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Generation expansion planning in Pool market: A hybrid modified game theory and particle swarm optimization

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ABSTRACT

Unlike the traditional policy, Generation Expansion Planning (GEP) problem in competitive framework is complicated. In the new policy, each GENeration COmpany (GENCO) decides to invest in such a way that obtains as much profit as possible. This paper presents a new hybrid algorithm to determine GEP in a Pool market. The proposed algorithm is divided in two programming levels: master and slave. In the master level a modified game theory (MGT) is proposed to evaluate the contrast of GENCOs by the Independent System Operator (ISO). In the slave level, a particle swarm optimization (PSO) method is used to find the best solution of each GENCO for decision-making of investment. The validity of the proposed method is examined in the case study including three GENCOs with multi-types of power plants. The results show that the presented method is both satisfactory and consistent with expectation.

1. Introduction

GEP is an important issue in power system studies. It determines which type of generating units should be constructed and when generating units should be committed over a long term planning horizon [1]. The approaches of GEP in the restructured power system, is dependent on models of power market (i.e. Pool market or Primal market). In other words, the objective function of GEP problem in the different market of countries, with consideration of power market models and also purposes of system operator and planning, is different. Because of technical and economic differences of the additional power plants in GEP problem, economic methodologies are used to determine the best technology for the additional capacity [3].

Generally, GEP in competitive framework, unlike traditional policy, can be analyzed in two levels: national level and regional level [3]. In the national level, the central entity such as Independent System Operator (ISO) or ISO is responsible for power system stabilization and manage the GENCOs to consider constrains of power system such as reserve margin and fuel mix. In the regional level, the GENCOs individually seek maximum profit considering its own zonal financial and technical constrains. In this paper, the national and regional level are named as master and slave level, respectively.

In the pool competitive framework, GENCOs with various types of generating units compete with each other to maximize their own profit. In this framework, each GENCO bids its price in market based on its marginal cost and the ISO clears the market and determines market clearing price (MCP). MCP and other necessary information for planning are transmitted to each GENCO of system, separately [2].

The game theory with 3-players, that each of them has only one type of generating unit, is used for GEP in a competitive electric power industry and solved by using genetic algorithm (GA) in [2]. This method determines the GEP problem for single-time horizon and its output does not includes any information of the years before the time horizon. In this method, for a GEP with a 5-year time horizon for example, the presented method estimate the developed capacity exactly for 5 year later and does not includes any information of 1 or 2 years before the deadline. In other words, for 5-year time horizon GEP, the proposed method cannot estimate the condition of the system for the third or forth years of time interval. Furthermore, this work estimates the developed capacity of the available plants and does not suggest a new generating unit construction. As a contribution of our work, the mentioned problem of GEP is solved in the proposed method. In [4], a framework for GEP in a competitive environment is presented and proposed GA as a useful technique in solving GEP optimization problem. In [5], a competitive GEP problem with 5-player, that each with only one type of generating unit, is presented. In this work, at first, each GENCO individually optimized its own objective function in an

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Nomenclature

i	number of GENCos
t	number of periods in planning horizon
G	number of GENCOs
N	number of iterations in Cournot equilibrium
B_i	profit ($) of the ith GENCO in planning horizon
R_i^t	revenue ($) of the ith GENCO in the tth year of horizon
C_i^t	investment cost ($) of the ith GENCO for construction of new generating unit in the tth year of horizon
F_i^t	fuel and O&M costs for existing unit and added unit ($) of the ith GENCO in the tth year of horizon
S_i^t	salvage value of investment costs ($) of the ith GENCO in the tth year of horizon
P_i^t	total capacity (existing and new added) (MW) of the ith GENCO in the tth year of horizon
$P_{i,c}^t$	total capacity (existing and new added) (MW) of the ith GENCO in the tth year of horizon in iteration c of Cournot equilibrium
q_i^t	new added capacity (MW) of the ith GENCO in the tth year of horizon
MCP_c^t	market clearing price ($) in the tth year of horizon in iteration c of Cournot equilibrium
α	demand factor refer to price elasticity in the Pool market

iterative manner. After that, the GEP problem is solved to determine the developed capacity of system for a given single-time horizon. The presented work however, uses a simple objective function and also MCP considered as a constant term in the market. Another contribution of the proposed method is the determination of MCP in Pool market by using Bertrand model.

GEP problem for Primal competitive model is discussed in different literatures by various techniques. In the Primal competitive model, several Independent Power Producers (IPPs) sell their power only to the utility. For example, in [6] Meta heuristic techniques, in [7] dynamic programming and in [8] GA are used for this model. Further studies in the application of GEP in the restructured power systems are carried out in [9].

In [10], the problem of GEP is formulated and solved based on the multiobjective programming to determine supply shares for some chosen technologies based on both renewable power conversion and natural gas use.

A Multi-Attribute Decision-Making (MADM) is proposed to solve GEP problem in competitive framework for price taker firms [10] and price maker ones [11]. In [3], GEP problem studied in China only in the national level, using intelligent engineering.

In this paper, the GEP in Pool market for a multi-time period (time horizon) in regional level is solved by applying the PSO algorithm. The PSO method, for the first time, is introduced by Kennedy and Eberhart in 1995 [12]. This technique is inspired by social behavior of organisms such as fish schooling and bird flocking. The PSO technique can generate high-quality solutions with shorter calculation time and stable convergence characteristic than other stochastic methods [13]. In [14], is applied PSO to solve Economic Dispatch (ED). For this reason, in the slave level of algorithm, we proposed this technique as a useful method for GEP rather than the whole enumeration dynamic programming method.

With the entrance of strategic conflict and gaming, GENCOs encounter more risk and thereby, each GENCO intends to obtain more profit. In this policy in fact, the decision-making of each GENCO affects the other firm's profit and decision-making. This paper proposed a modified game theory model based on Cournot model to solve the conflict among GENCOs in the master level of algorithm. Contribution of this paper can be summarized as follows:

(a) Introducing a modified game theory model in the master level and also PSO technique in the slave level of GEP. With the modified game theory, the new algorithm is applicable to GENCOs with multi-type generating units in Pool market.
(b) Determining the type of power plant to be installed in addition to the capacity of power plan in time horizon.
(c) Presenting a multi-time horizon GEP in a Pool market. For a given time horizon, the introduced method not only determine the required power plant installation of the interest horizon, but it also can successfully estimate the required power plant installation of any arbitrary year before the horizon in a correlating manner.

The reminder of this paper is organized as follows. In Section 2 the classic Cournot model is studied. The mathematical formulation of objective function and constrains of GEP problem in Pool market are taken Section 3. The PSO method is described to solve GEP problem in slave level in the next section. In Section 5, the hybrid MGT /PSO algorithm for solution of GEP in Pool market is presented. Section 6 includes numerical results. Finally, conclusions are taken in the last section.

2. Cournot model

The Cournot model of oligopoly competition was introduced by Augustin Cournot in 1838 [15]. Cournot games have the following characteristics in common:

- Competition occurs only in quantities.
- Product is no storable.
- Product is homogeneous.
- Market price is determined by auction.
- No entry occurs during the game.
- Decision-making of players occurs simultaneously.

In the Cournot model, each firm chooses an output quantity to maximize profit. Firms are assumed to produce homogeneous commodities that are not storable. So, all produced quantities should be immediately sold. Market clearing price in the model is determined in auction process by intersecting the demand and supply curves. Examples of Cournot style auction-based pricing can be found in organized markets such as those for agricultural products like wheat, corn, and rice. The model assumes that all firms in the industry can be identified at the beginning of the game, and also the firms simultaneously make their decision. So, it seems that the GEP problem in Pool market can be solved by the Cournot model. In expansion planning in fact, firms decide on how much capacity to expand, which is a decision variable of quantity. Also, the same as Cournot model, commodity of Pool market is not storable. Furthermore, in pool-dominated generation markets (e.g. California ISO/Power exchange (PX) system, the former British power pool, etc.) prices are primarily determined in the auctions and within each auction products are homogeneous. This is absolutely in line with the characteristic of the Cournot model, stating that all of commodities are homogeneous. Like the Cournot model, in the GEP problem in Pool market there is no entry during the game. From the above