IF(NFRM(M2,J).EQ.0) RETURN
      NH=M2
      TR(M2,J)=NFRM(M2,J)
  100 NF=TR(NH,J)
      NH=NH-1
      IF(NH.EQ.1)GO TO 200
      TR(NH,J)=NFRM(NH,NF)
      GO TO 100
  200 CONTINUE
      RETURN
      END
```

A.18. Subroutine OUTPUT

```
      SUBROUTINE OUTPUT(/ND/,/M2/,/COST/,/IT/,/TR/,/LAMBDA/,/NM/,
     1   /LASTST/)
C
C*****************************************************************************
C
C   THIS SUBROUTINE PRINTS THE HOURLY REPORTS AND COMMITMENT SUMMARY FOR
C   THE SPECIFIED NUMBER (NSKED) OF SCHEDULES DESIRED
C
C*****************************************************************************
C
      DIMENSION C(12),COST(25,12),NSD(80),NSU(80),LS(80,4),R(125)
      REAL MODE(80,4),KODE(80,4),NOON,MID,KN,KP
      REAL LAMBDA(25,12),TOTCOS(25)
      COMMON /COM1/II,KJ,PMAX(80),PMIN(80),PFIX(125,25)
      COMMON /COM7/ HRES(25),FM(3,25),HLT(25),PEAK1,RMW,MM,NQ,MOD1
      COMMON /COM9/ FL(25),REQ(25)
      COMMON /COM10/ DPL(125),PS,PL
      COMMON /COM13/ FCOST(25,12),SCOST(25,12),TCOST(25,12),TLOSS(25,12)
      COMMON /COM15/ MS,NSKED
      COMMON /COM16/ AS(80,25,12)
      DATA AM/'A.M.'/,NOON/'NOON'/, PM/'P.M.'/, MID/'MDNT'/,
     1    DIS/'DIS '/,BLK/'    '/,KP/' +  '/,FIX/'FIX '/,KN/' -  '/
      REAL   MAX/'MAX '/,MIN/'MIN '/
      INTEGER*2 AS
      INTEGER*2 TR(25,12),ISTATE(12),NU(80,4)
      REAL*8 NM(2,125)
C
C*****************************************************************************
C
C     ORDER COST(M2,J) FROM THE LOWEST COST TO THE HIGHEST COST.  THE
C     ORDER IS GIVEN BY ISTATE(J).
C
C*****************************************************************************
C
      DO 5 N=1,MS
      IF(COST(M2,N).LT.1.)COST(M2,N)=1.1E10
    5 C(N)=COST(M2,N)
      DO 20 M=1,LASTST
      JK=1
      TM=C(1)
      DO 15  J=1,LASTST
      IF(J.EQ.1)GO TO 15
      IF(TM-C(J))15,15,10
   10 TM=C(J)
      JK=J
   15 CONTINUE
      C(JK)=1.E11
   20 ISTATE(M)=JK
      IF(NSKED.GT.LASTST)  NSKED=LASTST
      DO 1000 I=1,NSKED
      J=ISTATE(I)
      IF(COST(M2,J).GT.1.E10)GO TO 1500
      TOTCOS(1)=0.0
      K=1
   50 NT=IT+K
C
```

```
C***********************************************************************************
C
C    K = PRESENT HOUR
C    M = NEXT HOUR
C    N0 = NO. OF UNITS ECONOMICALLY-UP THIS HOUR
C    N1 = NO. OF UNITS MUST-RUN THIS HOUR
C    N2 = NO. OF UNITS MUST-DOWN THIS HOUR
C    N3 = NO. OF UNITS ECONOMICALLY-DOWN THIS HOUR
C    NSD = NO. OF UNITS SHUT DOWN THIS HOUR
C    NSU = NO. OF UNITS STARTED THIS HOUR
C
C***********************************************************************************
C
      K=K+1
      M=K+1
      N0=0
      N1=0
      N2=0
      N3=0
      NSD(K)=0
      NSU(K)=0
C
C***********************************************************************************
C
C    DETERMINE TIME AND PRINT HOURLY REPORT HEADING
C
C***********************************************************************************
C
      IF(NT.GT.24)NT=NT-24
      IF(NT-12)300,400,500
  300 TIME= AM
      GO TO 600
  400 TIME= NOON
      GO TO 600
  500 NT=NT-12
      TIME=PM
      IF(NT.EQ.12) TIME= MID
  600 IF(I.EQ.1)GO TO 700
      WRITE(6,2000)I,NT,TIME
      GO TO 800
  700 WRITE(6,3000)NT,TIME
C
C***********************************************************************************
C
C    JJ = STATE NUMBER THIS HOUR
C    KK = LAST HOUR
C     N = STATE OCCUPIED ONE HOUR EARLIER
C
C***********************************************************************************
C
  800 JJ=TR(M,J)
      IF(K.EQ.M2)JJ=J
      WRITE(6,4000)
      KK=K-1
      N=TR(K,J)
C
C***********************************************************************************
```

```
C
C    CALCULATE COSTS OF THIS STATE
C
C***************************************************************************
C
      CALL EDP(FL(K),PFIX(1,K),R,AS(1,K,JJ),LAMBDA(K,JJ))
      TLOSS(K,JJ)=PL
      CALL PCOST(AS(1,K,JJ),PFIX(1,K),R,FCOST(K,JJ))
      TCOST(K,JJ)=FCOST(K,JJ)+SCOST(K,JJ)
      TOTCOS(K)=TOTCOS(K-1)+TCOST(K,JJ)
C
C***************************************************************************
C
C    CHECK EACH UNIT TO SEE WHAT STATUS IT IS TO BE IN, IF IT HAS BEEN
C    STARTED THIS HOUR ,IF IT IS DISPATCHED OR FIXED, AND IF IT IS ON ITS
C    MAXIMUM OR MINIMUM LIMITS. ALSO CALCULATE UP AND DOWN TIMES FOR
C    UNITS ECONOMICALLY UP OR DOWN. STORE THE INFORMATION IN AN
C    APPROPRIATE ORDER FOR PRINTOUT
C
C***************************************************************************
C
      DO 900 L=1,NO
      NN=0
      KCT=K
      IF(AS(L,KK,N).LE.1)GO TO 825
      IF(AS(L,K,JJ).GT.1)GO TO 875
      GO TO 850
  825 IF(AS(L,K,JJ).LE.1)GO TO 875
      NSD(K)=NSD(K)+1
      NN=2
      GO TO 875
  850 NSU(K)=NSU(K)+1
      NN=1
  875 NS=AS(L,K,JJ)+1
      IF(NS.GT.4)NS=4
      GO TO (880,885,890,895),NS
  880 NO=NO+1
      MODE(NO,1)= DIS
      IF(PFIX(L,K).GT.1.0)MODE(NO,1)=FIX
      IF(ABS(R(L)-PMAX(L)).LT.0.1)MODE(NO,1)=MAX
      IF(ABS(R(L)-PMIN(L)).LT.0.1)MODE(NO,1)=MIN
      NO(NO,1)=L
      KODE(NO,1)= BLK
      IF(NN.EQ.1)KODE(NO,1)= KP
      LS(NO,1)=0
  881 JCT=TR(KCT,J)
      KCT=KCT-1
      LS(NO,1)=LS(NO,1)+1
      IF(KCT.EQ.1) GO TO 900
      IF(AS(L,KCT,JCT).LE.1)GO TO 881
      GO T. 900
  885 N1=N1+1
      NO(N1,2)=L
      KODE(N1,2)= BLK
      IF(NN.EQ.1)KODE(N1,2)= KP
      MODE(N1,2)= DIS
      IF(PFIX(L,K).GT.1.)MODE(N1,2)= FIX
```

```
      IF(ABS(R(L)-PMAX(L)).LT.0.1)MODE(N1,2)=MAX
      IF(ABS(R(L)-PMIN(L)).LT.0.1)MODE(N1,2)=MIN
      GO TO 900
  890 N2=N2+1
      NU(N2,3)=L
      KODE(N2,3)= BLK
      IF(NN.EQ.2)KODE(N2,3)= KN
      GO TO 900
  895 N3=N3+1
      NU(N3,4)=L
      KODE(N3,4)= BLK
      IF(NN.EQ.2)KODE(N3,4)= KN
      LS(N3,2)=0
  896 JCT=TR(KCT,J)
      KCT=KCT-1
      LS(N3,2)=LS(N3,2)+1
      IF(KCT.EQ.1) GO TO 900
      IF(AS(L,KCT,JCT).GT.1)GO TO 896
  900 CONTINUE
C
C***********************************************************************
C
C   PRINT HOURLY REPORT
C
C***********************************************************************
C
      LN=MAX0(N0,N1,N2,N3)
      DO 950 I1=1,LN
      NUM=0
      WRITE(6,5000)
      IF(I1.GT.N0)GO TO 910
      NUM=NU(I1,1)
      RNUM=R(NUM)
      IF(RNUM.LT.0.1)RNUM=PFIX(NUM,K)
      WRITE(6,6000)NUM,KODE(I1,1),(NM(K1,NUM),K1=1,2),MODE(I1,1),
     1RNUM,LS(I1,1)
  910 IF(I1.GT.N1)GO TO 920
      NUM=NU(I1,2)
      RNUM=R(NUM)
      IF(RNUM.LT.0.1)RNUM=PFIX(NUM,K)
      WRITE(6,7000)NUM,KODE(I1,2),(NM(K1,NUM),K1=1,2),MODE(I1,2),RNUM
  920 IF(I1.GT.N2)GO TO 930
      NUM=NU(I1,3)
      WRITE(6,8000)NUM,KODE(I1,3),(NM(K1,NUM),K1=1,2)
  930 IF(I1.GT.N3)GO TO 940
      NUM=NU(I1,4)
      WRITE(6,9000)NUM,KODE(I1,4),(NM(K1,NUM),K1=1,2),LS(I1,2)
  940 IF(NUM.EQ.0)GO TO 955
  950 CONTINUE
  955 IF(K.EQ.M2)GO TO 960
      GO TO 50
C
C***********************************************************************
C
C   PRINT COMMITMENT SUMMARY
C
C***********************************************************************
```

```
C
  960 IF(I.NE.1)GO TO 970
      WRITE(6,9200)
      GO TO 980
  970 WRITE(6,9400)I
980   WRITE(6,9600)TOTCOS(M2)
      DO 990 L=2,M2
      JJ= L+1
      II=ISTATE(I)
      M= TR(JJ,II)
      IF(JJ.GT.M2) M=ISTATE(I)
      NT=IT+L-1
      IF(NT.GT.24)NT=NT-24
      WRITE(6,9800)NT,M,FL(L),TLOSS(L,M),LAMBDA(L,M),NSU(L),
     1NSD(L),FCOST(L,M),SCOST(L,M),TCOST(L,M),TOTCOS(L),HLT(L)
  990 CONTINUE
 1000 CONTINUE
 1500 CONTINUE
 2000 FORMAT(1H1,53X,'COMMITMENT SCHEDULE NO. ',I2,//57X,'SUMMARY FOR ',
     1I3,1X,A4,//)
 3000 FORMAT(1H1,50X,'LOWEST COST COMMITMENT SCHEDULE',//57X,'SUMMARY FO
     1R ',I3,1X,A4,//)
 4000 FORMAT(10X,'UNITS ECONOMICALLY UP',20X,'MUST RUN UNITS',18X,'MUST
     1DOWN UNITS',9X,'UNITS ECONOMICALLY DOWN',//' NO.',6X,'NAME',8X,'MO
     2DE',4X,'GEN',4X,'UT',6X,'NO.',6X,'NAME',8X,'MODE',4X,'GEN',4X,
     3'NO.',6X,'NAME',11X,'NO.',8X,'NAME',7X,'DT',/)
 5000 FORMAT(1H )
6000  FORMAT(1H+,I2,A2,2A8,2X,A3,F7.2,I4)
7000  FORMAT(1H+,41X,I5,A2,2A8,2X,A3,F9.2)
 8000 FORMAT(1H+,73X,I4,A2,2A8)
 9000 FORMAT(1H+,101X,I5,A2,2A8,I4)
9800  FORMAT(2I3,F10.2,F9.2,F10.5,11X,I5,I3,F11.2,F10.2,F11.2,F12.2,3F9.
     12)
 9200 FORMAT(1H1,44X,'SUMMARY OF LOWEST COST COMMITMENT SCHEDULE',//)
 9400 FORMAT(1H1,44X,'SUMMARY OF COMMITMENT SCHEDULE NO.',I3,//)
 9600 FORMAT(43X,'TOTAL COST FOR THIS SCHEDULE =',F11.2,///' HR ST',
     14X,'LOAD',5X,'LOSSES',4X,'LAMBDA',3X,'RESERVE',4X,'SU',
     21X,'SD',2X,'FUEL COST',3X,'SU COST',2X,'TOTAL COST',2X,'PATH COST'
     3,3X,'HYDRO',6X,'CT',6X,'XCHG',/)
      RETURN
      END
```

APPENDIX B

SAMPLE OUTPUT

The sample output on the following pages is actual output from case study 14. The hourly reports list the units by name and number according to their states. The mode and loading is given for each on-line unit. The modes are defined as follows:

MAX: Unit is on its maximum limit

MIN: Unit is on its minimum limit

DIS: Unit is loaded economically

FIX: Unit is loaded to a fixed level

A plus sign (+) indicates the unit has been started that hour and a minus sign (-) indicates the unit has been shut-down that hour. Units economically up or economically down have their up-times and down-times listed, respectively.

The commitment summary lists various system information for each hour of the commitment period. This information consists of the following items for each hour.

1. Hour of the day (HR) - 1 refers to 1 A.M., 2 refers to 2 A.M., on up to 24 which represents midnight.
2. State (ST) - The state in which the system is to be in that hour with respect to the minimum capacity state, where state 1 is the minimum capacity state, 2 is the state with 1 more unit on-line, 3 has 2 more units, etc.
3. Load demand.
4. System losses.
5. System lambda.
6. Reserves - Although the program does not calculate the hourly reserves, a column is included for future implementation.

7. Number of start-ups (SU).
8. Number of shut- downs (SD).
9. Fuel cost.
10. Total start-up cost.
11. Total production cost (equals sum of 9 and 10).
12. Total cost up to that hour (equals running sum of 11).
13. Hydro - Hydro and CT generation and tie-line flows are summed and listed under HYDRO. Columns headed CT and XCHG have been included for later implementation of an algorithm to list these separately.

LOWEST COST COMMITMENT SCHEDULE

SUMMARY FOR 8 P.M.

UNITS ECONOMICALLY UP

NO.	NAME	MODE	GEN	UT
2	UNIT 002	DIS	26.87	1
4	UNIT 004	DIS	28.84	1
5	UNIT 005	DIS	28.84	1
8	UNIT 008	MIN	16.60	1
9	UNIT 009	MIN	16.60	1
10	UNIT 010	MAX	156.80	1
11	UNIT 011	MAX	135.30	1
12	UNIT 012	MAX	23.80	1
13	UNIT 013	MAX	23.80	1
15	UNIT 015	MAX	104.50	1
17	UNIT 017	MAX	104.50	1
20	UNIT 020	MAX	61.80	1
21	UNIT 021	MAX	61.80	1
26	UNIT 026	MAX	104.50	1
29	UNIT 029	MAX	475.00	1
32	UNIT 032	MIN	27.90	1
33	UNIT 033	DIS	36.16	1
40	UNIT 040	DIS	41.53	1
48	UNIT 048	MIN	18.60	1
50	UNIT 050	MIN	18.60	1
54	UNIT 054	DIS	51.80	1
55	UNIT 055	DIS	51.79	1
57	UNIT 057	DIS	60.01	1
58	UNIT 058	DIS	65.95	1
59	UNIT 059	MAX	109.30	1
60	UNIT 060	DIS	220.57	1
67	UNIT 067	MAX	361.00	1
73	UNIT 073	DIS	388.66	1
74	UNIT 074	DIS	398.92	1
78	UNIT 078	MAX	332.50	1
79	UNIT 079	MAX	332.50	1

MUST RUN UNITS

NO.	NAME	MODE	GEN
1	UNIT 001	MAX	95.00
3	UNIT 003	MIN	41.90
6	UNIT 006	MIN	27.90
7	UNIT 007	MIN	37.20
16	UNIT 016	MAX	95.00
18	UNIT 018	DIS	50.49
19	UNIT 019	FIX	42.00
22	UNIT 022	MAX	247.00
23	UNIT 023	MAX	247.00
25	UNIT 025	MAX	133.00
28	UNIT 028	MAX	104.50
31	UNIT 031	MIN	23.30
34	UNIT 034	DIS	74.97
35	UNIT 035	DIS	74.98
37	UNIT 037	MAX	175.80
38	UNIT 038	MAX	256.50
39	UNIT 039	MAX	256.50
43	UNIT 043	MIN	4.70
44	UNIT 044	MAX	684.00
45	UNIT 045	MAX	133.00
46	UNIT 046	MAX	133.00
49	UNIT 049	FIX	20.00
51	UNIT 051	DIS	19.52
52	UNIT 052	DIS	19.52
53	UNIT 053	MAX	33.30
62	UNIT 062	MAX	684.00
63	UNIT 063	MAX	256.50
64	UNIT 064	MAX	256.50
65	UNIT 065	MAX	256.50
66	UNIT 066	MAX	256.50
68	UNIT 068	MAX	684.00
70	UNIT 070	MAX	308.80
71	UNIT 071	MAX	475.00
72	UNIT 072	MAX	494.00
75	UNIT 075	DIS	41.52
76	UNIT 076	MAX	874.00
77	UNIT 077	MAX	874.00

MUST DOWN UNITS

NO.	NAME
14	UNIT 014
24	UNIT 024
27	UNIT 027
30	UNIT 030
36	UNIT 036
47	UNIT 047
56	UNIT 056
61	UNIT 061
69	UNIT 069
80	UNIT 080

UNITS ECONOMICALLY DOWN

NO.	NAME	DT
41 -	UNIT 041	1
42 -	UNIT 042	1

LOWEST COST COMMITMENT SCHEDULE

SUMMARY FOR 9 P.M.

UNITS ECONOMICALLY UP

NO.	NAME	MODE	GEN	UT
2	UNIT 002	DIS	21.38	2
4	UNIT 004	DIS	16.99	2
5	UNIT 005	DIS	18.99	2
10	UNIT 010	MAX	156.80	2
11	UNIT 011	MAX	155.30	2
15	UNIT 015	DIS	83.20	2
17	UNIT 017	DIS	83.20	2
20	UNIT 020	MAX	61.80	2
21	UNIT 021	MAX	61.80	2
26	UNIT 026	MAX	104.50	2
29	UNIT 029	MAX	475.00	2
32	UNIT 032	MIN	27.90	2
33	UNIT 033	MIN	27.90	2
34	UNIT 034	DIS	49.39	2
35	UNIT 035	DIS	49.40	2
60	UNIT 060	DIS	236.03	2
67	UNIT 067	MAX	361.00	2
73	UNIT 073	DIS	283.13	2
74	UNIT 074	DIS	431.61	2
78	UNIT 078	MAX	332.50	2
79	UNIT 079	MAX	332.50	2

MUST RUN UNITS

NO.	NAME	MODE	GEN
1	UNIT 001	MAX	95.00
3	UNIT 003	MIN	41.90
6	UNIT 006	MIN	27.90
7	UNIT 007	MIN	37.20
16	UNIT 016	DIS	83.20
18	UNIT 018	DIS	34.04
19	UNIT 019	FIX	42.00
22	UNIT 022	MAX	247.00
23	UNIT 023	MAX	247.00
25	UNIT 025	MAX	133.00
28	UNIT 028	MAX	104.50
31	UNIT 031	MIN	23.30
34	UNIT 034	MIN	41.90
35	UNIT 035	MIN	41.90
37	UNIT 037	MAX	175.00
38	UNIT 038	MAX	256.50
39	UNIT 039	MAX	256.50
43	UNIT 043	MIN	4.70
44	UNIT 044	MAX	684.00
45	UNIT 045	MAX	133.00
46	UNIT 046	MAX	133.00
49	UNIT 049	FIX	20.00
51	UNIT 051	DIS	17.75
52	UNIT 052	DIS	17.76
53	UNIT 053	DIS	32.50
62	UNIT 062	MAX	684.00
63	UNIT 063	DIS	209.76
64	UNIT 064	DIS	209.76
65	UNIT 065	DIS	209.78
66	UNIT 066	DIS	209.80
68	UNIT 068	MAX	684.00
70	UNIT 070	MAX	308.60
71	UNIT 071	MAX	475.00
72	UNIT 072	MAX	494.00
75	UNIT 075	DIS	33.50
76	UNIT 076	MAX	874.00
77	UNIT 077	DIS	801.84

MUST DOWN UNITS

NO.	NAME
14	UNIT 014
24	UNIT 024
27	UNIT 027
30	UNIT 030
36	UNIT 036
47	UNIT 047
56	UNIT 056
61	UNIT 061
69	UNIT 069
80	UNIT 080

UNITS ECONOMICALLY DOWN

NO.	NAME	DT
8 -	UNIT 008	1
9 -	UNIT 009	1
12 -	UNIT 012	1
13 -	UNIT 013	1
40 -	UNIT 040	1
41	UNIT 041	2
42	UNIT 042	2
48 -	UNIT 048	1
50 -	UNIT 050	1
57 -	UNIT 057	1
58 -	UNIT 058	1
59 -	UNIT 059	1

LOWEST COST COMMITMENT SCHEDULE

SUMMARY FOR 10 P.M.

UNITS ECONOMICALLY UP

NO.	NAME	MODE	GEN	UT
4	UNIT 004	MIN	16.60	3
10	UNIT 010	MAX	156.80	3
11	UNIT 011	MAX	185.30	3
15	UNIT 015	DIS	61.64	3
17	UNIT 017	DIS	61.64	3
20	UNIT 020	DIS	46.73	3
21	UNIT 021	DIS	46.73	3
26	UNIT 026	MAX	104.50	3
29	UNIT 029	MAX	475.00	3
33	UNIT 033	MIN	27.90	3
60	UNIT 060	DIS	225.90	3
67	UNIT 067	MAX	361.00	3
74	UNIT 074	DIS	409.06	3
78	UNIT 078	DIS	296.50	3
79	UNIT 079	DIS	296.49	3

MUST RUN UNITS

NO.	NAME	MODE	GEN
1	UNIT 001	MAX	95.00
3	UNIT 003	MIN	41.90
6	UNIT 006	MIN	27.90
7	UNIT 007	MIN	37.20
16	UNIT 016	MIN	65.10
18	UNIT 018	DIS	22.91
19	UNIT 019	FIX	42.00
22	UNIT 022	DIS	233.65
23	UNIT 023	DIS	233.67
25	UNIT 025	DIS	111.10
28	UNIT 028	MAX	104.50
31	UNIT 031	MIN	23.30
34	UNIT 034	MIN	41.90
35	UNIT 035	MIN	41.90
37	UNIT 037	DIS	148.96
38	UNIT 038	MAX	256.50
39	UNIT 039	MAX	256.50
43	UNIT 043	MIN	4.70
44	UNIT 044	MAX	684.00
45	UNIT 045	MAX	133.00
46	UNIT 046	MAX	133.00
49	UNIT 049	FIX	20.00
51	UNIT 051	DIS	23.06
52	UNIT 052	DIS	23.06
53	UNIT 053	MAX	33.30
62	UNIT 062	MAX	684.00
63	UNIT 063	DIS	151.83
64	UNIT 064	DIS	151.80
65	UNIT 065	DIS	151.78
66	UNIT 066	DIS	151.78
68	UNIT 068	MAX	684.00
70	UNIT 070	MAX	308.80
71	UNIT 071	MAX	475.00
72	UNIT 072	MAX	494.00
75	UNIT 075	DIS	19.83
76	UNIT 076	MAX	874.00
77	UNIT 077	DIS	547.38

MUST DOWN UNITS

NO.	NAME
14	UNIT 014
24	UNIT 024
27	UNIT 027
30	UNIT 030
36	UNIT 036
47	UNIT 047
56	UNIT 056
61	UNIT 061
69	UNIT 069
80	UNIT 080

UNITS ECONOMICALLY DOWN

NO.	NAME	DT
2 -	UNIT 002	1
5 -	UNIT 005	1
8	UNIT 008	2
9	UNIT 009	2
12	UNIT 012	2
13	UNIT 013	2
32 -	UNIT 032	1
40	UNIT 040	2
41	UNIT 041	3
42	UNIT 042	3
48	UNIT 048	2
50	UNIT 050	2
54 -	UNIT 054	1
55 -	UNIT 055	1
57	UNIT 057	2
58	UNIT 058	2
59	UNIT 059	2
73 -	UNIT 073	1

LOWEST COST COMMITMENT SCHEDULE

SUMMARY FOR 12 MONT

UNITS ECONOMICALLY UP

NO.	NAME	MODE	GEN	UT
4	UNIT 004	DIS	24.90	5
5 +	UNIT 005	DIS	24.90	1
15	UNIT 015	DIS	96.26	5
17	UNIT 017	DIS	96.26	5
20	UNIT 020	MAX	61.80	5
21	UNIT 021	MAX	61.80	5
26	UNIT 026	MAX	104.50	5
33	UNIT 033	MIN	27.90	5
54 +	UNIT 054	DIS	76.58	1

MUST RUN UNITS

NO.	NAME	MODE	GEN
1	UNIT 001	MAX	95.00
3	UNIT 003	MIN	41.90
6	UNIT 006	MIN	27.90
7	UNIT 007	MIN	37.20
10	UNIT 010	FIX	70.00
11	UNIT 011	FIX	70.00
16	UNIT 016	MAX	95.00
18	UNIT 018	DIS	44.43
19	UNIT 019	FIX	42.00
22	UNIT 022	MAX	247.00
23	UNIT 023	MAX	247.00
25	UNIT 025	MAX	133.00
28	UNIT 028	MAX	104.50
29	UNIT 029	FIX	300.00
31	UNIT 031	MIN	23.30
34	UNIT 034	MIN	41.90
35	UNIT 035	MIN	41.90
37	UNIT 037	MAX	175.80
38	UNIT 038	MAX	256.50
39	UNIT 039	MAX	256.50
43	UNIT 043	MIN	4.70
44	UNIT 044	MAX	684.00
45	UNIT 045	MAX	133.00
46	UNIT 046	MAX	133.00
49	UNIT 049	FIX	20.00
51	UNIT 051	MAX	23.80
52	UNIT 052	MAX	23.80
53	UNIT 053	MAX	33.30
60	UNIT 060	FIX	150.00
62	UNIT 062	FIX	450.00
63	UNIT 063	DIS	222.32
64	UNIT 064	DIS	222.32
65	UNIT 065	DIS	222.31
66	UNIT 066	DIS	222.29
67	UNIT 067	FIX	180.00
68	UNIT 068	FIX	350.00
70	UNIT 070	MAX	308.80
71	UNIT 071	FIX	150.00
72	UNIT 072	FIX	150.00
73 +	UNIT 073	FIX	250.00
74	UNIT 074	FIX	250.00
75	UNIT 075	DIS	46.64
76	UNIT 076	FIX	450.00
77	UNIT 077	DIS	856.58
78	UNIT 078	FIX	170.00
79	UNIT 079	FIX	170.00

MUST DOWN UNITS

NO.	NAME
14	UNIT 014
24	UNIT 024
27	UNIT 027
30	UNIT 030
36	UNIT 036
47	UNIT 047
56	UNIT 056
61	UNIT 061
69	UNIT 069
80	UNIT 080

UNITS ECONOMICALLY DOWN

NO.	NAME	DT
2	UNIT 002	3
8	UNIT 008	4
9	UNIT 009	4
12	UNIT 012	4
13	UNIT 013	4
32	UNIT 032	3
40	UNIT 040	4
41	UNIT 041	5
42	UNIT 042	5
48	UNIT 048	4
50	UNIT 050	4
55	UNIT 055	3
57	UNIT 057	4
58	UNIT 058	4
59	UNIT 059	4

LOWEST COST COMMITMENT SCHEDULE

SUMMARY FOR 6 A.M.

UNITS ECONOMICALLY UP

NO.	NAME	MODE	GEN	UT
2 +	UNIT 002	DIS	22.57	1
4	UNIT 004	DIS	20.55	11
5	UNIT 005	DIS	20.55	7
8 +	UNIT 008	MIN	18.60	1
9 +	UNIT 009	MIN	18.60	1
10	UNIT 010	MAX	156.80	11
11	UNIT 011	MAX	185.30	11
12 +	UNIT 012	DIS	20.56	1
13 +	UNIT 013	DIS	20.56	1
15	UNIT 015	DIS	88.12	11
17	UNIT 017	DIS	58.12	11
20	UNIT 020	MAX	61.80	11
21	UNIT 021	MAX	61.80	11
26	UNIT 026	MAX	104.50	11
29	UNIT 029	MAX	475.00	11
32 +	UNIT 032	MIN	27.90	1
33	UNIT 033	MIN	27.90	11
40 +	UNIT 040	DIS	28.28	1
48 +	UNIT 048	MIN	16.60	1
50 +	UNIT 050	MIN	18.60	1
54	UNIT 054	DIS	46.69	7
55 +	UNIT 055	DIS	46.68	1
57 +	UNIT 057	DIS	56.54	1
58 +	UNIT 058	DIS	56.48	1
59 +	UNIT 059	MAX	109.30	1
60	UNIT 060	DIS	195.37	11
67	UNIT 067	MAX	361.00	11
73	UNIT 073	DIS	250.73	7
74	UNIT 074	DIS	350.09	11
78	UNIT 078	MAX	332.50	11
79	UNIT 079	MAX	332.50	11

MUST RUN UNITS

NO.	NAME	MODE	GEN
1	UNIT 001	MAX	95.00
3	UNIT 003	MIN	41.90
6	UNIT 006	MIN	27.90
7	UNIT 007	MIN	37.20
16	UNIT 016	DIS	88.12
18	UNIT 018	DIS	36.70
19	UNIT 019	FIX	42.00
22	UNIT 022	MAX	247.00
23	UNIT 023	MAX	247.00
25	UNIT 025	MAX	133.00
28	UNIT 028	MAX	104.50
31	UNIT 031	MIN	23.30
34	UNIT 034	MIN	41.90
35	UNIT 035	MIN	41.90
37	UNIT 037	MAX	175.80
38	UNIT 038	MAX	256.50
39	UNIT 039	MAX	256.50
43	UNIT 043	MIN	4.70
44	UNIT 044	MAX	684.00
45	UNIT 045	MAX	133.00
46	UNIT 046	MAX	133.00
49	UNIT 049	FIX	20.00
51	UNIT 051	DIS	17.26
52	UNIT 052	DIS	17.26
53	UNIT 053	DIS	31.86
62	UNIT 062	MAX	684.00
63	UNIT 063	DIS	221.48
64	UNIT 064	DIS	221.49
65	UNIT 065	DIS	221.49
66	UNIT 066	DIS	221.50
68	UNIT 068	MAX	684.00
70	UNIT 070	MAX	308.80
71	UNIT 071	MAX	475.00
72	UNIT 072	MAX	494.00
75	UNIT 075	DIS	28.27
76	UNIT 076	MAX	874.00
77	UNIT 077	DIS	852.96

MUST DOWN UNITS

NO.	NAME
14	UNIT 014
24	UNIT 024
27	UNIT 027
30	UNIT 030
36	UNIT 036
47	UNIT 047
56	UNIT 056
61	UNIT 061
69	UNIT 069
80	UNIT 060

UNITS ECONOMICALLY DOWN

NO.	NAME	DT
41	UNIT 041	11
42	UNIT 042	11

LOWEST COST COMMITMENT SCHEDULE

SUMMARY FOR 7 A.M.

UNITS ECONOMICALLY UP

NO.	NAME	MODE	GEN	UT
2	UNIT 002	DIS	36.02	2
4	UNIT 004	DIS	40.91	12
5	UNIT 005	DIS	40.91	8
8	UNIT 008	MIN	16.60	2
9	UNIT 009	MIN	16.60	2
10	UNIT 010	MAX	156.80	12
11	UNIT 011	MAX	185.30	12
12	UNIT 012	MAX	23.80	2
13	UNIT 013	MAX	23.80	2
15	UNIT 015	MAX	104.50	12
17	UNIT 017	MAX	104.50	12
20	UNIT 020	MAX	61.80	12
21	UNIT 021	MAX	61.80	12
26	UNIT 026	MAX	104.50	12
29	UNIT 029	MAX	475.00	12
32	UNIT 032	DIS	31.72	2
33	UNIT 033	MAX	61.80	12
40	UNIT 040	MAX	47.50	2
41 *	UNIT 041	DIS	5.92	1
42 *	UNIT 042	DIS	5.92	1
48	UNIT 048	MIN	18.60	2
50	UNIT 050	MIN	18.60	2
54	UNIT 054	DIS	56.32	8
55	UNIT 055	DIS	56.35	2
57	UNIT 057	MAX	80.80	2
58	UNIT 058	MAX	80.80	2
59	UNIT 059	MAX	109.30	2
60	UNIT 060	MAX	247.00	12
67	UNIT 067	MAX	361.00	12
73	UNIT 073	MAX	475.00	8
74	UNIT 074	MAX	475.00	12
78	UNIT 078	MAX	332.50	12
79	UNIT 079	MAX	332.50	12

MUST RUN UNITS

NO.	NAME	MODE	GEN
1	UNIT 001	MAX	95.00
3	UNIT 003	MIN	41.90
6	UNIT 006	MIN	27.90
7	UNIT 007	MIN	37.20
16	UNIT 016	MAX	95.00
18	UNIT 018	MAX	57.00
19	UNIT 019	FIX	42.00
22	UNIT 022	MAX	247.00
23	UNIT 023	MAX	247.00
25	UNIT 025	MAX	133.00
28	UNIT 028	MAX	104.50
31	UNIT 031	MIN	23.30
34	UNIT 034	MAX	109.30
35	UNIT 035	MAX	109.30
37	UNIT 037	MAX	175.80
38	UNIT 038	MAX	256.50
39	UNIT 039	MAX	256.50
43	UNIT 043	DIS	5.92
44	UNIT 044	MAX	684.00
45	UNIT 045	MAX	133.00
46	UNIT 046	MAX	133.00
49	UNIT 049	FIX	20.00
51	UNIT 051	MAX	23.80
52	UNIT 052	MAX	23.80
53	UNIT 053	MAX	33.30
62	UNIT 062	MAX	684.00
63	UNIT 063	MAX	256.50
64	UNIT 064	MAX	256.50
65	UNIT 065	MAX	256.50
66	UNIT 066	MAX	256.50
68	UNIT 068	MAX	684.00
70	UNIT 070	MAX	308.80
71	UNIT 071	MAX	475.00
72	UNIT 072	MAX	494.00
75	UNIT 075	MAX	47.50
76	UNIT 076	MAX	874.00
77	UNIT 077	MAX	874.00

MUST DOWN UNITS

NO.	NAME
14	UNIT 014
24	UNIT 024
27	UNIT 027
30	UNIT 030
36	UNIT 036
47	UNIT 047
56	UNIT 056
61	UNIT 061
69	UNIT 069
80	UNIT 080

UNITS ECONOMICALLY DOWN

NO.	NAME	DT

LOWEST COST COMMITMENT SCHEDULE

SUMMARY FOR 11 A.M.

UNITS ECONOMICALLY UP

NO.	NAME	MODE	GEN	UT
2	UNIT 002	DIS	29.28	6
4	UNIT 004	DIS	29.39	16
5	UNIT 005	DIS	29.39	12
8	UNIT 008	MIN	16.60	6
9	UNIT 009	MIN	16.60	6
10	UNIT 010	MAX	156.80	16
11	UNIT 011	MAX	185.30	16
12	UNIT 012	MAX	23.80	6
13	UNIT 013	MAX	23.80	6
15	UNIT 015	MAX	104.50	16
17	UNIT 017	MAX	104.50	16
20	UNIT 020	MAX	61.80	16
21	UNIT 021	MAX	61.80	16
26	UNIT 026	MAX	104.50	16
29	UNIT 029	MAX	475.00	16
32	UNIT 032	MIN	27.90	6
33	UNIT 033	DIS	35.06	16
40	UNIT 040	DIS	40.40	6
48	UNIT 048	MIN	16.60	6
50	UNIT 050	MIN	16.60	6
54	UNIT 054	DIS	51.62	12
55	UNIT 055	DIS	51.61	6
57	UNIT 057	DIS	65.25	6
58	UNIT 058	DIS	65.19	6
59	UNIT 059	MAX	109.30	6
60	UNIT 060	DIS	218.54	16
67	UNIT 067	MAX	361.00	16
73	UNIT 073	DIS	380.69	12
74	UNIT 074	DIS	395.00	16
78	UNIT 078	MAX	332.50	16
79	UNIT 079	MAX	332.50	16

MUST RUN UNITS

NO.	NAME	MODE	GEN
1	UNIT 001	MAX	95.00
3	UNIT 003	MIN	41.90
6	UNIT 006	MIN	27.90
7	UNIT 007	MIN	37.20
16	UNIT 016	MAX	95.00
18	UNIT 018	DIS	51.16
19	UNIT 019	FIX	42.00
22	UNIT 022	MAX	247.00
23	UNIT 023	MAX	247.00
25	UNIT 025	MAX	133.00
28	UNIT 028	MAX	104.50
31	UNIT 031	MIN	23.30
34	UNIT 034	DIS	71.72
35	UNIT 035	DIS	71.72
37	UNIT 037	MAX	175.80
38	UNIT 038	MAX	256.50
39	UNIT 039	MAX	256.50
43	UNIT 043	MIN	4.70
44	UNIT 044	MAX	684.00
45	UNIT 045	MAX	133.00
46	UNIT 046	MAX	133.00
49	UNIT 049	FIX	20.00
51	UNIT 051	DIS	19.39
52	UNIT 052	DIS	19.39
53	UNIT 053	MAX	33.30
62	UNIT 062	MAX	684.00
63	UNIT 063	MAX	256.50
64	UNIT 064	MAX	256.50
65	UNIT 065	MAX	256.50
66	UNIT 066	MAX	256.50
68	UNIT 068	MAX	684.00
70	UNIT 070	MAX	308.80
71	UNIT 071	MAX	475.00
72	UNIT 072	MAX	494.00
75	UNIT 075	DIS	40.39
76	UNIT 076	MAX	874.00
77	UNIT 077	MAX	874.00

MUST DOWN UNITS

NO.	NAME
14	UNIT 014
24	UNIT 024
27	UNIT 027
30	UNIT 030
36	UNIT 036
47	UNIT 047
56	UNIT 056
61	UNIT 061
69	UNIT 069
80	UNIT 080

UNITS ECONOMICALLY DOWN

NO.	NAME	DT
41 -	UNIT 041	1
42 -	UNIT 042	1

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1556837.47

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SD	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT	XCHG
20	4	12376.00	461.79	7.45832		0	2	74485.20	.00	74485.20	74485.20	397.00		
21	5	11193.00	376.42	6.72596		0	10	68016.01	.00	68016.01	142501.21	45.00		
22	9	9997.00	321.61	6.22223		0	6	59617.58	.00	59617.58	202118.79	5.00		
23	12	8801.00	283.23	5.82390		0	0	52179.87	.00	52179.87	254298.66	5.00		
24	4	8515.00	267.24	7.24067		3	0	54129.11	869.25	54998.36	309297.02	5.00		
1	8	8229.00	259.21	6.91985		0	0	51918.78	.00	51918.78	361215.79	5.00		
2	10	8099.00	248.34	6.78577		0	0	50967.73	.00	50967.73	412183.52	5.00		
3	10	8088.00	247.92	6.78041		0	0	50929.97	.00	50929.97	463113.49	5.00		
4	7	8424.00	266.39	6.94386		0	0	53199.96	.00	53199.96	516313.45	5.00		
5	12	9633.00	307.11	6.04062		0	0	57759.03	.00	57759.03	574072.47	5.00		
6	11	11453.00	404.95	6.81900		13	0	70521.50	3352.00	73873.50	647945.96	5.00		
7	1	12311.00	545.70	8.57650		2	0	77356.34	434.00	77790.34	725736.30	5.00		
8	1	12519.00	557.23	11.35380		0	0	79124.89	.00	79124.89	804861.19	45.00		
9	1	12623.00	550.35	10.69448		0	0	78676.58	.00	78676.58	883537.77	205.00		
10	1	12668.00	539.92	8.70970		0	0	77448.63	.00	77448.63	960986.39	379.00		
11	4	12467.00	454.62	7.45582		0	2	74333.84	.00	74333.84	1035320.23	514.00		
12	7	12376.00	446.83	7.26704		0	0	73626.99	.00	73626.99	1108947.20	514.00		
13	5	12506.00	451.67	7.36799		0	0	73959.44	.00	73959.44	1182906.64	592.00		
14	3	12597.00	469.06	7.57139		0	0	74715.39	.00	74715.39	1257622.03	592.00		
15	6	12564.00	426.27	7.17144		0	0	73460.30	.00	73460.30	1331082.33	722.00		
16	3	12662.00	449.79	7.41685		0	0	74449.10	.00	74449.10	1405531.42	672.00		
17	2	12792.00	477.10	7.67428		0	0	75343.50	.00	75343.50	1480874.92	697.00		
18	1	13000.00	497.98	7.81601		0	0	75962.56	.00	75962.56	1556837.47	847.00		

APPENDIX C

DETAILED DESCRIPTION OF CASE STUDIES

In Chapter III, twelve case studies were described in a general way. The purpose of this appendix is to provide the interested reader a more detailed description of the system conditions surrounding the case studies.

All the case studies had the following conditions in common:

1. The generation consisted of 124 units of which 80 were steam, 12 were CT's, 11 were hydro, and 21 were tie points. Each unit was assigned to one of 29 busses.
2. The commitment period was 24 hours long, starting at 7:00 P.M.
3. The unit and system data were also the same for all cases. The data were realistic data representing an actual power system in the southeastern United States.
4. The operating reserve requirements were set at 1050 MW.
5. The load model used was that of a typical weekday in the fall.
6. Each unit was assumed to have a minimum start-up cost equal to one-half its cold-start cost.
7. No CT generation or tie-line flows were scheduled.

Cases 1-6 assumed a peak load demand of 13,000 MW for both days while cases 7-12 used 10,000 MW for the peak demand. Cases 1-3 and 7-9 assumed that all steam generation was available and could be cycled. No hydro generation was scheduled.

In order to better simulate actual operating conditions, cases (4-6, 10-12) including deslagging, maintenance, must-run, and hydro schedules were examined. Tables C-1 and C-2 describe the steam unit schedules for the cases. The schedules differ slightly between the high and low peak demand cases. The same hydro schedule was used for both high and low peak demand cases and is described in Table C-3.

TABLE C-1

STEAM UNIT SCHEDULE FOR HIGH PEAK CASE STUDIES

A. Units Down for Maintenance

Unit	Capacity (MW)
14	152.0
24	133.0
27	104.5
30	66.5
36	166.3
47	247.0
56	332.5
61	684.0
69	256.5
80	760.0

B. Units Scheduled for Deslagging

Unit	Hours	Gen (MW)
10	12 P.M. - 6 A.M.	70.0
11	12 P.M. - 6 A.M.	70.0
29	1 A.M. - 5 A.M.	300.0
60	1 A.M. - 5 A.M.	150.0
62	1 A.M. - 5 A.M.	450.0
67	1 A.M. - 5 A.M.	180.0
68	1 A.M. - 5 A.M.	350.0
71	1 A.M. - 5 A.M.	150.0
72	1 A.M. - 5 A.M.	150.0
73	1 A.M. - 6 A.M.	250.0
74	1 A.M. - 5 A.M.	250.0
76	1 A.M. - 5 A.M.	450.0
78	1 A.M. - 4 A.M.	170.0
79	1 A.M. - 5 A.M.	170.0

C. Units Scheduled for Must-Run*

Unit	Mode	Unit	Mode
3	DIS	49	FIX(20.0)
6	DIS	62	DIS
7	DIS	68	DIS
16	DIS	71	DIS
18	DIS	72	DIS
19	FIX(42.0)	75	DIS
31	DIS	76	DIS
43	DIS	77	DIS
44	DIS		

* A unit in the DIS mode is economically loaded. A unit in the FIX mode is fixed. The generation is in parenthesis.

TABLE C-2

STEAM UNIT SCHEDULE FOR LOW PEAK CASE STUDIES

A. Units Down for Maintenance

Unit	Capacity (MW)
14	152.0
24	133.0
27	104.5
30	66.5
36	166.3
47	247.0
56	332.5
61	684.0
69	256.5
80	760.0

B. Units Scheduled for Deslagging

Unit	Hours	Gen (MW)
10	12 P.M. - 6 A.M.	70.0
11	12 P.M. - 6 A.M.	70.0
60	1 A.M. - 5 A.M.	150.0
62	1 A.M. - 5 A.M.	450.0
67	1 A.M. - 5 A.M.	180.0
68	1 A.M. - 5 A.M.	350.0
71	1 A.M. - 5 A.M.	150.0
72	1 A.M. - 5 A.M.	150.0
74	1 A.M. - 5 A.M.	250.0
76	1 A.M. - 5 A.M.	450.0
78	1 A.M. - 4 A.M.	170.0
79	1 A.M. - 5 A.M.	170.0

C. Units Scheduled for Must-Run*

Unit	Mode	Unit	Mode
3	DIS	62	DIS
6	DIS	68	DIS
7	DIS	71	DIS
16	DIS	72	DIS
31	DIS	76	DIS
43	DIS	77	DIS
44	DIS		

* In this case all must-run units are in a DIS mode; i.e., their loading is determined economically.

TABLE C-3

HYDRO GENERATION SCHEDULE FOR CASE STUDIES

Unit	Hours	Generation (MW)
93	1 A.M. - 4 P.M.	100.0
	4 P.M. - 1 A.M.	5.0
96	2 P.M. - 9 P.M.	78.0
98	11 A.M. - 9 P.M.	74.0
99	9 A.M. - 12 A.M.	40.0
	12 A.M. - 4 P.M.	210.0
	4 P.M. - 9 P.M.	280.0
	10 P.M. - 11 P.M.	40.0
100	12 A.M. - 1 P.M.	170.0
	1 P.M. - 3 P.M.	225.0
	3 P.M. - 7 P.M.	265.0
	7 P.M. - 9 P.M.	225.0
	9 P.M. - 10 P.M.	102.0
101	4 P.M. - 5 P.M.	40.0
	5 P.M. - 6 P.M.	85.0
	6 P.M. - 8 P.M.	125.0
	8 P.M. - 9 P.M.	85.0
102	5 P.M. - 6 P.M.	130.0
103	4 P.M. - 7 P.M.	80.0
	7 P.M. - 9 P.M.	190.0
	9 P.M. - 10 P.M.	80.0

APPENDIX D

COMMITMENT SUMMARIES FOR CASE STUDIES

The commitment summaries of the case studies are listed on the following pages. The first twelve are those described in Chapter III. The last four are the summaries of the cases using fuel cost estimation.

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1417001.70

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SD	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT
20	1	12376.00	429.84	6.10295		0	0	68858.02	.00	68858.02	68858.02	.00	
21	1	11193.00	386.11	5.71943		0	0	61385.17	.00	61385.17	130243.20	.00	
22	1	9997.00	357.28	5.30311		0	0	54369.47	.00	54369.47	184632.67	.00	
23	1	8801.00	319.51	4.94980		0	0	47792.43	.00	47792.43	232425.10	.00	
24	1	8515.00	310.87	4.87480		0	0	46305.63	.00	46305.63	278730.73	.00	
1	1	8229.00	297.52	4.79355		0	0	44836.15	.00	44836.15	323566.87	.00	
2	1	8099.00	290.96	4.75605		0	0	44123.54	.00	44123.54	367690.41	.00	
3	1	8086.00	290.95	4.75605		0	0	44128.74	.00	44128.74	411819.15	.00	
4	1	8424.00	307.89	4.84980		0	0	45880.90	.00	45880.90	457700.05	.00	
5	1	9633.00	344.73	5.19270		0	0	52317.47	.00	52317.47	510017.52	.00	
6	1	11453.00	394.19	5.80047		0	0	62988.66	.00	62988.66	573006.17	.00	
7	1	12311.00	427.20	6.08259		0	0	68467.35	.00	68467.35	641473.52	.00	
8	1	12519.00	436.56	6.15759		0	0	69873.03	.00	69873.03	711346.55	.00	
9	1	12623.00	440.88	6.19509		0	0	70531.43	.00	70531.43	781877.98	.00	
10	1	12685.00	443.79	6.22009		0	0	70968.51	.00	70968.51	852846.48	.00	
11	1	12467.00	433.61	6.13259		0	0	69417.38	.00	69417.38	922263.86	.00	
12	1	12376.00	430.48	6.10759		0	0	68950.29	.00	68950.29	991214.15	.00	
13	1	12506.00	435.85	6.15134		0	0	69762.09	.00	69762.09	1060976.23	.00	
14	1	12597.00	439.40	6.18259		0	0	70309.37	.00	70309.37	1131285.59	.00	
15	1	12584.00	439.41	6.18259		0	0	70311.41	.00	70311.41	1201597.00	.00	
16	1	12662.00	442.31	6.20759		0	0	70749.00	.00	70749.00	1272346.00	.00	
17	1	12792.00	448.26	6.25759		0	0	71622.32	.00	71622.32	1343968.31	.00	
18	1	13000.00	458.11	6.34509		0	0	73033.40	.00	73033.40	1417001.70	.00	

D.1. Commitment Summary for Case 1

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1416640.55

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SU	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT
20	1	12376.00	429.84	6.10295		0	0	68858.02	.00	68858.02	68858.02	.00	
21	1	11193.00	386.00	5.71900		0	0	61368.65	.00	61368.65	130226.68	.00	
22	1	9997.00	357.15	5.30173		0	0	54370.90	.00	54370.90	184597.57	.00	
23	1	8801.00	319.69	4.95120		0	0	47819.61	.00	47819.61	232417.18	.00	
24	1	8515.00	310.68	4.87308		0	0	46275.68	.00	46275.68	278692.86	.00	
1	1	8229.00	297.77	4.79495		0	0	44858.53	.00	44858.53	323551.39	.00	
2	1	8099.00	291.19	4.75745		0	0	44158.19	.00	44158.19	367709.58	.00	
3	1	8086.00	291.19	4.75745		0	0	44154.30	.00	44154.30	411863.87	.00	
4	1	8424.00	307.56	4.84731		0	0	45843.43	.00	45843.43	457707.30	.00	
5	1	9633.00	344.63	5.19194		0	0	52295.77	.00	52295.77	510003.07	.00	
6	1	11453.00	394.01	5.79892		0	0	62956.16	.00	62956.16	572959.23	.00	
7	1	12311.00	427.16	6.08242		0	0	68461.83	.00	68461.83	641421.05	.00	
8	1	12519.00	435.98	6.15268		0	0	69783.01	.00	69783.01	711204.05	.00	
9	1	12623.00	440.45	6.19129		0	0	70465.62	.00	70465.62	781669.68	.00	
10	1	12688.00	443.49	6.21725		0	0	70920.98	.00	70920.98	852590.66	.00	
11	1	12467.00	434.03	6.13600		0	0	69480.45	.00	69480.45	922071.10	.00	
12	1	12376.00	430.03	6.10475		0	0	68888.25	.00	68888.25	990959.35	.00	
13	1	12506.00	435.53	6.14854		0	0	69710.97	.00	69710.97	1060670.31	.00	
14	1	12597.00	439.36	6.18196		0	0	70301.78	.00	70301.78	1130972.09	.00	
15	1	12584.00	439.34	6.18196		0	0	70299.54	.00	70299.54	1201271.62	.00	
16	1	12662.00	442.24	6.20666		0	0	70735.30	.00	70735.30	1272006.92	.00	
17	1	12792.00	446.18	6.25624		0	0	71604.46	.00	71604.46	1343611.37	.00	
18	1	13000.00	458.08	6.34473		0	0	73029.18	.00	73029.18	1416640.55	.00	

D.2. Commitment Summary for Case 2

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1407650.92

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SD	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT
20	1	12376.00	434.82	6.22735		0	8	68616.95	.00	68616.95	68616.95	.00	
21	1	11193.00	388.83	6.12735		0	12	60733.60	.00	60733.60	129350.55	.00	
22	8	9997.00	347.88	5.67209		0	1	53202.15	.00	53202.15	182552.70	.00	
23	9	8801.00	301.78	5.51180		0	5	46125.92	.00	46125.92	228678.62	.00	
24	9	8515.00	294.95	5.35582		0	0	44495.19	.00	44495.19	273173.80	.00	
1	9	8229.00	286.71	5.23218		0	0	42808.78	.00	42808.78	315982.58	.00	
2	9	8099.00	283.16	5.19344		0	0	42165.91	.00	42165.91	358148.49	.00	
3	9	8086.00	282.44	5.18388		0	0	42021.67	.00	42021.67	400170.16	.00	
4	9	8424.00	292.19	5.31197		0	0	43928.07	.00	43928.07	444098.22	.00	
5	11	9633.00	340.83	5.52864		5	0	51005.45	1688.15	52693.60	496791.82	.00	
6	11	11453.00	395.37	5.87645		14	0	62728.49	4349.00	67077.49	563869.30	.00	
7	3	12311.00	429.28	6.17692		0	0	68229.51	.00	68229.51	632098.81	.00	
8	2	12519.00	438.95	6.23986		1	0	69604.59	267.00	69871.59	701970.40	.00	
9	1	12623.00	444.34	6.26261		1	0	70290.94	267.00	70557.94	772528.33	.00	
10	1	12688.00	445.60	6.26405		1	0	70760.93	315.00	71075.93	843604.25	.00	
11	4	12467.00	435.97	6.18176		0	0	69334.35	.00	69334.35	912938.59	.00	
12	5	12376.00	431.91	6.14601		0	0	68701.64	.00	68701.64	981640.23	.00	
13	4	12506.00	437.33	6.19372		0	0	69540.77	.00	69540.77	1051181.00	.00	
14	3	12597.00	441.67	6.23119		0	0	70188.59	.00	70188.59	1121369.59	.00	
15	3	12584.00	441.25	6.22760		0	0	70126.45	.00	70126.45	1191496.03	.00	
16	1	12662.00	444.37	6.25382		0	0	70581.66	.00	70581.66	1262077.69	.00	
17	1	12792.00	449.32	6.29526		1	0	71478.17	245.00	71723.17	1333800.84	.00	
18	1	13000.00	458.09	6.34486		3	0	73031.08	819.00	73850.08	1407650.92	.00	

D.3. Commitment Summary for Case 3

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1559088.23

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SD	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT
20	1	12376.00	461.61	7.45233		0	0	74600.85	.00	74600.85	74600.85	397.00	
21	1	11193.00	379.40	6.61899		0	0	68523.79	.00	68523.79	143124.64	45.00	
22	1	9997.00	315.60	6.02768		0	0	60750.55	.00	60750.55	203875.19	5.00	
23	1	8801.00	271.69	5.67851		0	0	53424.27	.00	53424.27	257299.46	5.00	
24	1	8515.00	281.13	6.72894		0	0	54410.34	.00	54410.34	311709.80	5.00	
1	1	8229.00	259.57	6.48340		0	0	52377.25	.00	52377.25	364087.05	5.00	
2	1	8099.00	251.56	6.38340		0	0	51520.47	.00	51520.47	415607.52	5.00	
3	1	8080.00	250.59	6.37090		0	0	51412.47	.00	51412.47	467019.98	5.00	
4	1	8424.00	263.59	6.48905		0	0	53589.44	.00	53589.44	520609.42	5.00	
5	1	9633.00	304.88	5.94730		0	0	58546.57	.00	58546.57	579155.98	5.00	
6	1	11453.00	404.55	6.61525		0	0	70618.68	.00	70618.68	649774.66	5.00	
7	1	12311.00	545.98	8.60550		0	0	77376.31	.00	77376.31	727150.98	5.00	
8	1	12519.00	557.24	11.35701		0	0	79127.23	.00	79127.23	806278.20	45.00	
9	1	12623.00	558.32	10.70250		0	0	78681.46	.00	78681.46	884959.66	205.00	
10	1	12688.00	539.92	8.71034		0	0	77448.98	.00	77448.98	962408.63	379.00	
11	1	12467.00	463.20	7.43565		0	0	74394.99	.00	74394.99	1036803.62	514.00	
12	1	12576.00	448.46	7.25988		0	0	73736.23	.00	73736.23	1110539.84	514.00	
13	1	12506.00	451.26	7.35988		0	0	74065.96	.00	74065.96	1184605.80	592.00	
14	1	12597.00	468.96	7.56649		0	0	74833.38	.00	74833.38	1259439.17	592.00	
15	1	12584.00	427.12	7.17809		0	0	73643.20	.00	73643.20	1333082.36	722.00	
16	1	12662.00	449.70	7.41275		0	0	74570.17	.00	74570.17	1407652.53	672.00	
17	1	12792.00	477.07	7.67069		0	0	75464.75	.00	75464.75	1483117.28	697.00	
18	1	13000.00	494.53	7.77069		0	0	75970.96	.00	75970.96	1559088.23	647.00	

D.4. Commitment Summary for Case 4

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1558657.08

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SD	FUEL COST	SU COST	TOTAL COST	PATH. COST	HYDRO	CT
20	1	12376.00	461.61	7.45233		0	0	74600.85	.00	74600.85	74600.85	397.00	
21	3	11193.00	380.67	6.71536		0	1	68240.61	.00	68240.61	142841.46	45.00	
22	7	9997.00	317.99	6.07316		0	0	60435.20	.00	60435.20	203276.66	5.00	
23	7	8801.00	276.54	5.71512		0	0	53044.24	.00	53044.24	256320.90	5.00	
24	1	8515.00	281.13	6.72697		1	0	54410.54	438.90	54849.44	311170.34	5.00	
1	1	8229.00	259.57	6.48340		0	0	52377.25	.00	52377.25	363547.59	5.00	
2	1	8099.00	251.56	6.38340		0	0	51520.47	.00	51520.47	415068.06	5.00	
3	1	8086.00	250.59	6.37090		0	0	51412.47	.00	51412.47	466480.52	5.00	
4	2	8424.00	264.07	6.49496		0	0	53641.06	.00	53641.06	520121.59	5.00	
5	7	9633.00	304.83	5.94621		0	0	58533.72	.00	58533.72	578655.30	5.00	
6	2	11453.00	405.32	6.62196		0	0	70686.32	.00	70686.32	649341.62	5.00	
7	1	12311.00	546.00	8.60788		0	0	77377.89	.00	77377.89	726719.52	5.00	
8	1	12519.00	557.24	11.35730		0	0	79127.45	.00	79127.45	805846.96	45.00	
9	1	12623.00	558.32	10.70325		0	0	78681.91	.00	78681.91	884528.87	205.00	
10	1	12688.00	539.92	8.71038		0	0	77449.00	.00	77449.00	961977.86	379.00	
11	1	12467.00	463.19	7.43553		0	0	74394.54	.00	74394.54	1036372.40	514.00	
12	1	12376.00	448.46	7.25988		0	0	73736.25	.00	73736.25	1110108.64	514.00	
13	1	12506.00	451.26	7.35988		0	0	74065.97	.00	74065.97	1184174.61	592.00	
14	1	12597.00	468.96	7.56649		0	0	74833.39	.00	74833.39	1259007.98	592.00	
15	1	12584.00	427.12	7.17810		0	0	73643.21	.00	73643.21	1332651.19	722.00	
16	1	12662.00	449.70	7.41275		0	0	74570.17	.00	74570.17	1407221.36	672.00	
17	1	12792.00	477.07	7.67069		0	0	75464.75	.00	75464.75	1482686.11	697.00	
18	1	13000.00	494.53	7.77069		0	0	75970.97	.00	75970.97	1558657.08	647.00	

D.5. Commitment Summary for Case 5

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1556088.45

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SD	FUEL COST	SU COST	TOTAL COST	PATH. COST	HYDRO	CT
20	2	12376.00	453.86	7.51159		0	4	74460.42	.00	74460.42	74460.42	397.00	
21	3	11193.00	375.28	6.96421		0	10	67774.42	.00	67774.42	142234.84	45.00	
22	9	9997.00	321.69	6.22277		0	4	59627.44	.00	59627.44	201862.27	5.00	
23	12	8801.00	285.46	5.62541		0	0	52214.20	.00	52214.20	254076.47	5.00	
24	2	8515.00	297.03	7.42313		1	0	54102.81	501.60	54604.41	308680.89	5.00	
1	7	8229.00	262.78	6.99709		1	0	51867.93	196.00	52063.93	360744.81	5.00	
2	10	8099.00	247.68	6.77704		1	0	50907.38	243.95	51151.33	411896.14	5.00	
3	10	8086.00	247.31	6.77249		0	0	50873.44	.00	50873.44	462769.58	5.00	
4	7	8424.00	265.93	6.93829		0	0	53160.47	.00	53160.47	515930.05	5.00	
5	12	9033.00	306.96	6.03946		0	0	57737.64	.00	57737.64	573667.68	5.00	
6	3	11453.00	397.33	6.90468		5	0	70198.80	1236.00	71434.80	645102.48	5.00	
7	1	12511.00	545.98	8.60604		10	0	77376.67	2550.00	79926.67	725029.15	5.00	
8	1	12519.00	557.24	11.35711		0	0	79127.30	.00	79127.30	804156.45	45.00	
9	1	12623.00	558.32	10.70276		0	0	78681.61	.00	78681.61	882838.05	205.00	
10	1	12688.00	539.92	8.71024		0	0	77448.93	.00	77448.93	960286.98	379.00	
11	4	12467.00	465.35	7.46321		0	2	74364.35	.00	74364.35	1034651.33	514.00	
12	7	12376.00	448.61	7.26321		0	0	73615.54	.00	73615.54	1108266.86	514.00	
13	5	12506.00	452.30	7.37447		0	0	73986.66	.00	73986.66	1182253.52	592.00	
14	3	12597.00	468.57	7.56464		0	0	74693.50	.00	74693.50	1256947.00	592.00	
15	6	12584.00	425.56	7.16592		0	0	73415.25	.00	73415.25	1330362.25	722.00	
16	3	12662.00	451.96	7.44276		0	0	74546.25	.00	74546.25	1404908.50	672.00	
17	2	12792.00	476.22	7.06319		0	0	75305.56	.00	75305.56	1480214.05	697.00	
18	1	13000.00	495.63	7.78803		0	0	75874.41	.00	75874.41	1556088.45	647.00	

D.6. Commitment Summary for Case 6

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1040524.14

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SD	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT
20	1	9520.00	339.91	5.47510		0	0	50355.91	.00	50355.91	50355.91	.00	
21	1	8610.00	313.66	5.13449		0	0	45131.36	.00	45131.36	95487.27	.00	
22	1	7690.00	292.01	4.84208		0	0	40234.37	.00	40234.37	135721.64	.00	
23	1	6770.00	253.26	4.60623		0	0	35688.27	.00	35688.27	171409.90	.00	
24	1	6550.00	243.97	4.55936		0	0	34577.90	.00	34577.90	205987.81	.00	
1	1	6330.00	235.61	4.51248		0	0	33489.43	.00	33489.43	239477.23	.00	
2	1	6230.00	231.98	4.49061		0	0	33003.95	.00	33003.95	272481.18	.00	
3	1	6220.00	231.98	4.49061		0	0	33004.97	.00	33004.97	305486.15	.00	
4	1	6480.00	241.09	4.54373		0	0	34212.70	.00	34212.70	339698.85	.00	
5	1	7410.00	279.92	4.75937		0	0	38806.84	.00	38806.84	378505.69	.00	
6	1	8810.00	319.12	5.20301		0	0	46258.65	.00	46258.65	424764.34	.00	
7	1	9470.00	339.22	5.44307		0	0	50016.48	.00	50016.48	474780.82	.00	
8	1	9630.00	340.75	5.52432		0	0	50953.87	.00	50953.87	525734.68	.00	
9	1	9710.00	341.99	5.56182		0	0	51454.23	.00	51454.23	577188.91	.00	
10	1	9760.00	342.93	5.58057		0	0	51734.50	.00	51734.50	628923.41	.00	
11	1	9590.00	340.42	5.50557		0	0	50730.79	.00	50730.79	679654.20	.00	
12	1	9520.00	339.80	5.46807		0	0	50269.10	.00	50269.10	729923.29	.00	
13	1	9620.00	340.64	5.51807		0	0	50880.41	.00	50880.41	780803.70	.00	
14	1	9690.00	341.67	5.55557		0	0	51359.62	.00	51359.62	832163.31	.00	
15	1	9680.00	341.34	5.54932		0	0	51262.30	.00	51262.30	883425.61	.00	
16	1	9740.00	342.57	5.57432		0	0	51635.59	.00	51635.59	935061.20	.00	
17	1	9840.00	344.61	5.61182		0	0	52221.33	.00	52221.33	987282.52	.00	
18	1	10000.00	348.04	5.67432		0	0	53241.62	.00	53241.62	1040524.14	.00	

D.7. Commitment Summary for Case 7

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1037356.70

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SU	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT
20	9	9520.00	339.88	5.47345		0	0	50335.45	.00	50335.45	50335.45	.00	
21	3	8610.00	296.35	5.41095		0	6	44944.98	.00	44944.98	95280.43	.00	
22	3	7690.00	271.83	5.05543		0	0	39805.55	.00	39805.55	135085.98	.00	
23	2	6770.00	248.85	4.70677		0	1	34959.46	.00	34959.46	170045.44	.00	
24	1	6550.00	242.16	4.64427		0	1	33848.27	.00	33848.27	203893.72	.00	
1	1	6330.00	235.17	4.58802		0	0	32823.53	.00	32823.53	236717.24	.00	
2	1	6230.00	231.45	4.56302		0	0	32305.16	.00	32305.16	269022.40	.00	
3	1	6220.00	231.23	4.56181		0	0	32275.81	.00	32275.81	301298.21	.00	
4	1	6480.00	239.91	4.62745		0	0	33536.29	.00	33536.29	334834.50	.00	
5	1	7410.00	266.95	4.97142		0	0	38278.02	.00	38278.02	373112.52	.00	
6	1	8810.00	300.95	5.55181		0	0	46153.56	.00	46153.56	419266.08	.00	
7	1	9470.00	315.90	5.81318		0	0	50206.11	.00	50206.11	469472.19	.00	
8	1	9630.00	319.70	5.87557		0	0	51096.25	.00	51096.25	520568.44	.00	
9	1	9710.00	322.02	5.91434		0	0	51618.86	.00	51618.86	572187.30	.00	
10	1	9760.00	323.52	5.93768		0	0	51937.03	.00	51937.03	624124.33	.00	
11	1	9590.00	318.93	5.86218		0	0	50916.24	.00	50916.24	675040.56	.00	
12	1	9520.00	317.04	5.83202		0	0	50480.24	.00	50480.24	725520.80	.00	
13	1	9620.00	319.75	5.87662		0	0	51108.83	.00	51108.83	776629.62	.00	
14	1	9690.00	321.60	5.90739		0	0	51525.61	.00	51525.61	828155.23	.00	
15	1	9680.00	321.44	5.90460		0	0	51489.17	.00	51489.17	879644.40	.00	
16	1	9740.00	322.78	5.92594		0	0	51779.36	.00	51779.36	931423.75	.00	
17	1	9840.00	326.11	5.97666		0	0	52466.19	.00	52466.19	983889.93	.00	
18	1	10000.00	331.38	6.05037		0	0	53466.78	.00	53466.78	1037356.70	.00	

D.8. Commitment Summary for Case 8

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1035475.50

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SU	FUEL COST	SU COST	TOTAL COST	PATH·COST	HYDRO	CT
20	11	9520.00	339.88	5.47352		0	0	50336.36	.00	50336.36	50336.36	.00	
21	8	8610.00	295.92	5.43261		0	7	44972.71	.00	44972.71	95309.06	.00	
22	5	7090.00	278.51	5.33097		0	6	39440.42	.00	39440.42	134749.48	.00	
23	7	6770.00	247.43	5.08269		0	1	34423.20	.00	34423.20	169172.68	.00	
24	8	6550.00	245.63	4.94290		0	0	33226.04	.00	33226.04	202398.71	.00	
1	9	6330.00	244.93	4.78606		0	0	32101.86	.00	32101.86	234500.57	.00	
2	10	6230.00	243.31	4.73254		0	0	31568.38	.00	31568.38	266068.95	.00	
3	10	6220.00	243.21	4.73106		0	0	31550.24	.00	31550.24	297619.20	.00	
4	9	6480.00	245.11	4.88805		0	0	32833.42	.00	32833.42	330452.61	.00	
5	6	7410.00	272.19	5.19401		1	0	37909.99	593.75	38503.74	368956.35	.00	
6	7	8810.00	299.75	5.54383		6	0	46151.37	2195.00	48346.37	417302.71	.00	
7	4	9470.00	314.08	5.79624		0	0	50107.74	.00	50107.74	467410.45	.00	
8	3	9630.00	318.49	5.86503		0	0	51147.65	.00	51147.65	518558.09	.00	
9	2	9710.00	320.91	5.90295		0	0	51693.56	.00	51693.56	570251.66	.00	
10	2	9760.00	322.31	5.92586		0	0	52005.38	.00	52005.38	622257.03	.00	
11	4	9590.00	317.28	5.84626		0	0	50870.02	.00	50870.02	673127.05	.00	
12	4	9520.00	315.58	5.81962		0	0	50468.19	.00	50468.19	723595.23	.00	
13	3	9620.00	318.19	5.86035		0	0	51078.38	.00	51078.38	774673.60	.00	
14	2	9690.00	320.13	5.88987		0	0	51513.12	.00	51513.12	826186.72	.00	
15	2	9680.00	319.82	5.88504		0	0	51443.96	.00	51443.96	877630.67	.00	
16	2	9740.00	321.70	5.91592		0	0	51870.71	.00	51870.71	929501.38	.00	
17	2	9840.00	324.74	5.96366		0	0	52518.11	.00	52518.11	982019.48	.00	
18	1	10000.00	329.53	6.03266		0	0	53456.02	.00	53456.02	1035475.50	.00	

D.9. Commitment Summary for Case 9

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1130394.62

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SD	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT
20	1	9520.00	276.00	6.14900		0	0	53828.29	.00	53828.29	53828.29	397.00	
21	1	8610.00	254.55	5.89928		0	0	50261.63	.00	50261.63	104089.92	45.00	
22	1	7690.00	228.05	5.53560		0	0	44895.23	.00	44895.23	148985.14	5.00	
23	1	6770.00	207.53	5.15262		0	0	39742.70	.00	39742.70	188727.84	5.00	
24	1	6550.00	186.52	6.20284		0	0	40018.74	.00	40018.74	228746.58	5.00	
1	1	6330.00	175.93	6.03276		0	0	38588.48	.00	38588.48	267335.05	5.00	
2	1	6230.00	171.89	5.96557		0	0	37939.75	.00	37939.75	305274.80	5.00	
3	1	6220.00	171.55	5.95932		0	0	37882.32	.00	37882.32	343157.12	5.00	
4	1	6480.00	181.97	6.05620		0	0	39508.55	.00	39508.55	382665.67	5.00	
5	1	7410.00	226.61	5.45817		0	0	43366.09	.00	43366.09	426031.75	5.00	
6	1	8810.00	267.15	6.00006		0	0	51812.73	.00	51812.73	477844.48	5.00	
7	1	9470.00	297.80	6.33241		0	0	56152.96	.00	56152.96	533997.44	5.00	
8	1	9630.00	302.07	6.43777		0	0	56957.10	.00	56957.10	590954.53	45.00	
9	1	9710.00	295.18	6.39871		0	0	56385.62	.00	56385.62	647340.15	205.00	
10	1	9760.00	281.92	6.31277		0	0	55508.93	.00	55508.93	702849.07	379.00	
11	1	9590.00	273.97	6.13804		0	0	53520.32	.00	53520.32	756369.39	514.00	
12	1	9520.00	270.76	6.10444		0	0	53060.28	.00	53060.28	809429.66	514.00	
13	1	9620.00	266.52	6.11226		0	0	53170.65	.00	53170.65	862600.31	592.00	
14	1	9690.00	270.10	6.15366		0	0	53637.96	.00	53637.96	916238.27	592.00	
15	1	9680.00	261.70	6.05635		0	0	52706.42	.00	52706.42	968944.68	722.00	
16	1	9740.00	266.97	6.11147		0	0	53429.21	.00	53429.21	1022373.88	672.00	
17	1	9840.00	275.85	6.15835		0	0	53945.20	.00	53945.20	1076319.08	697.00	
18	1	10000.00	287.24	6.16382		0	0	54075.55	.00	54075.55	1130394.62	647.00	

D.10. Commitment Summary for Case 10

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1125980.22

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SU	FUEL COST	SU COST	TOTAL COST	PATH. COST	HYDRO	CT
20	6	9520.00	276.24	6.19105		0	4	53634.25	.00	53634.25	53634.25	397.00	
21	8	8610.00	254.59	5.92508		0	0	50054.70	.00	50054.70	103688.95	45.00	
22	11	7690.00	228.50	5.55983		0	0	44673.96	.00	44673.96	148362.91	5.00	
23	9	6770.00	207.50	5.17425		0	0	39499.26	.00	39499.26	187862.16	5.00	
24	4	6550.00	189.18	6.29594		0	0	39845.38	.00	39845.38	227707.54	5.00	
1	4	6330.00	177.14	6.08786		0	0	38395.18	.00	38395.18	266102.73	5.00	
2	4	6230.00	172.75	6.01865		0	0	37744.08	.00	37744.08	303846.80	5.00	
3	4	6220.00	172.39	6.01229		0	0	37686.35	.00	37686.35	341533.15	5.00	
4	5	6480.00	183.37	6.10616		0	0	39323.69	.00	39323.69	380856.84	5.00	
5	9	7410.00	226.49	5.49065		0	0	43125.29	.00	43125.29	423982.13	5.00	
6	7	8810.00	267.29	6.02685		0	0	51604.04	.00	51604.04	475586.17	5.00	
7	5	9470.00	298.98	6.40920		0	0	55980.22	.00	55980.22	531566.38	5.00	
8	3	9630.00	304.33	6.52348		0	0	56795.29	.00	56795.29	588361.66	45.00	
9	4	9710.00	297.41	6.48135		0	0	56220.45	.00	56220.45	644582.11	205.00	
10	5	9760.00	283.61	6.38962		0	0	55336.98	.00	55336.98	699919.09	379.00	
11	6	9590.00	274.51	6.18653		0	0	53340.37	.00	53340.37	753259.45	514.00	
12	6	9520.00	271.11	6.14222		0	0	52868.42	.00	52868.42	806127.87	514.00	
13	6	9620.00	267.31	6.15881		0	0	52989.55	.00	52989.55	859117.41	592.00	
14	6	9690.00	270.68	6.20195		0	0	53448.51	.00	53448.51	912565.92	592.00	
15	7	9680.00	261.89	6.09309		0	0	52513.19	.00	52513.19	965079.11	722.00	
16	6	9740.00	269.30	6.14876		0	0	53242.27	.00	53242.27	1018321.37	672.00	
17	6	9840.00	276.48	6.20700		0	0	53766.90	.00	53766.90	1072088.27	697.00	
18	6	10000.00	287.91	6.21209		0	0	53891.96	.00	53891.96	1125980.22	647.00	

D.11. Commitment Summary for Case 11

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1125980.80

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SD	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT
20	4	9520.00	276.31	6.19176		0	4	53642.34	.00	53642.34	53642.34	397.00	
21	8	8610.00	254.60	5.92519		0	0	50055.72	.00	50055.72	103698.06	45.00	
22	11	7690.00	228.48	5.55989		0	0	44672.53	.00	44672.53	148370.58	5.00	
23	12	6770.00	207.47	5.17396		0	0	39494.95	.00	39494.95	187865.53	5.00	
24	6	6550.00	189.23	6.29738		0	0	39851.73	.00	39851.73	227717.26	5.00	
1	6	6330.00	177.13	6.08740		0	0	38392.99	.00	38392.99	266110.25	5.00	
2	7	6230.00	172.79	6.01863		0	0	37747.45	.00	37747.45	303857.70	5.00	
3	7	6220.00	172.34	6.01195		0	0	37680.43	.00	37680.43	341538.12	5.00	
4	6	6480.00	183.33	6.10611		0	0	39320.63	.00	39320.63	380858.75	5.00	
5	10	7410.00	226.48	5.49074		0	0	43123.72	.00	43123.72	423982.46	5.00	
6	7	8610.00	267.30	6.02684		0	0	51605.18	.00	51605.18	475587.64	5.00	
7	2	9470.00	299.02	6.40974		0	0	55984.52	.00	55984.52	531572.16	5.00	
8	1	9630.00	304.35	6.52365		0	0	56797.84	.00	56797.84	588369.99	45.00	
9	1	9710.00	297.47	6.48191		0	0	56225.76	.00	56225.76	644595.75	205.00	
10	2	9760.00	283.60	6.38898		0	0	55334.99	.00	55334.99	699930.74	379.00	
11	5	9590.00	274.48	6.18621		0	0	53334.98	.00	53334.98	753265.72	514.00	
12	5	9520.00	271.12	6.14216		0	0	52869.60	.00	52869.60	806135.31	514.00	
13	5	9620.00	267.27	6.15818		0	0	52984.82	.00	52984.82	859120.12	592.00	
14	4	9690.00	270.71	6.20238		0	0	53453.73	.00	53453.73	912573.84	592.00	
15	5	9680.00	261.87	6.09287		0	0	52510.09	.00	52510.09	965083.93	722.00	
16	5	9740.00	269.31	6.14892		0	0	53244.46	.00	53244.46	1018328.39	672.00	
17	4	9640.00	276.48	6.20703		0	0	53767.28	.00	53767.28	1072095.67	697.00	
18	4	10000.00	287.87	6.21148		0	0	53885.14	.00	53885.14	1125980.80	847.00	

D.12. Commitment Summary for Case 12

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1407999.78

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SU	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT
20	4	12376.00	433.63	6.17011		0	5	68683.75	.00	68683.75	68663.75	.00	
21	1	11193.00	389.02	6.12933		0	15	60763.04	.00	60763.04	129446.79	.00	
22	6	9997.00	347.90	5.67190		0	1	53202.96	.00	53202.96	182649.74	.00	
23	11	8801.00	311.96	5.41348		0	3	46209.75	.00	46209.75	228859.49	.00	
24	11	8515.00	302.91	5.30138		0	0	44573.84	.00	44573.84	273433.33	.00	
1	11	8229.00	293.97	5.21267		0	0	42978.55	.00	42978.55	316411.87	.00	
2	11	8099.00	290.39	5.16797		0	0	42281.50	.00	42281.50	358693.37	.00	
3	11	8086.00	289.92	5.16125		0	0	42182.87	.00	42182.87	400876.25	.00	
4	11	8424.00	300.33	5.27325		0	0	44101.17	.00	44101.17	444977.41	.00	
5	11	9633.00	340.78	5.52370		3	0	50952.01	1114.35	52066.36	497043.78	.00	
6	10	11453.00	396.84	5.69546		13	0	62635.56	4034.00	66669.56	563713.34	.00	
7	5	12311.00	430.81	6.14511		3	0	68242.88	849.00	69091.88	632805.22	.00	
8	3	12519.00	440.04	6.22603		0	0	69659.23	.00	69659.23	702464.45	.00	
9	1	12623.00	444.79	6.26669		0	0	70357.67	.00	70357.67	772822.11	.00	
10	1	12688.00	445.84	6.26669		1	0	70798.72	315.00	71113.72	843935.82	.00	
11	4	12467.00	435.98	6.18187		0	0	69335.72	.00	69335.72	913271.54	.00	
12	5	12376.00	432.09	6.14760		0	0	68730.87	.00	68730.87	982002.41	.00	
13	4	12506.00	437.37	6.19415		0	0	69547.73	.00	69547.73	1051550.12	.00	
14	3	12597.00	441.11	6.22648		0	0	70106.50	.00	70106.50	1121656.61	.00	
15	3	12584.00	441.12	6.22655		0	0	70109.15	.00	70109.15	1191765.75	.00	
16	1	12662.00	444.34	6.25419		0	0	70581.35	.00	70581.35	1262347.09	.00	
17	1	12792.00	449.58	6.29794		1	0	71517.01	245.00	71762.01	1334109.09	.00	
18	1	13000.00	458.36	6.34794		3	0	73071.69	819.00	73890.69	1407999.78	.00	

D.13. Commitment Summary for Case 3 using Fuel Cost Estimation

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1556837.47

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SD	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT
20	4	12376.00	461.79	7.45832		0	2	74485.20	.00	74485.20	74485.20	397.00	
21	5	11193.00	378.42	6.72596		0	10	68016.01	.00	68016.01	142501.21	45.00	
22	9	9997.00	321.61	6.22223		0	6	59617.58	.00	59617.58	202118.79	5.00	
23	12	8801.00	283.23	5.82390		0	0	52179.87	.00	52179.87	254298.66	5.00	
24	4	8515.00	287.24	7.24067		3	0	54129.11	869.25	54998.36	309297.02	5.00	
1	6	8229.00	259.21	6.91985		0	0	51918.78	.00	51918.78	361215.79	5.00	
2	10	8099.00	246.34	6.78577		0	0	50967.73	.00	50967.73	412183.52	5.00	
3	10	8086.00	247.92	6.78041		0	0	50929.97	.00	50929.97	463113.49	5.00	
4	7	8424.00	266.39	6.94386		0	0	53199.96	.00	53199.96	516313.45	5.00	
5	12	9033.00	307.11	6.84082		0	0	57759.03	.00	57759.03	574072.47	5.00	
6	11	11453.00	404.95	6.81900		13	0	70521.50	3352.00	73873.50	647945.96	5.00	
7	1	12311.00	545.70	8.57650		2	0	77356.34	434.00	77790.34	725736.30	5.00	
8	1	12519.00	557.23	11.35380		0	0	79124.89	.00	79124.89	804861.19	45.00	
9	1	12623.00	558.35	10.69448		0	0	78676.58	.00	78676.58	883537.77	205.00	
10	1	12688.00	539.92	8.70970		0	0	77448.63	.00	77448.63	960986.39	579.00	
11	4	12467.00	464.62	7.45582		0	2	74333.84	.00	74333.84	1035320.23	514.00	
12	7	12376.00	448.83	7.26704		0	0	73626.99	.00	73626.99	1108947.20	514.00	
13	5	12506.00	451.67	7.36799		0	0	73959.44	.00	73959.44	1182906.64	592.00	
14	3	12597.00	469.06	7.57139		0	0	74715.39	.00	74715.39	1257622.03	592.00	
15	6	12584.00	426.27	7.17144		0	0	73460.30	.00	73460.30	1331082.33	722.00	
16	3	12662.00	449.79	7.41685		0	0	74449.10	.00	74449.10	1405531.42	672.00	
17	2	12792.00	477.10	7.67428		0	0	75343.50	.00	75343.50	1480874.92	697.00	
18	1	13000.00	497.98	7.81601		0	0	75962.56	.00	75962.56	1556837.47	647.00	

D.14. Commitment Summary for Case 6 using Fuel Cost Estimation

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1035380.56

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SD	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT
20	11	9520.00	339.89	5.47123		0	0	50314.80	.00	50314.80	50314.80	.00	
21	8	8610.00	295.84	5.42945		0	7	44947.81	.00	44947.81	95262.61	.00	
22	5	7690.00	276.65	5.53400		0	6	39472.40	.00	39472.40	134735.01	.00	
23	8	6770.00	259.57	4.89402		0	0	34499.16	.00	34499.16	169234.17	.00	
24	9	6550.00	255.11	4.77275		0	0	33323.40	.00	33323.40	202557.57	.00	
1	10	6330.00	247.93	4.69228		0	0	32170.17	.00	32170.17	234727.74	.00	
2	11	6230.00	244.16	4.66237		0	0	31675.55	.00	31675.55	266403.29	.00	
3	11	6220.00	244.25	4.66273		0	0	31679.98	.00	31679.98	298083.26	.00	
4	10	6480.00	252.58	4.74452		0	0	32931.57	.00	32931.57	331014.83	.00	
5	6	7410.00	272.37	5.19714		0	0	37948.23	.00	37948.23	368963.05	.00	
6	8	8610.00	300.88	5.52410		7	0	46136.25	2539.00	48675.25	417638.30	.00	
7	11	9470.00	339.13	5.43937		6	0	49984.63	2121.00	52105.63	469743.94	.00	
8	10	9630.00	340.77	5.52548		0	0	50967.69	.00	50967.69	520711.62	.00	
9	9	9710.00	341.92	5.56053		0	0	51434.28	.00	51434.28	572145.90	.00	
10	9	9760.00	342.61	5.57916		0	0	51707.44	.00	51707.44	623853.33	.00	
11	11	9590.00	340.39	5.50212		0	0	50693.28	.00	50693.28	674546.60	.00	
12	11	9520.00	339.87	5.47076		0	0	50306.59	.00	50306.59	724853.20	.00	
13	10	9620.00	340.70	5.51967		0	0	50903.70	.00	50903.70	775756.89	.00	
14	9	9690.00	341.57	5.55370		0	0	51330.91	.00	51330.91	827087.80	.00	
15	9	9680.00	341.28	5.54812		0	0	51243.95	.00	51243.95	878331.74	.00	
16	9	9740.00	342.52	5.57239		0	0	51613.20	.00	51613.20	929944.94	.00	
17	9	9840.00	344.56	5.61088		0	0	52204.42	.00	52204.42	982149.35	.00	
18	8	10000.00	348.02	5.67359		0	0	53231.22	.00	53231.22	1035380.56	.00	

D.15. Commitment Summary for Case 9 using Fuel Cost Estimation

SUMMARY OF LOWEST COST COMMITMENT SCHEDULE

TOTAL COST FOR THIS SCHEDULE = 1128053.67

HR	ST	LOAD	LOSSES	LAMBDA	RESERVE	SU	SU	FUEL COST	SU COST	TOTAL COST	PATH COST	HYDRO	CT
20	4	9520.00	276.27	6.19143		0	4	53637.86	.00	53637.86	53637.86	397.00	
21	8	8610.00	254.57	5.92496		0	0	50052.57	.00	50052.57	103690.44	45.00	
22	11	7690.00	228.51	5.55962		0	0	44674.10	.00	44674.10	148364.54	5.00	
23	12	6770.00	207.48	5.17392		0	0	39493.05	.00	39493.05	187857.59	5.00	
24	6	6550.00	189.15	6.29528		0	0	39841.73	.00	39841.73	227699.32	5.00	
1	6	6330.00	177.17	6.08790		0	0	38398.02	.00	38398.02	266097.34	5.00	
2	7	6230.00	172.82	6.01987		0	0	37755.13	.00	37755.13	303852.46	5.00	
3	7	6220.00	172.36	6.01162		0	0	37681.15	.00	37681.15	341533.61	5.00	
4	6	6480.00	183.33	6.10581		0	0	39319.67	.00	39319.67	380853.29	5.00	
5	10	7410.00	226.49	5.49027		0	0	43124.63	.00	43124.63	423977.91	5.00	
6	7	8810.00	267.28	6.02688		0	0	51603.97	.00	51603.97	475581.89	5.00	
7	10	9470.00	299.96	6.13211		8	0	55854.63	2305.00	58159.63	533741.52	5.00	
8	9	9630.00	302.70	6.18833		0	0	56626.58	.00	56626.58	590368.09	45.00	
9	9	9710.00	295.47	6.16030		0	0	56070.52	.00	56070.52	646438.61	205.00	
10	10	9760.00	282.24	6.09885		0	0	55212.66	.00	55212.66	701651.27	379.00	
11	12	9590.00	273.37	6.02343		0	1	53370.24	.00	53370.24	755021.50	514.00	
12	12	9520.00	270.16	5.99453		0	0	52916.70	.00	52916.70	807938.20	514.00	
13	12	9620.00	265.91	6.00195		0	0	53034.18	.00	53034.18	860972.37	592.00	
14	11	9690.00	269.11	6.03073		0	0	53485.07	.00	53485.07	914457.44	592.00	
15	12	9680.00	261.28	5.95000		0	0	52573.90	.00	52573.90	967031.33	722.00	
16	12	9740.00	269.15	5.99531		0	0	53293.81	.00	53293.81	1020325.13	672.00	
17	11	9640.00	276.34	6.03562		0	0	53799.31	.00	53799.31	1074124.44	697.00	
18	11	10000.00	287.96	6.04069		0	0	53929.24	.00	53929.24	1128053.67	647.00	

D.16. Commitment Summary for Case 12 using Fuel Cost Estimation

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