Generation Expansion Planning in a Competitive Environment Using a Genetic Algorithm

Jong-Bae Park, Member, Jin-Ho Kim, Student Member, and Kwang Y. Lee, Fellow, IEEE

Abstract - In this presentation, we propose a new framework for a generation expansion planning (GEP) applicable in a competitive environment using a genetic algorithm (GA). Unlike the traditional approaches, the new GEP in a competitive market is very complex due to conflicts among generation companies (GENCOs). The objective function of each GENCO for investment decision making is to maximize its profit, while the objective of profit maximization of each GENCO is linked to others. Also, one of the objectives of the market regulatory body will be market stabilization through coordination between GENCOs by providing long-term market information to GENCOs, which can prevent extreme over/under investments in the electricity market. This presentation suggests a new solution algorithm that can deal with these conflicting objectives between GENCOs and the regulatory body using a genetic algorithm. Using a genetic algorithm solution scheme, the GEP problem for a competitive environment application can easily be solved.

Index Terms - Competitive Electricity Market, Generation Expansion Planning, Genetic Algorithm.

I. INTRODUCTION

The demise of the traditional regulated markets and the emergence of competitive markets for electricity service is changing the way that electricity is and will be priced and is making increasingly difficult for market participants to appraise the prospects for the future electricity markets [1]. Conventional generation expansion planning (GEP) determining the least-cost capacity addition plan that meets forecasted demand within a pre-specified reliability criteria over a planning horizon (typically 10 to 20 years) should be modified to reflect the changed market environments. Therefore, it requires developing new generation expansion planning methodologies applicable in various perspectives such as an investment aspect of a generating company (GNECO), which are applicable to the changed business environments and also able to address the post-privatization situation where individual GENCOs seek to maximize their returns on investment against market prices [1].

Traditionally, the objective of a least-cost GEP problem has been the minimization of the expected sum of yearly discounted costs which incorporate construction costs, operating costs, salvage value, and so on [2-5]. However, the objective function of a new GEP problem in a competitive electricity market is to maximize the profits of individual GENCOs, which are composed of the revenues based on market prices and of the costs covering the capital and operating costs. Also, the objectives of individual GENCOs are correlated, interlinked, and conflicting each other. Together with the objectives of GENCOs to maximize their profits, there can be another objective of regulatory body to stabilize the long-term electricity market. The stabilization of an electricity market includes the prevention of over/under capacity investments in a market as well as the guarantee of sustainable development and evolution of the market, which is one of the main roles of the regulatory body.

It is very difficult to formulate these changed GEP environments including GENCOs and the regulatory body in a mathematical form and solve the problem using conventional optimization techniques. One alternative to tackle this problem is the application of a game theory [6]. Although there are many inherent advantages in the application of game theories to a competitive electricity market, the problem of dimensionality for N-player applications still exists [7].

In this presentation, we propose a new solution scheme to mimic the changed capacity investment environments of each GENCO and the regulatory body based on a genetic algorithm. To do this the problem is decomposed into two problems, that is, the main problem and the subproblems. The main problem for the regulatory body is to evaluate the market prices and capacity stability in a long-term sense based on the investment strategies of individual GENCOs. The subproblems correspond to individual GENCOs where each GENCO tries to maximize its profits using a genetic algorithm using the information supplied by the main problem. An iterative process between the main problem and the subproblems is applied to find an equilibrium investment solution.
II. FORMULATION OF NEW GENERATION EXPANSION PLANNING PROBLEM IN A COMPETITIVE ENVIRONMENT

The generation expansion planning problem in a competitive electricity market involves the investment decision-making of individual GENCOs whose objectives are the maximization of profits. In a complete competitive market, the decision-making of each GENCO on capacity investment is its own role based on its load-demand forecasting, market share, business strategies, etc. All GENCOs should make decisions on future capacity investments without exchanging information with other GENCOs. However, there can be some regulations on the total investments to preserve national energy fuel mix strategies and to prevent over/under capacity investments in the market.

In this presentation, therefore, we propose a new GEP framework in which each GENCO first decides its new capacity investments based on its own decision criteria and the initial decisions of individual GENCOs are submitted to an upper organization such as ISO or the regulating body. The upper organization aggregates all the new resources provided by each GENCO to assess the adequacy of future capacities, fuel mixes, and expected price levels using conventional probabilistic production costing techniques. The obtained informations such as the expected price levels, the propensities of fuel mixes, the expected revenue of each GENCO, the expected capacity factor and generation energy of each GENCO, and the system reliability levels are transmitted to each GENCO independently. Based on the information supplied by the upper organization and each GENCO's decision criteria such as its sharing of system future demand (i.e., [d_1, ..., d_T]), d_i^t: demand sharing of GENCO-i in year t) and its fuel mix strategies to meet national mix securities as well as to hedge the future fuel price risks, each GENCO does self-optimization to find the optimal solution using a genetic algorithm. Note that the price information (i.e., [p_1, ..., p_T], p_i: price information in year t) provided by the regulatory body is filtered by an adjustment factor of GENCO-n (i.e., α_i).

The optimal decision of each GENCO is resubmitted to the regulatory body and this process is repeated until every GENCO does not change its decision-making and the generation investment market reaches an equilibrium. Figure 1 shows the basic structure of the proposed new GEP problem.

The GEP problem for GENCO-i in a competitive environment can be formulated as follows:

\[
\begin{align*}
\text{Max} & \quad \sum_{t=1}^{T} \left[ f_i^t (X_i^t) - \left( g_i^t (U_i^t) + h_i^t (X_i^t) - s_i^t (U_i^t) \right) \right] \\
\text{s.t.} & \quad X_i^t = X_i^{t-1} + U_i^t \quad (t = 1, \ldots, T) \\
& \quad \sum_{j=1}^{F} x_i^{j,t} \leq M_i^j \quad (t = 1, \ldots, T, j = 1, \ldots, F) \\
& \quad 0 \leq U_i^t \leq U_i^t \quad (t = 1, \ldots, T)
\end{align*}
\]

where

\[i \in \{1, 2, \ldots, N\},\]

\[N \quad \text{Number of GENCOs},\]

\[F \quad \text{Number of fuel types},\]

\[T \quad \text{Number of periods (years) in a planning horizon},\]

\[\Omega_j \quad \text{Index set for j}^\text{th} \text{ fuel type plants},\]

\[x_i^{j,t} \quad \text{Cumulative capacity [MW] vector by plant types in year t of GENCO-i},\]

\[U_i^t \quad \text{Capacity addition [MW] vector by plant types in year t of GENCO-i},\]

\[M_i^j \quad \text{Upper and lower bounds of j}^\text{th} \text{ fuel type’s capacity [MW] in year t of GENCO-i},\]

\[f_i^t (X_i^t) \quad \text{Discounted revenue [\$] from market associated with X_i^t in year t of GENCO-i},\]

\[g_i^t (U_i^t) \quad \text{Discounted investment costs [\$] associated with U_i^t in year t of GENCO-i},\]

\[h_i^t (X_i^t) \quad \text{Discounted fuel and O&M costs [\$] associated with X_i^t in year t of GENCO-i},\]

\[s_i^t (U_i^t) \quad \text{Discounted salvage value [\$] associated with U_i^t in year t of GENCO-i}.
\]
Note that the objective function of equation (1) implies the profits of GENCO-i during a planning horizon where the price information is supplied by the main problem in the one-step before iteration and demand share is determined by the strategies of each GENCO. Equation (2) means the state equation, and equation (3) is to reflect the fuel mix strategies of GENCO-i. Also, Equation (4) implies the investment capabilities of GENCO-i, which reflects the financial constraints.

In the main problem, the system reliability level based on the submitted investment plans from all GENCOs together with the existing plants in the market is reviewed whether the alternative violates the constraints expressed in equation (5) and equation (6). Also the alternative is checked whether it meets the national energy security by fuel types using the constraint of equation (7). Finally, the market prices during a planning horizon are evaluated based on the investment plans of all GENCOs and existing plants. The evaluated market prices are transmitted to each GENCOs with information obtained from equation (5) to equation (7).

\[
LOLP \left( \sum_{i=1}^{N} X_{i} \right) < \varepsilon \quad (t = 1, \ldots, T) \tag{5}
\]

\[
R \leq R \left( \sum_{i=1}^{N} X_{i} \right) \leq \bar{R} \quad (t = 1, \ldots, T) \tag{6}
\]

\[
M_{i}^{L} \leq \sum_{i=1}^{N} x_{i}^{k} \leq M_{i}^{U} \quad (t = 1, \ldots, T, j = 1, \ldots, F) \tag{7}
\]

where

\[
LOLP \left( \sum_{i=1}^{N} X_{i} \right) = \text{Loss-of-load-probability (LOLP) with}
\]

\[
\sum_{i=1}^{N} X_{i} \quad \text{in year } t,
\]

\[
R \left( \sum_{i=1}^{N} X_{i} \right) = \text{Reserve margin with } \sum_{i=1}^{N} X_{i} \quad \text{in year } t,
\]

\[
\varepsilon = \text{Reliability criterion expressed in LOLP},
\]

\[
R, \bar{R} = \text{Upper and lower bounds of reserve margin},
\]

\[
M_{i}^{L}, M_{i}^{U} = \text{Upper and lower bounds of } j^{\text{th}} \text{ fuel type's capacity [MW] in year } t \text{ in a market.}
\]

III. APPLICATION OF GENETIC ALGORITHM FOR THE NEW GENERATION EXPANSION PLANNING PROBLEM

GA is a search algorithm based on the hypothesis of natural selections and natural genetics [8]. Recently, global optimization techniques using GA has been successfully applied to various areas of power system [12] such as generation expansion planning [4,5], economic dispatch [9], unit commitment [10], and power plant control [11]. GA-based approaches for the conventional GEP have several advantages. Naturally, they can not only treat the discrete variables but also overcome the dimensionality problem. In addition, they have the capability to search for the global optimum or quasi-optimums within a reasonable computation time [5].

As we have discussed in Section 2, the objective function of GENCO-i is implicitly interlinked by the investment decision-making of other GENCOs via the calculated prices. This kind of problem cannot be solved directly by a mathematical method since the variables of other GENCOs are unknown. To get an optimal investment decision under these situations, a genetic algorithm can be usefully used since it can evolve adaptively under the environments of other GENCOs decision-making changes.

The following figure illustrates the string structure of GENCO-i for GA applications. The control vector of each GENCO-i, \( U^{t}_{i} \) (for \( t = 1, \ldots, T \)), is used for string implementation of the i-th subproblem.

![Figure 2: String Structure of GA Applications](image_url)

The cost of a candidate plan of GENCO-i is calculated through the probabilistic production costing and the direct investment cost calculation [2,3] based on the demand sharing estimation of GENCO-i. Also the revenues of GENCO-i can be evaluated from the price information, price adjustment factor, and the expected generation of existing and candidate power plants. Therefore, the fitness value of a string can be evaluated using the following equation:

\[
f'(i) = \frac{f(i) - f_{\text{min}}}{f_{\text{max}} - f_{\text{min}}} \tag{8}
\]

where

\[
f(i): \text{fitness value of string } i \text{ using equation (1)},
\]

\[
f_{\text{max}}, f_{\text{min}}: \text{maximum and minimum fitness value in a generation},
\]

\[
f'(i): \text{modified fitness value of string } i.
\]
IV. CONCLUSION

This presentation suggests a new framework for a generation expansion planning applicable to a competitive electricity market using a genetic algorithm. The suggested scheme can provide each GENCO with a stable investment alternative ensuring the profit maximization via the iterative methodology. Also, the regulatory body can make the market stable in terms of prices, over/under investments, and national energy fuel mixes in long-term perspectives.

To find the optimal solution of GENCO-i, a genetic algorithm will be successfully applied to solve the conflicting, interlinked, correlated subproblems among GENCOs while the conventional mathematical-based approaches have limitations in application.

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VI. REFERENCES


VII. BIOGRAPHIES

Jong-Bae Park was born in Jinju, Korea, on November 24, 1963. He received his B.S., M.S., and Ph.D. degrees from Seoul National University in 1987, 1989, and 1998, respectively. For 1989-1998, he worked as a researcher of Korea Electric Power Corporation (KEPCO), and from 1998 to 2001 he was an Assistant Professor at Anyang University, Anyang, Korea. Currently, he is an Assistant Professor at Konkuk University, Seoul, Korea. His research interests are power system operation, planning and economic studies.

Jin-He Kim was born in Insehoon, Korea, on November 27, 1971. He received his B.S. and M.S. degrees from Seoul National University, Korea, in 1995 and 1997, respectively. He is currently working at Electricity Economic Center, Electrical Engineering and Science Research Institute, Seoul National University, Korea. His research interests are analysis of power markets, power system operation and planning.

Kwang Y. Lee received B.S. degree in electrical engineering from Seoul National University, Korea, in 1964, M.S. degree in electrical engineering from North Dakota State, Fargo in 1968, and Ph.D degree in System Science from Michigan State, East Lansing in 1991. He has been with Michigan State, Oregon State, University of Houston, and Pennsylvania State University, where he is a Professor of Electrical Engineering and Director of Power Systems Control Laboratory. His interests include control and intelligent systems and their applications to power plant and power system control, operation and planning. Dr. Lee is a Felllow of IEEE.