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Generation expansion planning in electricity market considering uncertainty in load demand and presence of strategic GENCOs

Jaber Valinejad[a], Mousa Marzband[b,c,*], Mudathir Funsho Akorede[d], Taghi Barforoshi[a], Milutin Jovanović[b]

[a] Faculty of Electrical and Computer Engineering, Babol Noshirvani University of Technology, Babol, Iran
[b] Faculty of Engineering and Environment, Department of Physics and Electrical Engineering, Northumbria University Newcastle, Newcastle upon Tyne NE1 8ST, UK
[c] Dept. of Electrical Engineering, Lahijan Branch, Islamic Azad University, Lahijan, Iran
[d] Dept. of Electrical & Electronics Engineering, Faculty of Engineering and Technology, University of Ilorin, P.M.B. 1515, Ilorin, Nigeria

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ABSTRACT

This paper presents a new framework to study the generation capacity expansion in a multi-stage horizon in the presence of strategic generation companies (GENCOs). The proposed three-level model is a pool-based network-constrained electricity market that is presented under uncertainty in the predicted load demand modeled by the discrete Markov model. The first level includes decisions related to investment aimed to maximize the total profit of all GENCOs in the planning horizon, while the second level entails decisions related to investment aimed at maximizing the total profit of each GENCO. The third level consists of maximizing social welfare where the power market is cleared. The three-level optimization problem is converted to a one-level problem through an auxiliary mixed integer linear programming (MILP) using primal–dual transformation and Karush–Kuhn–Tucker (KKT) conditions. The efficiency of the proposed framework is examined on MAZANDARAN regional electric company (MREC) transmission network – a part of the Iranian interconnected power system. Simulation results confirm that the proposed framework could be a useful tool for analyzing the behaviour of investment in electricity markets in the presence of strategic GENCOs.

1. Introduction

Security and quality of supply, which implies the physical availability of electric power in sufficient quantities at all times and prices that are affordable for consumers, have remained top priorities since the electricity market liberalization [1–5]. These two vital features of the electric power supply must be ensured on the short and long-term basis [6]. To achieve this goal, it is important to have a positive correlation between generation expansion and the demand growth to maintain balance between production and consumption. However, generation expansion planning has become a complex issue in the power generation industry in the competitive space [7–9]. In a limited competitive space, it is necessary that the independent system operator is equipped with the capabilities of models and computational tools to enable it to study the behaviour of the expansion of the generation sector in power systems under uncertainty [5,7,10–27].

Generation investment market involves competition of a set of strategic companies of which each can exact power with its decisions in the market. Given this scenario, challenges and significant difficulties will be created in strategic companies, decisions include short-term decisions which include strategic offers in the instantaneous market and long-term decisions invested in a new power plant. Also in this model, the market price is considered reliably effected by the decisions of the strategic companies. In this case, both the market price and the companies productions are variable, while investor in on-level models such as [1–3,8,9,11–18] must have a prediction pattern of market price. in these models, Investment capacity for optimizing profit is affected this prediction pattern of price.

A number of models have been developed to address the generation expansion problem both before and after restructuring of the electricity market. However, many of these models are deficient in one way or another. For example, in many bi-level models such as [7,10,28–34] presented, the market price prediction model was used but the existence of a strategic company for the production development planning was not considered.

* Corresponding author.
E-mail address: mousa.marzband@manchester.ac.uk (M. Marzband).

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Indices

Indices

w/w'	index for scenario
r/r'	index for year
t	index for demand blocks
y	index for GENCOs
i/k	index for new/existing generation unit of strategic GENCO
d	index for demand
h	index for size of investment option
n/m	index for bus

Parameters

σ_{rt}	weight of demand block t in year r
W_w	weight of scenario w and year r
Q_{wr}	demand growth of scenario w in year r
K_{yri}	annual investment cost of new generating unit i of strategic GENCO y in year r (€/MW)
$\bar{K}_y$	available investment budget of strategic GENCO y (M€)
X_{ih}	option h for investment capacity of new unit i (MW)
$\bar{P}^{ES}_{yk}$	capacity of existing generation unit k of strategic GENCO y (MW)
$\bar{P}^{D}_{td}$	maximum load of demand d in block t (MW)
C^S_i/C^{ES}_k	marginal cost of new/existing unit of strategic GENCO (€/MWh)
U^D_{rtd}	price bid of demand d in demand block t and year r (€/MWh)
B_{mn}	musceptance of line n–m (p.u.)
F_{nm}	transmission capacity of line n–m (MW)
f	discount rate

Decision variables

X_{yri}	capacity investment of new unit i of the strategic GENCO y in year r (MW)
u_{yrih}	binary variable that is equal to 1 if the hth investment option of technology i is selected in year r, otherwise it is equal to 0
$P^{ES}_{yrtkw}/P^S_{yrtiw}$	power produced by existing/new unit k/i of strategic GENCO y in year r, demand block t and scenario w (MW)
$X_{yrr'i}/P^{Sr}_{yrr'tiw}$	available capacity/power produced of new unit i of strategic GENCO y in year r', in years after the installation in year r (MW)
P^D_{rtdw}	demand d, in year r, demand block t and scenario w (MW)
$O^{ES}_{yrtkw}/O^S_{yrtiw}$	price offered by existing/new unit k/i of strategic GENCO y in year r, demand block t and scenario w (€/MWh)
$O^{Sr}_{yrr'tiw}$	price offered by new unit i of strategic GENCO y, in year r', in the years after the installation in year r, demand block t and scenario w (€/MWh)
λ_{rtnw}	location marginal price or market clearing price (€/MWh)
$C^r_{yrr'i}$	marginal cost of new unit of GENCO i, in year r', in the years after the installation in year r (€/MWh)
θ_{rtnw}	voltage angle of bus n, in year r, demand block t and scenario w

The market in [30,31] was modeled using the conjecture price approach in the lower level of the problem while ref [29] used Cournot modeling approach their work. Although, the market price was considered a variable in the bi-level models presented for the production expansion planning problem in [9,13] strategic companies were not taken into account in the studies. In some other bi-level models such as [35–37] the supply function model was used to consider the strategic companies. However, these models include competition of only one strategic company with a set of non-strategic companies. Meanwhile, there is no competition among the strategic companies in the approach used in [35,36], due to the static nature of planning. Its worth mentioning that one of the other important advantages of multi-level models is that the objectives that are in conflict with each other are observed in them. In [38], a three level model for generation expansion planning without considering the strategic companies is presented. Similarly, though competition among a set of strategic companies was considered for the generation expansion planning in [39,40], certain important features such as dynamism, consideration for uncertainty and capacities of true investment are missing in these references.

Furthermore, the models proposed in [29,36,39,41–48] did not take into account the dynamic nature of investment decisions. Similarly, uncertainty in the demand growth were not included in the models proposed in [36,37,44,49] just as the investors in the models in [36,39,44,50] have no choice of different technologies.

Interestingly, the present work tries to address most of the deficiencies highlighted above, to present a very accurate model. In this respect, it considers the dynamics of the investment decisions, just as it puts into account strategic GENCOs. It also considers the problem as a three-level model consisting of the transmission network constraints. The uncertainty regarding demand growth is equally accounted for in this study. In addition, the model takes into account peak and base technologies in different capacities from which the user could select. In the proposed model, small and large private GENCOs compete with one another. Fig. 1 shows the effectiveness of investment and planning.

By way of summary, the contributions of this paper are listed below:

- The proposed model for the strategic GENCOs is dynamic in nature. To the best of the authors' knowledge, none of the equilibrium programming with equilibrium constraint (EPEC) models presented in the literature considered the dynamic nature of investment decisions. Thus, the multi-period stochastic three-level model consisting of transmission network constraints is presented here.
- Inclusion of uncertainty in the load demand in the dynamic competition of strategic GENCOs: Scenarios are used to describe the uncertainty pertaining to the demand growth modelled by the discrete Markov model because no anticipativity constraints are inherent in all multi stage stochastic optimization problems;
- Consideration of investment decision variable as discrete variables in the three-level stochastic dynamic model for competition among the strategic GENCOs: Two scenarios (base and peak) in which each has different option for investment capacity are considered for each candidate.
- In this model, small and large strategic GENCOs compete with one another.

2. The proposed algorithm

The generation planning problem in this study is solved using the algorithm presented in Algorithm 1. It is desired to have the objective function established at the scheduled time. The following procedure is repeated for each scenario. At first, for each company participating in this competition, the investment is done with the aim of maximizing profits in the market. Non-anticipativity is considered at the output of the optimization offers in the market as well