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Generation Expansion Planning Strategies on Power System: A Review

V. Phupha, T. Lantharthong, N. Rugthaicharoencheep

***Abstract*—**The problem of generation expansion planning (GEP) has been extensively studied for many years. This paper presents three topics in GEP as follow: statistical model, models for generation expansion, and expansion problem. In the topic of statistical model, the main stages of the statistical modeling are briefly explained. Some works on models for GEP are reviewed in the topic of models for generation expansion. Finally for the topic of expansion problem, the major issues in the development of a long-term expansion plan are summarized.

***Keywords*—**Generation expansion planning, strategies, power system

I. Introduction

GENERATION expansion planning (GEP) is one of the most important decision-marking activities in electric utilities. Least-cost GEP is to determine the minimum-cost capacity addition plan (the type and number of candidate plants) that meets forecasted demand within a prespecified reliability criterion over a planning horizon [1]. The GEP problem has been one of the most studied problems. GEP is a challenge topic for several reasons. The first reason since there is uncertainty associated with the input data. The second one since difficulty arises as a result of a need to consider several conflicting objectives simultaneously. With the aid of a multiobjective model, decision makers may grasp the conflicting nature and the tradeoffs among the different objectives in order to select satisfactory compromise solutions for the GEP problem. In the past, there have been many attempts to deal with GEP problem [2]. Some of them used deterministic criteria whereas other incorporated analysis of uncertainties. These uncertainties could be either technical, such as hydrological conditions and generators stoppage, or economical, like fuel prices and interest rates [3]. There are difficulties, however, in taking into account too many aspects of the problem because of the overwhelming complexity that rapidly arises. The classical formulation of the least-cost GEP is not a suitable approach to modeling the behavior of generation firm, seeking to maximize profits, in competitive environments. Supposed that the revenue is based on the marginal price, some generation firms will choose to retain higher priced units to continue to set marginal price high and increase their revenue and profit by higher marginal price while others replace the higher priced units with efficient and cheap ones and increase revenue by higher utilization factor [4].

Vallop Phupha is with the Department of Industrial Engineering, Faculty of Engineering, Rajamangala University of Technology Phra Nakhon, Bangkok, 10800, Thailand. (phone: 662 913-2424; fax: 662 913-2424; e-mail: v.phupha@hotmail.com).

Thong Lantharthong is with the Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Phra Nakhon, Bangkok, 10800, Thailand. (phone: 662 913-2424 ext. 150; fax: 662 913-2424 ext. 151; e-mail: thong.l@rmutp.ac.th)

Nattachote Rugthaicharoencheep is with the Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Phra Nakhon, Bangkok, 10800, Thailand. (phone: 662 913-2424 ext. 150; fax: 662 913-2424 ext. 151; e-mail: nattachote@ieee.org).

Choices are left to each player, which is made according to their own estimation on the prospect for the price level and market environment in the future. Therefore, it is strongly required to develop a new practical expansion planning methodology which is applicable to the changed electric power industry environment where individual generation firms seek to maximize the returns on their expansion planning decision. In this section, new generation expansion planning formulations in competitive markets are explored [5].

We can represent the optimum status of the set of power plants, by the equality between the operation marginal cost and the expansion marginal cost [6], [7].

This condition can be understood if we imagine the two possibilities to meet one part of market in the system:

1) Through the existing means, incurring in operational costs increase.

2) Through incorporating a new power plant to the system and/or reinforce the transfer ability among the subsystems.

II. Statistical Model

Because of the importance of the demand and price in planning procedure, only these two data, i.e. the demand of the whole system and the corresponding market energy price, from the historical information of the market are used in this statistical study. These information are hourly available in any of the real life market in the world. The main stages of the statistical modeling are as follows [8].

A. Data Justification

After choosing a base year, the demand and prices are justified according to annual demand growth and discount rates. By this, the whole system load duration curve can be constructed and with a good approximation, it can be assumed that the shape of this curve remains unchanged.

B. Price Grouping

After choosing the equivalent load levels for the load duration curve of the system, the corresponding prices data are devoted to the suitable groups. Then, for each demand level, the maximum price, the minimum price and the median of prices as the most realistic price for that load level are determined.

C. Generalization

The last stage in the statistical study is data generalization to the planning horizon. For this, It is assumed that the shape of the load duration curve remain unchanged. For each of the planning horizon years, after applying the annual load growth rate to the load levels, the new load levels are formed and then the new duration time for each load level is determined by rearranging the historical data.

D. Basic Assumptions

GEP problems in competitive market environments are basically modeled as games among competing generation firms [9], [10]. Electricity industry environment in which the generation expansion games should be solved has been so changing that it is very difficult to incorporate practical considerations of electric power industries in the formulation of GEP games. In order to properly address the generation expansion games in competitive markets, therefore, we make some basic assumptions about the market environments and game variables. In our proposed games, electric markets are modeled by uniform pricing auctions. We assume that there exists a single gross power pool where buying and selling of energy among firms happen in the form of auctions. The market price is based on the operating cost of the marginal generation firm. Since we do not consider the bilateral contract between firms in this model, the profit of every generation firm can be simplified revenues from energy market modeled by auctions and construction and/or operation costs of plants [11].

After defining the quality criteria of meeting the market, the optimum status of system expansion is given by minimizing the total cost of meeting the market, which includes investment costs, maintenance and operational costs, expected costs with thermal plant fuel and the cost of non-meeting a market share (energy deficit cost) [12], [13]. Naturally, some restrictions associated to the hydrothermal coordination shall be considered, as meeting the market, hydrological balance, interconnection ability, assured energy balance, among others.

III. Models for Generation Expansion

In this section, some works on models for GEP are reviewed, government incentive policy and inverse optimization. [14] and [15] apply the Cournot model of oligopoly to model GEP. The model of [14] incorporates plant capacity limitations and energy balance constraint in competitive environments dominated by auction markets. They present an analytical formulation of the generation planning process involving decisions on new plant construction at a single point in time with multiple technology options available. In [15], three capacity expansion models are analyzed in the context of a restructured electricity industry. The first model assumes a perfect, competitive equilibrium. The second model (open loop Cournot game) extends the Cournot model to include investments in new generation capacities. The third model (closed-loop Cournot game) separates the investment and sales decision with investment in the first stage and sale in the second stage. The study of [16] presents 3-Tier game theoretic model to obtain multi-period, multi-player equilibrium capacity expansion plans. This model provides an excellent means of conducting analysis of sensitivity of the expansion and the corresponding market power indices with respect to several restructuring policy related parameters, such as varying levels of price caps, arbitrage, pricing and settlement mechanisms, demand side bidding, and capacity payment. The works in [17], [18] propose a multiobjective model for generation expansion planning (MGEP).

The model in [17], objectives are the minimization of investment, operation and transmission costs, environment impact, imports of fuel and fuel prices risks of the whole system. Multiobjective linear programming and analytical hierarchy process are made use of to solve this problem. The model of Antunes et al.[19] is presented to provide decision support in the evaluation of power generation capacity expansion policies. The objective functions are the total expansion cost, the environmental impact associated with the installed power capacity and the environmental impact associated with the energy output. Ahmed et al. [18] use a scenario tree approach to model the evolution of uncertain demand and cost parameters, and fixed-charge cost function to model the economies of scale in expansion costs. Several works have focused on government regulations on energy markets.

The study in [20] provides a framework for representing selected price-oriented government regulations in mathematical programming model of a market. The work of [21] compares effects of R&D and demand subsidies on the future costs of purely organic photovoltaics (PV) which is not currently commercially available. They combine an expert elicitation and a manufacturing cost model to compare the outcomes of policy choices over various scenarios.

IV. Expansion Planning Problem

This section examines the major issues in the development of a long-term expansion plan for the generating system [22].

A. Demand

The forecast of electrical demand is clearly one of the most important components of a generating system analysis. The forecast typically must be for power (kW), energy (kW-h) and load variation for time intervals within a year, such as a month or season, for all years of the study. If a great deal of effort is to be devoted to analyzing the alternative expansion possibilities, the demand forecast should also receive a significant effort. There are two distinct types of uncertainty in demand forecasting. First, there is the uncertainty that results from the randomness of the load at any time because of, for example, weather conditions. This type of uncertainty is, of course, a major concern for the load dispatcher. The other type of uncertainty is associated with the estimate of future demand, i.e. the estimate may be too high or too low. Underestimating future demand can create serious difficulties because service dates for new facilities can seldom be advanced appreciably. The result may be a generating system with low reliability and the inability to serve some portion of demand.

Overestimating the demand is also undesirable because excess generating equipment imposes increased costs on the system. Service dates for new facilities under construction can be delayed if load growth has been overestimated, but such delays can be very expensive.

B. Technology Options

Various technologies are currently available as candidates for expanding electrical generating systems. Each has a unique set of characteristics that must be considered from a system viewpoint to determine the mix of future additions that provides the best outcome for the stated objectives for expansion. In addition to existing technologies, long-term studies of generation expansion must consider whether advanced technologies will become available and, if so, what their costs and characteristics will be. Power generation technologies may be classified into existing major options and potential future options.

C. Economic Evaluation

A fundamental aspect of any economic evaluation is the time element, since implementation time and economic lifetime of a generating unit require a certain number of years: a particularly large number in the case of nuclear units, where the overall period to be considered usually varies between 30 and 45 years (typical values are 10 years for implementation and 30 years for economic lifetime).

A key concept in understanding the basic principles of economic evaluation is the time value of money, i.e. how streams of costs or incomes (or alternatively of produced electricity since it generates an income) occurring through time can be compared on an equivalent basis.

The relationship between time and money is affected by:

1) Inflation (or deflation) which changes the buying power of money.

2) The value given to possession of money now rather than later, since the former allows this amount of money to be invested for an interval of time to earn a real return (i.e. in addition to inflation).

Alternatively, raising capital through a financial market implies the payment of a cost of capital for years to come (again independent of inflation). The annual factor that accounts for the time value of money independently of inflation is called the real discount rate (or real present worth rate).

D. Reliability

The objective of electric system planning was stated as adequately meeting the demand for electrical power at the minimum cost. Adequately meeting the demand can be interpreted in various ways with major implications for the generation planning effort. Typically, a technical constraint is used as the minimum acceptable level of generating system performance, or an economic criterion is introduced in an attempt to include the generating system reliability considerations directly in the determination of minimum cost.

The generation planner must design the future generating system to be responsive to such problems as:

- Random breakdowns of generating equipment (forced outages.
- Variations in demand to be met by the generating system (including random variations).
- Variations in hydraulic conditions which affect hydroelectric capacity and energy available to the generating system.
- Scheduled maintenance of generating equipment and refuelling of nuclear units.
- Changes in anticipated new capacity scheduled to come on line, e.g. delays or cancellations because of financial and other constraints.

E. Constraints

Mathematically, the problem referring to power plant expansion is formulated as a problem of integer linear programming difficult to solve and which present some particularities, such as:

1). non-convex solution region, which allows existing several solutions.

2). Combinatorial nature of expansion process, which leads to the combinatorial explosion phenomena related to generating alternatives, causing increased computing time. Considering that for problems of discrete nature, Applications as optimization method is being greatly surveyed and disseminated, mainly by obtained result quality. Therefore, a new algorithm was developed in this work, based on optimization technique, in order to establish an optimal strategy of generation expansion [23].

In a general context, the solution of the expansion problem is the schedule of plant additions and network development over a certain period of time which yields the optimum benefits while satisfying the projected electricity demand with a certain margin of reserve and respecting certain foreseeable constraints.

In other words, the expansion program must include [24]:

1) The year-by-year capacity additions needed to satisfy the projected electricity demand with a satisfactory level of reliability with due regard to the characteristics of generating units in the existing system.

2) The timely reinforcement of the transmission system so that the proposed network is capable of meeting power flow requirements under any foreseeable condition with due regard to load flows, power station siting, circuit and switchgear ratings, and transient stability limits.

Definition of the benefits to be optimized is of paramount importance since it leads to selection of the economic criteria to be used for evaluating and comparing all alternative expansion policies for the power system.

On the other hand, definition of the constraints is perhaps more complex since this requires the resolution of important issues, such as [25]:

- Adequate reserve margins or level of reliability.
- Required quality of service in terms of continuity of supply, frequency and voltage.
- Availability of resources (manpower, fuel, funds).
- Technical considerations.
- Infrastructure needs.
- Environmental consideration.
- The country's policies concerning new units for electricity generation.

V. CONCLUSION

The aim of GEP requires minimum-cost capacity addition plan that meets the forecasted demand within a reliability criterion. This work presents an overview of some issues in GEP. It is clear from the previous studies that GEP is one of the most important decision-marking activities in electric utilities.

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Vallop Phupha received his Ph.D. in Industrial Engineering from King Mongkut’s University of Technology North Bangkok (KMUTNB), Thailand in 2011. He is an assistant professor at the Department of Industrial Engineering, Faculty of Engineering, Rajamangala University of Technology Phr Nakhon, His research interests are energy and planning.

Thong Lantharthong received his M.Eng in Electrical Engineering from Rajamangala University of Technology Thanyaburi, Pathumthani, Thailand in 2010. He is currently a lecturer at the Department of Electrical Engineering, Faculty of Engineering Rajamangala University of Technology Phra Nakhon (RMUTP), Bangkok, Thailand. His research interests include power system operation, optimization technique, and distributed generation.

Nattachote Rugthaicharoencheep (M’10) received his Ph.D. in Electrical Engineering from King Mongkut’s University of Technology North Bangkok (KMUTNB), Thailand in 2010. He is currently a lecturer at the Department of Electrical Engineering, Faculty of Engineering Rajamangala University of Technology Phra Nakhon (RMUTP), Bangkok, Thailand. His research interests include power system operation, optimization technique, and distributed generation.