Integrated Power System Planning

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Abstract – **This paper discusses the Integrated Resource Planning as a decision-making framework in the context of electricity generation capacity addition planning. Multicriteria decision-making methods allow comparing different alternatives and constructively discussing the trade-off associated with any one decision. A case study examining the future role of natural gas as an important fuel for the Macedonian electric system.**

Keywords – **Integrated resource planning, multiple criteria, decision analysis, uncertainty, risk**

I. Introduction

One of the basic objectives of power system planning is to determine an investment schedule for the construction of generation plants and interconnection links which ensure an economic and reliable supply to the predicted demand over a planning horizon. The criteria are to minimize the total cost and maximize the reliability with different type of constraints. The total cost has two basic components: the investment cost given by construction cost of generating units and interconnection links; and the operating cost associated to the fuel cost of the thermal system units.

The standard approach in the investment planning model is to formulate an operating and investment cost minimization problem subject to a demand constraint. This problem was first solved using linear programming, but recent applications have relied on dynamic programming and other approaches. Probabilistic analysis tools such as production costing and reliability evaluation are now widely used by utilities in their planning and operating studies. The implementation of these probabilistic tools has been an important step toward the incorporation of some type of uncertainty (equipment availability, load variation) into planning activities.

However, several other sources of uncertainty which may have an important impact on future supply conditions are still represented as deterministic parameters in most planning studies (load growth rates; fuel costs ; financial constraints; environmental constraints; interest rate; construction time). It becomes necessary to introduce in the decision making process a systematic and consistent treatment of these sources of uncertainty.

Minimizing cost for the most likely realization of uncertain parameters without considering risk, does not provide adequate bases for decision-making. Many things are uncertain during real decision making process. The degree of uncertainty may vary, ranging from items showing stochastic behavior within a known probability distribution to those exhibiting apparently chaotic behavior. Magnitudes may be known but not frequency or timing. Uncertainty imposes risk and each type of uncertainty has different implication for decision makers and analysts.

Risk management and evaluating of risk management strategies is now an important part of the integrated resource planning process.

Therefore, to provide adequate support in decision making, a planning tool need has the following characteristics:

- ability to considered strategies that minimize risk in the presence of various type of uncertainties;
- accurate modeling of hydro uncertainties;
- consideration of demand side management options (conservation and load management) as alternatives to building additional capacity;
- evaluation of convenience of interconnections and power purchases from other power producers;
- analysis of the financial viability of the expansion plan;
- information on environmental impacts;

II. Generation Expansion Planning Problem

As discussed in the Introduction, the objective in the traditional least cost planning model is the total present worth of investment and operation costs subject to various types of constraints: hydro energy availability, investment availability, capacity constraint, meeting demand, emissions targets and etc. The determination of this optimal expansion plan can be formulated as the following optimization problem:

$$B = \min \sum_{i=1}^{T} \left[a_t(u_t) + b_t(x_t) - c_t(u_t) \right] \qquad (1)$$

subject to

$$x_t = x_{t-1} + u_t$$
$$LOLP(x_t) \le \varepsilon$$
$$o \le u_t \le \overline{u_t}$$
$$t = 1,.....,T$$

where,

x_t - cumulative capacity vector of plant types in year t,

u_t - capacity addition vector of candidate types,

$\overline{u_t}$ - maximum construction capability vector of candidate types,

$LOLP(x_t)$ - loss of load probability associated with x_t ,

ε - reliability criteria of LOLP,

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$a_t(u_t)$ - discounted construction costs associated with capacity addition u_t,

$a_t(u_t)$ - discounted fuel and O&M costs associated with x_t

$a_t(u_t)$ - discounted salvage value associated with capacity addition u_t,

In formulation (1) we assume that the problem parameters are constant values i.e. that they are known with certainty. In this case, the optimal solution of problem (1) is indeed the most adequate expansion plan. However, as discussed in Introduction, there is a great uncertainty with influence on optimal solution. The solution approaches can be classified under the following categories:

- deterministic optimization
- scenarios
- stochastic optimization

In the deterministic approach, the expansion plan is based on the best available forecasts and take the optimal investment decision associated to the first stage of this plan (for example, the current year). This approach does not necessarily lead to the most adequate expansion strategy because an investment decision for the current stage is optimal under the assumption that the future conditions will occur as predicted.

In scenario approach, system performance is evaluated for different scenarios obtaining a set of solution. Based on this set, several analysis are carried out. The effects of uncertainties than may be tested by using the sensitivity analysis. The primary analytical effort is devoted to specifying a detailed, most probable base case. Then changes-one variable at a time relative to the base case-can show the sensitivity of the results to changes in inputs. Sensitivity analysis tests robustness in a crude way: if changed input changes the optimal plan, then the plan is not robust. This helps in understanding the vulnerabilities of a favored plan, but it does not allow easy comparisons across a range of risk management strategies. Unlike sensitivity analysis that changes only one variable at a time relative to a base case, scenario analysis constructs several different internally consistent futures and identifies optimal and near-optimal plans for each of them. Robust elements are those included in most of the optimal plan generated for the range of scenarios.

The stochastic optimization approach recognizes explicitly that the objective is to determine a unique expansion plan that is optimal "on the average" for all scenarios. The stochastic optimization has the potential to represent various sources of uncertainty. Its major limitation is related to computational effort, because it involves the solution of an optimization problem which is much more complex than the other approach.

III. INTEGRATED RESOURCE PLANNING

Integrated Resource Planning (IRP) is a contemporary approach to evolve strategies toward electric utility planning for future energy requirements. IRP strategies enable relevant cost analysis, optimizing its effectiveness, as well as they include considerations as regard to the benefits of the entire supply-side and demand-side options. They also take into consideration the financial integrity, size and physical capability, as well as those factors of the utility company, which have impact on the consumer, the environment, culture, community life style, the state's economy and upon the society as a whole.

Integrated Resource Planning requires, by its nature, a multi player analytic framework. IRP can be defined as a process that attempts to find an optimal combination of supply-side and demand-side measures to meet energy needs within an electric utility's service territory. Supply-side options can range from new generation plant construction to bulk power purchases and transmission efficiency improvements. Demand-side management (DSM) include utility programs that encourage more efficient energy use, trim or shift peak loads, encourage demand during off-peak periods.

A number of comprehensive IRP models for optimizing supply and demand-side options have been applied by electric utilities. The purpose of these models is to allow users to efficiently sort through a large number of options. There are at least two major classes of optimization-based IRP models: 1. Mathematical programming-based IRP models define decision variables for the capacity of new supply sources and the amount of DSM. The optimal rules of these variables are obtained by efficient numerical algorithms. 2. Dynamic programming and decision tree-based model enumerate a set of discrete options whose performance is assessed by the financial and production costing modules.

In IRP models, an "optimal" plan is most typically defined as one that "least cost": the combination of resources that minimizes the cost to utility or society of meeting demands for energy services. Like any optimized model, IRP model include an objective function to be optimized (cost), decision variables whose values are to be solved for (generator output, DSM program implementation) and a set of technologic and economic constraints that must be respect (generation must meet demand, generator output cannot exceed capacity).

The framework and methodology presented in this paper accepts the reality that there is no optimal solution, in that the future is essentially unknowable. For these reason the framework is based on the comparative analysis of multiple scenarios concerning alternative futures. The framework allows the resource planner to utilize existing accepted planning and financial tools to develop the information upon which the trade-off analysis is based. High speed and inexpensive computational capabilities make the generation and evaluation of multiple scenarios possible. In this analysis the WASP III Plus was used as the core production-cost simulation model. Used in conjunction with other analytic methods, a wide range of options and uncertainties can be evaluated.

By evaluating how different supply strategies perform under a variety of possible futures, robust strategies can be identified. Capacity expansion strategies are evaluated against a range of possible changes in electric demand, fuel prices, fuel availability. The comparative performance of various strategies over the range of possible future events identifies the most robust or least vulnerable strategies with respect to price, reliability, environmental emissions and other important measures.

Integrated Resource Planning method combining a set of controllable choices, called options, with a set of uncontrollable events called uncertainties, which together form scenarios. These individual scenarios are then evaluated and their attributes, or measures of value, tabulated. The resulting sets of attributes are than compared using trade-off analysis to identify which strategies are clearly dominated by others. These dominated strategies can then be eliminated from further consideration. In addition, it is possible to rule out from further scenario evaluation those uncertainties which do not have an effect on the final resource plan.

IV. CASE STUDY

The Integrated Resource Planning framework was used to evaluate the relative impacts of some capacity expansion strategies affecting to the development of Macedonian power system over a period of twenty year.

At present, the major characteristic of Macedonian electric power system is domination of thermal power plants, which produced about 85% of total electricity demand. The whole installed capacity is 1440 MW distributed as fellows: (1) Steam power pants: 795 MW; (2) Fuel oil power plants 210 MW; (3) Hydroelectric power plants 435 MW.

In modeling the demand for electricity, three scenarios (shown on Figure 1) were considered: low growth; the authors estimate medium growth (base case) and high growth predicted by Macedonian electric power utility.

Two fuel price escalation were used in the analysis. The first assumes that there is no fuel price escalation over inflation, and second assumes that natural gas and fuel oil prices escalate at 1,5% above inflation.

The generating system expansion options was based, mostly, on rehabilitation/rebuilding of thermal power plants "Bitola", imported coal and involved a natural gas-fired plants. The new capacity thermal units are described in Table 1.

TABLE I. Thermal Candidate Units

Name	Net Capacity (MW)	Fuel Cost ($/GJ)	Overnight Cost ($/kW)	Fuel Type
Bitola Rehabilitation	207	1,42	810	Lignite
Imported Coal	207	1,78	1450	Lignite
Gas Turbine	122	2,86	280	Natural Gas
Combined Gas Turbine	220	2,86	620	Natural Gas
Cogeneration	175	2,86	670	Natural Gas

The reserve margin (the percentage of capacity over a peak annual load) was adopted at level 10÷50 % and maximum value of LOLP (Loss of Load Probability) 1,5%.

As was mention above, generating system expansion options are based on rehabilitation/rebuilding of Bitola thermal power plant units with the same lignite-fired steam technology. In according to this assumption, the ability to add new thermal capacity is limited and can come on line after year 2013 (date of retirement of Bitola I). The WASP III Plus, developed at IAEA (International Atomic Energy Agency) was used as a production costing and optimizing program.

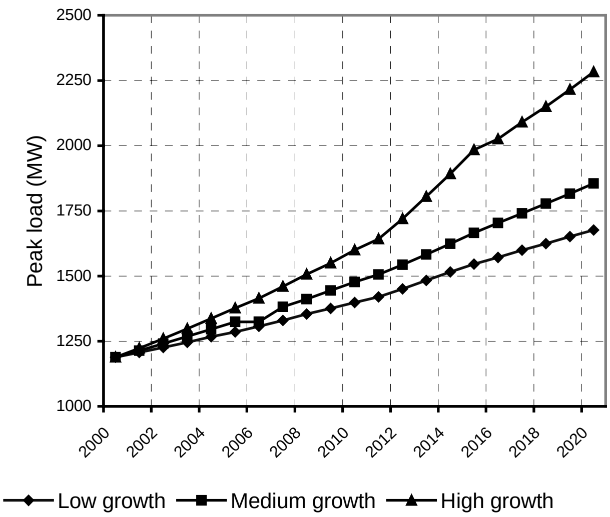

Figure 1. Comparison of Load Growth Scenarios

The major results of the planning strategies analysis for the base case is shown in Figure 2 (electricity generation by fuel type) and Figure 3 (least-cost expansion plan).

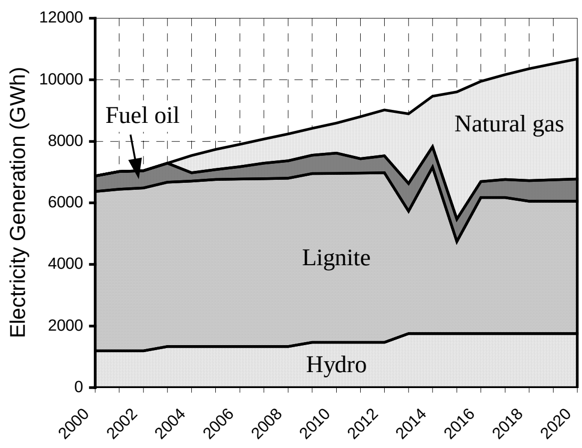

Figure 2. Electricity Generation by Fuel Type (Base Case)

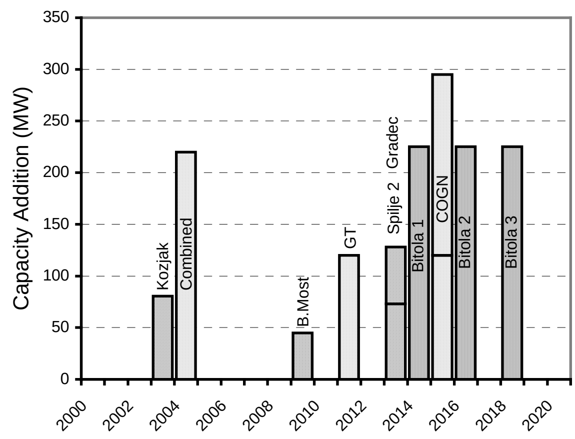

Figure 3. Least-Cost Expansion Plan for the Base Case

V. Conclusion

The use of an Integrated Resource Planning framework is useful in assessing how different options are suited to preparing for an uncertain future. Different perceptions of relative value of competing attributes allows decision-makers to weigh and constructively discuss trade-off associated with any one decision.

The strength of the Integrated Resource Planning framework lies in that it is not, nor does it require, a static one time forecast. New information can be easily incorporated into the process. As a planning tool, the framework shifts a focus from finding a single optimal plan based on today's best forecasts, to finding a solution that is robust over a wide range of possible future alternatives.

The analysis of planning strategies for the electric power industry in Macedonia has shown the following major results:

- Natural gas is fuel of choice for future electricity generation. Natural gas fired combined cycle units are the preferred technology. Ensuring supply of natural gas by additional pipeline capacity is beneficial and should be explored, especially by evaluating the performance of different supply strategies with respect on environmental impacts.
- Rehabilitation/rebuilding of existing thermal plants "Bitola" offer an economical alternative and robust solution. It was a part of the least-cost expansion plan in all analyzed scenarios.
- A detailed study should be performed for additional scenario generation by expanding the set of option and uncertainties, particularly a more explicit treatment of demand-side management alternatives.

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