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GENERATION EXPANSION PLANNING USING DECISION TREE TECHNIQUE

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Abstract

This paper presents an efficient technique to solve the problem of generation expansion planning within a reasonable computation burden. The proposed technique is based on the decision tree approach instead of the currently used techniques of mathematical programming. New concepts based on the natural properties of the problem are developed to minimize the computation burden by making the decision tree in the minimal size. The solution technique satisfies the current objectives of strategic planning and is capable of modeling the various uncertainties inherent in the problem of generation expansion planning.

INTRODUCTION

Generation system planning is one of the most crucial steps in the expansion planning of a modern electric utility. Decisions made at this stage have tremendous effect on all other phases of system expansion and dictate the financial posture a utility must assume. The generation planning problem (GPP) aims at determining for each year of the planning horizon the economical type and size of generation plants which should be constructed in order to satisfy a region's forecasted demand for electricity with specified constraints. In broad terms, a suitable generation expansion plan must provide the utility with the capability of meeting customer needs for reasonable price, clean, and reliable quality electric energy source. Choosing a generation expansion plan among many available alternatives is a complicated problem since all utilities must strive for the best strategy in an environment of uncertainty.

The problem of generation planning has been studied extensively using mathematical programming techniques [1-7]. The formulation of the problem in mathematical terms has been widely used by most of the utility planners. This problem was first formulated as a linear program by Masse and others [1]. Although the nonlinear programs [2,3] are more difficult to solve the problem than linear programs, they can take into account all of the primary economic factors involved in the GPP. But their low computational efficiency has required considerable aggregation of the investment decision variables or shortening the planning horizon. Other combinatorial programming methods applied to the GPP are:-

i- the dynamic programming [4,5] which appears suitable for solving problems with random variables up to three or four variables, ii- the branch and bound technique [6] can be used when the number of variables is greater than three and when the objective function is not separable. But the branch and bound process does not fit very well with the stochastic environment.

Also, socioeconomic and environmental developments created a planning environment which requires explicit treatment of uncertainty. Sanghvi [7] presented a mathematical optimization model which can handle the uncertainty and its impact in the key variables by defining a number of possible states that are likely to occur. However, this method is unable to analyze the impact of different states upon the decision variables to produce recommended strategies for each state. Since it provides only one general solution for all states.

The application of network optimization techniques in the generation planning problem is very limited [8]. Most of the problem difficulties such as stochastic nature, nonlinearity and dynamic properties can be faced without any more effort. One of the most suitable techniques for the GPP is the decision tree technique. However, the solution of the problem by the ordinary decision tree results in a large size of branching possibilities which have limited its application to very small problems. Thus, it seems to be a necessity for considerable explicit treatment of uncertainty and development for the decision tree technique to be applicable for practical problems of generation expansion planning.

This paper presents an efficient technique based on the decision tree approach to solve the problem of generation planning and generate a variety of recommended solutions (strategies) under different circumstances and uncertain events. New concepts based on the natural properties of the problem are developed to minimize the computation burden by minimizing the size of the decision tree.

DECISION TREE CONCEPT

The effect of uncertainty is of prime importance in planning problem. The impact of uncertainty can be captured in the key variables by defining a number of possible states that are likely to occur. A state completely defines the load growth outcome, fuel supply levels, weather conditions that defines the power output profiles of renewable technologies, fuel prices, general inflation, capital cost of new constructions, interest rates, construction lead times, rate relief and any other exogenous variables outcome that are treated as uncertain in the analysis. Each exogenous variable (random variable) can be represented by its probability distribution. Throughout the planning period, any one of the K different states can occur with probabilities Pr(1), Pr(2), ..., Pr(K), respectively, and these states are indexed so that; $Pr(1) > Pr(2) > .... > Pr(K)$. Thus, the first state is more expected to occur than the second state. And in turn, the first state must be given more attention.

All the decision variables of the generation planning process can be modeled in a decision tree which displays the different available decisions in each year in order to select the best sequence of decisions to be made over the planning horizon. A decision tree is a graph with the following characteristics;

1)- The tree contains exactly one node that does not have a parent.
2)- Every other node in the tree is a dependent of the root node.

3)- Every other node in the tree has exactly one parent.

The root node represents the existing generating system at year t=0 before any expansion. The successors to the root node are placed immediately below it, and arcs are drawn from the root node to each of the successors. The root node and its successors are known as the "top nodes" of the tree. The process is then repeated for each of the successors to the root node. The purpose of a decision tree is to represent separately each of the possible paths through the state space of the planning process; that is a sequence of decision nodes. The expansion or generation of a planning tree terminates with those decision variables that do not have successors; a terminal node in a decision tree is often referred to as a tip node. Each decision variable is denoted by D (i,j,..,m,n) where the integer variable to the right represent the index the decision family of the considered decision and the adjacent variables (from right to left) represents the

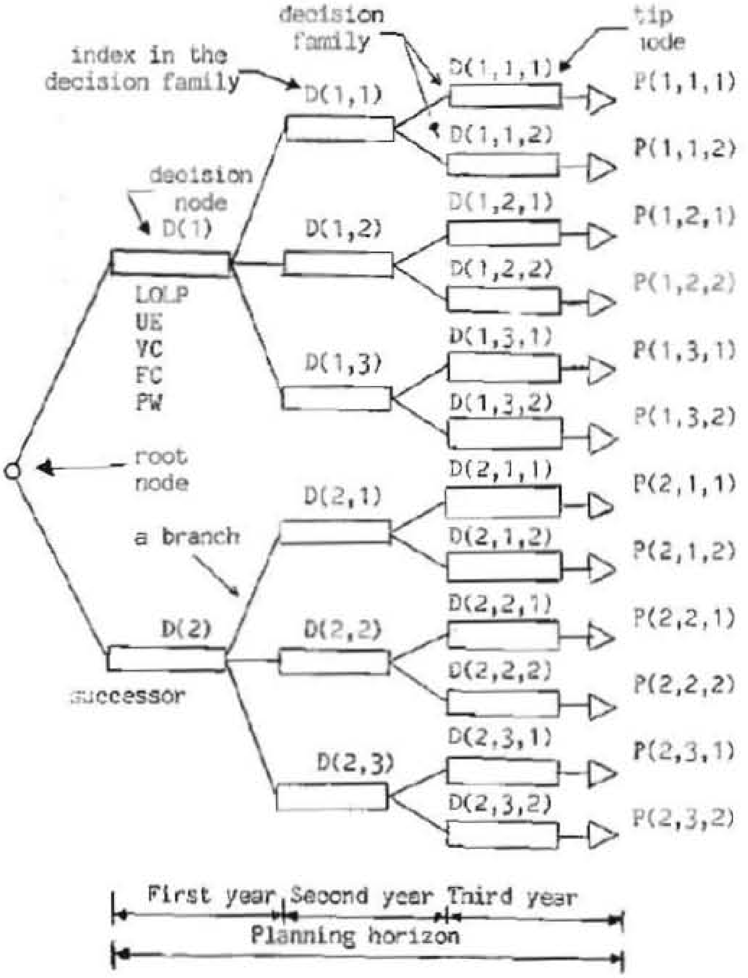

Fig.1 Decision tree of three years planning horizon

successors which have been made (descendant of the root node). The number of variables is an indication to the year at which the decision has been taken in the tree. In this manner each decision variable is uniquely defined in the tree. Also each path in the tree can be denoted by $P_k(i,j,..,m,n)$. This path includes the decision $D_k(i,j,..,m,n)$ and all parent decisions. To treat the uncertainty, the decision tree is subjected to each state k where $k = 1, \ldots, K$. Fig.(1) shows a decision tree subjected to a state k (a scenario) which represents the generation planning decision variables (planning state space) for a look ahead period of 3 years. The decision attributes (criteria of merits) which is located under the decision node are calculated using different models described in the next section.

The major advantage of the decision tree is the insights that can be gained through the planning process. These insights include the identification of alternative strategies, analysis called for to aid each decision, critical uncertainties and decision variables, timing of commitment (decision) points and data, and hedging strategies against uncertainties.

Sensitivity analysis is an important study in the planning process under uncertainty. There are two measures that have a great concern in the sensitivity analysis. These two measures are flexibility and robustness. They are difficult to quantify. Flexibility implies a low cost for changing a plan in response to changes in the underlying uncertainties. This can be measured by comparing the behaviors of the decision and attribute variables associated with a certain path under two states having a conflict difference in their exogenous variables. Robustness implies that a plan does not need to be modified over some reasonable range of uncertainties. This can be measured by comparing the behaviors of the decision and attribute variables associated with a certain path under two states having a reasonable difference in their exogenous variables.

MODELING THE CRITERIA OF MERITS

(Attribute Calculations)

The investment decision patterns and qualities of realized plans are affected by many factors such as the cost of expected power generation, system reliability, finance, and demand forecast. These factors constitute the criteria of merits in the generation planning.

Simulation model of the generation system

The simulation model provides the planner with a probabilistic method of evaluating the major factors related to the production cost and reliability of the generation system. This model uses the probabilistic production costing techniques [9,10] and the method of cumulants [11,12] to simulate the effects of generating units forced outages. The model performs the dispatch under upper and lower limitations on fuel usage as set by the planner. The simulation model consists of two stages. In the first stage, the load curves should be modified to simulate the operation of the non-thermal resources (hydro, pumped storage, wind, solar). Thus, the annual thermal load duration curve can be obtained. In the second stage, the expected generation of the thermal units within the year can be simulated by the probabilistic convolution technique [13,14]. The outputs of this stage are the expected generation of each unit and the two indices of system reliability (the loss of load probability (LOLP) and the expected unserved energy (UE)). Using these reliability indices, the planner can easily check that they are not outside the boundaries of the reliability constraint.

The Cost Model

The cost model provides the planner with a method of readily comparing and evaluating generation alternatives by incorporating the relevant capital costs with the estimated variable costs. Also, it allows to examine and analyze the financial implications of an individual project or an entire construction program. To evaluate the total present value associated with, a particular expansion plan, the cost components to be considered for the overall expansion plan are the fixed (capacity) cost, the variable (production) cost, and the reliability (unserved energy) cost.

The cost of a new generating plant comes from new financing through the sale of bonds and debentures referred to as debt financing and from the sale of common and preferred stock, referred to as equity financing. The return (the money that the utility must pay for the use of both debt and equity money) is allowed as a revenue requirement for rate-making purposes and is a part of the fixed cost associated with an investment. The other components of the fixed cost which are calculated through the service life period include book depreciation, federal and local income taxes, property taxes, and insurance.
The fixed cost of unit i in year t is simply given by;

$$FC_i(t) = FCR_i * UC_i * IC_i \quad \$ \qquad --- (1)$$

where FCR_i is the levelized fixed charge rate of unit i, which is calculated by considering the interest rate, capital recovery factor, debt repayment, equity return, depreciation, income taxes, property taxes, insurance, etc.:

UC_i is the unit cost of unit i ($/MW),

IC_i is the unit installed capacity (MW).

The system annual fixed cost in year t associated with a decision $D(i,j,..,m,n)$ is given as;

$$FC[D(i,j,..,m,n)] = FC[D(i,j,..,m)] + \sum_{i=1}^{I} FC_i(t) \quad \$ \qquad --- (2)$$

Where, I is the number of new units added to the system in year t associated with the decision $D(i,j,..,m,n)$.

The production cost of unit i in year t is simply given by:-

$$PC_i(t) = FF_i(t) + OM_i(t) + SS_i(t) \quad \$ \qquad --- (3)$$

where, $FF_i(t)$ is the fuel cost of unit i in year t ($),

$OM_i(t)$ is the operating and maintenance cost of unit i in year t ($),

$SS_i(t)$ is the other variable costs (supplies, taxes, supervision, ... etc.) of unit i in year t ($).

These later three terms depend mainly on the expected energy generated from unit i and they are calculated using the simulation model. The system annual variable cost in year t associated with decision D(i,j,..,m,n) is given by;

$$VC[D(i,j,..,m,n)] = \sum_{i=1}^{I} PC_i(t) \quad \$ \qquad --- (4)$$

where, I is the number of units existed in year t associated with the decision D(i,j,..,m,n).

The third component of the cost is the reliability cost of power shortfalls that might result under states characterized by unexpected high loads e.g., unduly high demands for back-up electricity by solar heating and cooling customers, and/or low power output of solar generators -- or due to a major fuel supply disruptions. The system annual reliability cost in year t associated with decision D(i,j,..,m,n) is given by ;

$$UEC[D(i,j,..,m,n)]=UE[D(i,j,..,m,n)]* UEF(t) \quad \$ \qquad --- (5)$$

Where, UE[D(i,j,..,m,n)] is the system annual unserved energy calculated using the simulation model with considering the decision D(i,j,..,m,n) in year t,

UEF(t) is the cost of MWH of unserved energy ($)

The system annual total cost in year t associated with decision D(i,j,..,m,n) is given by;

$$ATC[D(i,j,..,m,n)]=FC[D(i,j,..,m,n)]+VC[D(i,j,..,m,N)] +UEC[D(i,j,..,m,n)] \quad \$ \qquad --- (6)$$

The system annual present worth in year t associated with decision D(i,j,..,m,n) is given by;

$$PW[D(i,j,..,m,n)]=PWF(t) * ATC[D(i,j,..,m,n)] \quad \$ \qquad --- (7)$$

Where, PWF(t) is the present worth factor of year t.

Then the total present worth for the system over a period from year t=1 through year t=T associated with a path P(i,j,..,m,n) is the sum of the system present worth associated with the decisions included in this path and is given by;

$$Z[P(i,j,..,m,n)] = PW[D(i)] + PW[D(i,j)] + ... + PW[D(i,j,..,m)]+PW[D(i,j,..,m,n)] \quad \$ \qquad --- (8)$$

Financial Model

The financial model provides the planner with the financial information required to answer the following question: can the utility fund the expansion program with no cash flow deficit? i.e. is an expansion alternative financially infeasible?

Through the construction period of each generating plant, the main items calculated are capital expenditure, construction work in progress (CWIP), allowance for funds used during construction (AFUDC), and investment tax credit (ITC). Also, the model assists the planner to do financial planning at the level of the individual generating plant and obtain the analysis of internal versus external financing for each generating plant by the parent utility.

For the entire utility, the model considers construction expenditures, revenue requirements, generation and non generation costs, taxes, and financing alternatives to analyze the impact of a given strategy. In response to the need to achieve a given level of cash, the model performs both long term and short term financing either according to specified criteria or according to user-supplied information regarding the amount and timing of specific financial instruments. Also, the model calculates the necessary incremental rate relief to achieve the required rate of return on total capital, rate base, or common equity as specified by the planner.

Thus, the financial model allows the strategic planner to simulate the effects of various construction programs, generation plans, cost and inflation scenarios, capital market conditions, and acquisition alternatives on the consolidated financial operation of utility.

MINIMIZATION OF THE DECISION TREE

Even though a computer program cannot usually generate the entire decision tree below a given node, it can still generate a portion of that tree. In most of the possible situations (nodes in the state space) that might occur in the planning process, for example, the average decision variable node may have six successors, but of these six perhaps only three would be considered "reasonable" by a human expertise. If a program could be designed to select the alternative below its current situation with the highest reasonable evaluation, it would still be able to execute the planning process in a reasonable size. In order to generate and analyze a portion of the reasonable decision tree below a given node, it is necessary to judge the "reasonableness" of nodes in some way that is not dependent upon having judged many of their successor nodes. A static evaluation function is a method for estimating the value of a node which is not dependent on the values of the successors to the node. Elsewhere, a dynamic evaluation is required.

The major purpose of this section is simply to generate a reasonable portion of the complete decision tree below a given node, this is in contrast to its purpose in making sure that the generated portion is plausibly ordered. A proposed decision tree procedure uses forward pruning when it decide not to continue generating successors of a node that might otherwise be considered. Thus, we propose guiding rules utilizing the experience in this field and the knowledge about the nature of the problem, to help in deciding early which of the available decision variables are inevitably inferior to the others and thus can be pruned or terminated. And then, the decision tree is reduced to a minimum size. In broad terms, these rules direct the search in the planning process to achieve quickly the desired objectives.

Rule 1 Rejection of the infeasible decision variables

The feasible decision variables are those which satisfy the problem constraints such as reliability, financial, and environmental constraints. The decision variable which do not satisfy these constraints is said to be infeasible and can be pruned.

The system reliability as an attribute, which is evaluated by the two reliability indices LOLP and UE, associated with a certain decision variable is determined using the simulation model.
Let α and β are the LOLP and the unserved energy levels imposed by the utility planner, respectively.

Thus , for a decision $D(i,j,..,n,m)$ in year t;

if $\quad LOLP[D(i,j,..,n,m)] \geq \alpha$

and/or $\quad UE[D(i,j,..,n,m)] \geq \beta$

Then, decision $D(i,j,..,n,m)$ is reliability infeasible and can be pruned. The system financial statement, which is affected by the financial impact variables such as dividend pay out, new financing required, rate relief required, and interest coverage, associated with a certain decision variable is determined using the financial model. Thus, if these are out of the allowable boundaries and/or their impacts cause a cash flow deficit, then this decision is financially infeasible and can be pruned.

The system environmental impact variables, such as air quality, water quality, sludge production, ash production, and noise, associated with a certain decision variable are determined using an environmental model. Thus, if each of these variables is greater than the standard level imposed by the utility planner, then this decision is environmental infeasible and can be pruned.

Rule 2 Termination of the uneconomical paths

The search routine through the decision tree is directed to select the series of decision variables which are feasible and cost effective. The economical decision variables are those which achieve the objective of minimum total present worth over the planning horizon. These decisions construct the optimal path. To judge that a certain path is cost effective, there is a need to a relative comparison with another path. Also, to minimize the size of the decision tree, it is required to identify which path in certain year would be the most economical one w.r.t. the overall plan. Actually, this is not possible in the practical problems because, for example, as each new generating unit is added to a system, it has the potential for modifying the cost components (variable and fixed). But there is a possibility to know which path is the cost effective one in each subplan terminated at each specified year. This path can be defined as the suboptimal path for each subplan. There is a possibility to determine when each suboptimal path becomes uneconomical path in the future. So, a reference path can be taken into consideration in parallel with each suboptimal path to know whether it remains suboptimal or not in the future years by making economical comparison between the total present worth and the cost components associated with the suboptimal path and those associated with the reference. If we are in the start of the planning process, the first path in the tree is considered as the suboptimal path and the reference path is the next path where all paths of the tree are indexed from right to left.

Consider we have the two paths $P(i,j, \ ..,m,n)$ and $P(m,i, \ ..,n,1)$ in year t where;

$$Z[P(i,j,..,m,n)] \leq Z[P(m,i,..,n,1)]$$

Then, P(i,j,..,m,n) and P(m,i,..,n,1) are considered as the suboptimal path and the reference path respectively. Now, let F(t) be the difference between the total present worth associated with P(m,i,..,n,1) and that associated with P(i,j,..,m,n) in year t as;

$$F(t) = Z[P(m,i,\dots,n,1)] - Z[P(i,j,\dots,m,n)]$$

Comparing between the total present worth associated with these two paths, one of the following conditions may occur:-

1) If the difference increases annually as;

$$F(t) \leqslant F(t+1) \leqslant F(t+2) \leqslant \dots$$

Then, there is no chance for the reference path to be economically effective and thus can be terminated. This condition may occur when the reference path composes generating system which includes generating units of higher fuel prices or higher capital costs. And in turn, the next path can be considered as a new reference path.

2) If the difference decreases annually as,

$$F(t) \geqslant F(t+1) \geqslant F(t+2) \geqslant \dots.$$

Then, a break even point will be obtained and after this point the reference path will be economically effective than the suboptimal path. Therefore, the suboptimal path can be terminated, and hence the reference path can be considered as the new suboptimal path and the next path can be considered as a new reference path.

3) If the difference alters annually, then, neither of these two paths can be terminated until the end of the planning period. The path which is not terminated can be considered as the suboptimal path and the next path can be considered as the reference path.

Selection of the most economical path from the equivalent paths

In the decision tree of generation planning, there is a possibility to select the most economical path from those which are characterized as equivalent paths. Two paths are equivalent if they have at the end of each path the same criteria of merits (installed capacity, annual variable cost and reliability indices). Actually, each of the equivalent paths contains the same system of generating units. Each system of generating units is added to the utility in different sequences. The contribution of each equivalent path to the system installed capacity, total variable cost and the system reliability indices will be equal during the next period of planning horizon. Therefore, an economical comparison among these equivalent paths with a static look ahead at the end of each path is quite enough to decide which path will be economically effective in the end of the planning horizon instead of using dynamic look ahead for the remaining horizon in the plan.

For the two equivalent paths P(..,i,m,n) and P(..,i,n,m), there are only two possible conditions:-

a) The first condition yields;

and,
$$FC[D(..,i,m,n)] \geq FC[D(..,i,n,m)]$$
$$Z[P(..,i,m,n)] \geq Z[P(..,i,n,m)]$$

This means that the difference in total present worth of these two equivalent paths increases annually. And in turn, there is no possibility that the path P(..,i,m,n) can produce less total present worth than the path P(..,i,n,m). Then, path P(..,i,m,n) can be terminated from the search routine.

(b) The second condition yields:

$$FC[D(..,i,m,n)] \leq FC[D(..,i,n,m)]$$
and,
$$Z[P(..,i,m,n)] \geq Z[P(..,i,n,m)]$$

This means that the difference between the total present worth of these two equivalent paths decreases annually and in turn the path P(..,i,n,m) which is economically effective in this year will not remain so after some years in the future and thus it must be called for the situation at the end of the planning horizon as;

$$F_{nm}(T) = F_{nm}(t) - USPWF(T-t) * B_{mn}(t)$$

Where,

T is the number of years of the planning period ,

USPWF(T-t) is the uniform series present worth factor of the interval(T-t), which is given by;

$$USPWF = \frac{1-(1+i)^{(T-t)}}{i(1+i)^{(T-t)}}$$

$$B_{mn}(t) = FC[D(..,i,n,m) - FC[D(..,i,m,n)],$$

i is the interest rate.

Then, if $F_{nm}(T)$ is +ve. value, path P(..,i,m,n) can be terminated. But if $F_{nm}(T)$ is -ve. or zero value, path P(..,i,n,m) can be terminated.

SOLUTION TECHNIQUE

The solution of the generation expansion planning problem requires an explicit treatment of the uncertainty. So, all possible states that may occur through the planning period are defined using the forecasted exogenous variables. For each state k (k = 1, .. , K) the decision tree is analyzed path by path using the planning models (simulation model, cost model, financial model, ... etc.). Throughout the analysis of each path the rules of minimum size tree can be applied in order to generate only the feasible and economically attractive path. Once a path is generated, it can be added to a priority list. The priority list contains the best M paths arranged with ascending total present worth. The value of M is a programmer judging (10-20) to obtain a compromise between the solution speed and accuracy.

To produce a global solution which is satisfactory for all states, we must calculate the sum of multiplying the attribute variables associated with a path j under certain state by the probability of that state. Thus the global optimal solution can be obtained and also a variety of paths (plans) can be generated and recommended with respect to all states. The proposed technique develops the decision tree concept to act as an expert system applicable for solving the generation planning problem. This expert system consists of;

1) A knowledge base (or knowledge source) of domain facts and heuristics associated with the generation planning problem.
2) An inference procedure (or control structure) for utilizing the knowledge base in the solution of the generation planning problem.
3) A working memory (or global data base) for keeping track of the problem status, the input data for the particular problem, and the relevant history of what has been done.

APPLICATIONS

Test system

As an example, consider the generation planning for a system based on the EPRI Synthetic Utility "D" [15] which currently has 52 existing units, described in table 1. The planning horizon is nine years beginning in 1990. Future installation costs escalate at an annual rate of 6%, and fuel costs at 7% for uranium, 6.1% for coal-derived liquids, 6.7% for coal, and 7.4% for oil. The emergency energy cost is 250 $/MWh with an annual growth rate of 13%. A discount rate of 15% is used in computing present values. Table 1 gives three types of alternative units which are available for installation in each year, a light water nuclear reactor, an oil burning combined cycle unit, and a combustion turbine burning coal-derived liquids. Table 2 shows the forecasted load data. Costs are based on projections for 1985 escalated to the beginning of the planning horizon.

Description of scenarios

The planning process is designed to explore alternative courses of action that could avoid the effect of the future uncertain events. Calculations of the financial impacts on the utility from that events and the potential alternatives are necessary inputs to the decision making process. Four different events (scenarios) are analyzed:-

1- Normal operation of all units.
2- 50% derate of a base unit, 600 MW coal unit, beginning in 1993.
3- Normal fuel supply.
4- 10% oil disruption beginning in 1994.

In the first case, it is assumed that all permits and license amendments are received in time to allow normal operation. Scenario 2 depicts the case where it is apparent that a required modifications in the unit cannot be completed on time and the unit are derated to extend the shut down date. In the third event, it is assumed that all required amounts of fuel are available and there is enough stock. Scenario 4 addresses the financial impact on the utility from a 10% oil disruption beginning in 1994.

Sensitivities

As it is for any study, the results are valid only to the extent that reasonable assumptions are made. The total number of model runs to fully quantify the range of uncertainty in the input assumptions is equal to the number of possible states that may occur. The input load assumptions are selected to test the sensitivity of the results to changes in these assumptions. The selections are made based on the anticipated sensitivity to changes in these assumptions and because of the degree of uncertainty

Table 1 Significant input unit data

Type	Size (MW)	Capital ($/KWH)	Operating Cost (MILLS/KWH)	Forced Outage Rate %
Committed and existing units				
Nuclear (total, 2 units)	1200 (2400)	-	10.41	14.9
Coal (total, 12 units)	600-200 (3600)	-	17.88-18.93	15.5-8.1
Oil (total, 9 units)	800-200 (2600)	-	45.68-49.29	17.6-8.1
Combustion Turbine (total, 29 units)	50 (1450)	-	61.57	10.5
Candidate units, available each year				
Nuclear	1000	1818	10.41	14.9
Combined Cycle	300	764	38.31	10.0
Combustion Turbine	100	453	62.22	10.5

Table 2 Significant input load data

Forecast	Year	Hi Range	Mid Range	Low Range
Energy (GWH)	1990	43000	43000	43000
	1994	52316	51071	49849
	1998	61202	58604	56104
Peak Demand (MW)	1990	8250	8250	8250
	1994	10037	9798	9564
	1998	11742	11243	10765

associated with each one. A description of each model run, for each state k (k = 1, ..., 12), is contained in table 3.

Results

The present worth is selected as a financial parameter to analyze the potential impact of the various scenarios. The total present worth is selected because it represents the prime objective. The significant output results are presented in tables 4 and 5. Table 4 shows the associated

Table 3 Description of model runs

Run	State k	Prob. P(k)	Energy Forecast	Oil Supply	600 MW Coal unit Operation
1	1	0.363	Mid.	Normal	Normal
2	2	0.120	Mid.	Normal	50% derate '93
3	3	0.074	Mid.	90% N. '94	Normal
4	4	0.040	Mid.	90% N. '94	50% derate '93
5	5	0.154	Hi.	Normal	Normal
6	6	0.051	Hi.	Normal	50% derate '93
7	7	0.031	Hi.	90% N. '94	Normal
8	8	0.010	Hi.	90% N. '94	50% derate '93
9	9	0.099	Lo.	Normal	Normal
10	10	0.032	Lo.	Normal	50% derate '93
11	11	0.020	Lo.	90% N. '94	Normal
12	12	0.006	Lo.	90% N. '94	50% derate '93

capacity added with the optimal solution (plan) of each state where A is the light water nuclear reactor of 1000 MW, B is the oil burning combined cycle of 300 MW, and C is the combustion turbine burning combined cycle of 100 MW. The table shows for each optimal plan the associated total added capacity (TAC) in MW and the total present worth (Z) in million $. Also the table shows the associated capacity added with the global optimal solution and the associated weighted total present worth.

Each potential plan is subjected to a sensitivity analysis and recommended with respect to the two sensitivity measures, robustness and flexibility. Table 5 shows a sensitivity analysis of the global optimal plan where the annual present worth (PW) and the total present worth in all scenarios are analyzed. From the analysis of this plan, it is recommended as a highly flexible and robustness plan because:-

- there is no noticeable change in the capacity added when it moves from state to another state,
- the relative changes in the total present worth seems to be little with respect to the total present worth associated with the optimal plan of each state. Also, it is recommended as an optimal solution under state No. 6 (table 4) and as a near optimal solution under the states 2, 3, 4, 7 and 11.

Table 5 shows the impact of each state on the present worth associated with the global optimum plan. Under the medium range of energy forecasting, there is a 1.75% increase in the total present worth due to the 50% derating of the 600 MW coal unit beginning in 1993.

CONCLUSIONS

This paper presents a proposed technique suitable for the problem of generation expansion planning. This technique is based on the decision tree concept and has the following advantages:-

- It has sufficient robustness, where the uncertainty can be modeled by defining a number of possible states that are likely to occur.
- It allows for the human decision making and hence makes use of the planner experience and the management guidance in the planning process.

Table 4 The optimum generation plan in each state and the global optimum solution.

YEAR	THE CAPACITY INSTALLED FOR THE OPTIMUM PLAN IN EACH STATE																																						
	State No. 1			State No. 2			State No. 3			State No. 4			State No. 5			State No. 6			State No. 7			State No. 8			State No. 9			State No.10			State No.11			State No.12			Global Solution		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1990	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1992	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	2	1	0	0	0	0	2	1	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
1994	0	0	1	0	1	0	0	1	1	0	1	2	0	0	2	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	2	0	0	2	1	0	0
1995	1	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	2	0	0	2	0	0	2	0	1	0	0	0	2	0	0	0
1996	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	2	1	0	0	0	1	0
1997	0	0	2	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	1	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
1998	0	1	1	0	0	2	0	0	2	0	1	0	0	1	1	0	1	1	0	1	2	0	1	2	0	0	1	0	0	1	0	1	1	0	0	1	0	1	1
TAC	3700			3900			3900			4100			4100			4100			4400			4600			3300			3500			3400			3700			4100		
Z	8109.32			8331.26			8192.88			8364.87			8343.27			8522.70			8398.22			8560.35			7893.72			8063.28			8045.43			8107.02			8242.80		

Table 5 The cost analysis of the global optimum solution.

YEAR	THE PRESENT WORTH ASSOCIATED WITH THE GLOBAL OPTIMUM SOLUTION THROUGH THE PLANNING HORIZON												WEIGHTED PRESENT WORTH
	State No. 1 PW	State No. 2 PW	State No. 3 PW	State No. 4 PW	State No. 5 PW	State No. 6 PW	State No. 7 PW	State No. 8 PW	State No. 9 PW	State No. 10 PW	State No. 11 PW	State No. 12 PW	
1990	997.78	997.78	997.78	997.78	997.78	997.78	997.78	997.78	997.78	997.78	997.78	997.78	997.78
1991	964.36	964.36	964.36	964.36	971.31	971.31	971.31	971.31	957.07	957.07	957.07	957.07	962.01
1992	977.29	977.29	977.29	977.29	988.88	988.88	988.88	988.88	966.65	966.65	966.65	966.65	975.50
1993	931.30	961.50	931.30	961.50	949.45	980.82	949.45	980.82	913.55	942.14	913.55	942.14	938.00
1994	945.84	962.88	947.16	971.81	965.27	983.66	966.88	986.03	927.80	943.40	928.79	944.83	949.97
1995	890.23	910.21	892.19	919.65	914.95	936.27	917.49	945.06	868.16	884.57	874.51	886.59	902.80
1996	858.19	883.05	860.00	887.31	887.93	910.88	892.23	919.18	830.20	848.05	836.38	849.81	865.26
1997	828.12	854.22	829.85	858.14	864.51	886.81	868.61	895.12	795.90	813.70	801.94	815.25	836.37
1998	801.18	826.51	802.81	830.36	842.24	866.29	850.79	879.60	763.29	782.02	774.20	783.34	815.18
Z	8194.30	8337.80	8202.80	8468.20	8382.30	8522.70	8403.40	8564.40	8020.40	8135.40	8050.90	8143.50	8242.80

- It has the capability to deal with the practical generation planning problems and develops empirical rules to minimize the size of the tree and thus directs the search for obtaining the required solution quickly.
- With the advantage of minimum size tree with little computational efforts, the planner has the capability to extend the planning horizon, use a large candidate list, and/or develop much of scenarios and plans.
- It is able to handle and integrate the output from a wide variety of models such as the simulation model, cost model, financial model, .. etc.
- It provides the planner with the capability to recommend a variety of generated plans where some of which are satisfactory under certain states and others are satisfactory for all states. also, the more probable state may take more attention in the analysis and in turn its solution.

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