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Electricity Market Nash-Cournot Equilibrium Analysis with High Proportion of Gas-Fired Generators

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Abstract

With the increasing penetration of renewable energy in the power system and stricter restrictions on the air pollutants, more gas-fired generators have been accessed into the power system. To analyze the impacts of high proportion of gas-fired units on the power system, a liberalized electricity market Nash-Cournot equilibrium model has been proposed in this paper. Then a numerical example is given to present the influence of high proportion of gas-fired units on the energy price, demand and the accommodation of renewable energy in the market equilibrium. Comparisons between high and low proportion of gas-fired units in the power systems are also presented.

Keywords: Gas-fired units; electricity market; Nash-Cournot equilibrium

Nomenclature

ESS	Energy storage system.
MCP	Marginal clearing price.
NCP	Nonlinear complementarity programming.
KKT	Karush-Kuhn-Tucker.
MIQCP	Mixed integer quadratic constrained programming.
LPGF	Low proportion of gas-fired units.
HPGF	High proportion of gas-fired units.
i	Unit index.
t	Time index.
T	Set of time.

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C	Subscript for coal-fired units and set of coal-fired units.
G	Subscript for gas-fired units and set of gas-fired units.
R	Subscript for renewable units and set of renewable units.
D	Subscript for demand.
RMPD	Superscript for ramp down limits of units.
RMPU	Superscript for ramp up limits of units.
$a_{(\cdot)}$, $b_{(\cdot)}$	Coefficient of the total generation cost.
$\alpha(t)$, $\beta(t)$	Coefficient of the inverse demand function in period *t*.
$\pi_{(\cdot)}(t)$	Profit of the unit in period *t*.
$\lambda(t)$	Marginal clearing price of the energy market in period *t*.
$Q_{(\cdot)}(t)$	the generation output of the unit in the period *t*.

1. Introduction

Facing stricter restrictions on emissions of air pollutants during energy generation and the increasing demand of clean energy, the penetrations of renewable energy are getting higher in many areas. Renewable energy, such as wind power and solar energy, is eco-friendly and low-carbon, but with the intermittent and stochastic generating natures [1, 2], which put plenty of pressure on the operations of power systems and electricity markets at the supply side. Moreover, more and more high power electric equipment, such as electrical vehicles, have got access to power systems, bringing more uncertainty at the demand side of power systems and electricity markets.

To accommodate the trend of high penetration of renewable energy and stochastic power generation and demand, energy generation mix has changed in many areas, where the conventional fossil energy is undergoing a decreasing share in the primary inputs to power generation. At the meantime, the energy storage systems (ESSs) and gas-fired units have grabbed more attention. Due to the ability in charging and discharging within a short time, ESSs have great potential to provide flexibility to the power systems [3]. Since the prices of ESSs are relatively expensive, it is rarely a practical and economic method to build a number of ESSs in the power systems. In the meantime, gas-fired units, which have faster ramping rates, less air pollutants output and more economical cost, have become appropriate alternatives of obsolete coal-fired units [4].

Recently, Chinese government has issued a series of policies, aiming at promoting the accommodation of renewable energy, increasing the proportion of gas-fired units and reducing the proportion of coal-fired units [5, 6]. There have been many studies on the electricity market equilibrium with multiple generations. Reference [4] analyzed the competitiveness of gas-fired units under different environmental policies. But it didn't analyze the impacts of high proportion of gas-fired units on the renewable energy accommodation and the electricity price is given by historical data. Reference [7] used a stochastic Cournot model to represent the strategic behavior of the wind generators. With the bidding strategy proposed in the paper, the profit for wind firms might be increased. Reference [8] proposed a Cournot model solved by potential function to evaluate the contribution of energy storage to support large-scale renewable generation in joint energy and ancillary service markets. Reference [9] presented a multi-nodal intertemporal Cournot gaming model to simulate capacity and energy-only markets under high renewable penetration.