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Energy-saving generation dispatch toward a sustainable electric power industry in China

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HIGHLIGHTS

- We propose a new type of Energy-Saving Generation Dispatch (ESGD) framework.
- Sequential coordination among different time-scale generation schedules.
- We propose SCUC and SCED models for the ESGD framework.
- Empirical analysis is conducted using the realistic data obtained from the Guangdong Power Grid.
- The existing financial interest distribution is maintained while energy savings are achieved.

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ABSTRACT

Energy shortages, climate change and environmental pollution are critical issues that the entire world is faced with currently. To tackle the challenge and realize sustainable development, the Chinese government launched the Energy-Saving Generation Dispatch (ESGD) in 2007. In the ESGD scheme, generating units are dispatched based on fuel consumption rates and pollutant emission intensities from low to high. However, annual generation quotas still widely exist. With the mandatory shutdown of small-capacity and low-efficiency thermal generating units in 2006–2010, most of the currently running thermal generating units are large-capacity and highly efficient units. The additional improvement of the overall energy efficiency under this situation is a key problem for the Chinese electric power industry. To this end, a new type of ESGD framework is designed in this paper. Sequential coordination among yearly, monthly, day-ahead and real-time generation schedules is proposed. Based on the framework, the corresponding models are formulated. Empirical analysis is conducted using the realistic data obtained from the Guangdong Power Grid Corporation. Four generation dispatch modes are compared. The results indicate that the proposed ESGD mode can further reduce energy consumption and pollutant emissions. Hopefully, this paper can provide a valuable reference for policy making in the Chinese power sector.

1. Introduction

1.1. Background of energy-saving generation dispatch (ESGD)

Energy shortages, climate change and environmental pollution are critical issues that the entire world is faced with currently. To tackle these challenges and realize sustainable development, many countries and regions have adopted policies to improve the energy efficiency and to increase the share of renewable energy (Lund et al., 2008).

In China, coal plays a dominant role in the energy supply system, and this situation is likely to persist for a relatively long term. Since November 2013, the electricity generation of thermal power plants accounts for over 80% of the total electricity generation (China Electricity Council, 2013a). In 2012, approximately 3.64 billion tons of standard coal were consumed in China, and among that, 1.79 billion tons were utilized for electricity generation (China, 2012). In addition, among the CO_2 emissions produced by fossil fuels, the power industry accounts for approximately 38% (Kang et al., 2012). The transportation sector is another large energy consumer. The energy consumption of transport sectors is about 20% of the total energy consumption in China (Wang et al., 2014). Therefore, from the perspective of sustainable development, effective actions must be taken to improve energy efficiency and to reduce CO_2 emissions, such as integration of renewable

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Nomenclature

N	Number of generating units
B	Number of nodes
L	Number of transmission lines
K	Number of critical interfaces
T	Number of periods
$C_i(\cdot)$	Fuel consumption function of generating unit i
$P_{i,t}$	Power output of generating unit i in period t
Δt	Duration of each period
$C_{i,t,U}$	Startup cost of generating unit i in period t
$C_{i,t,D}$	Shutdown cost of generating unit i in period t
$P_{i,t}$	Power output of unit i in period t
W_t	Power output of renewable energy generation units
D_t	System load demand in period t
$\alpha_{i,t}$	Binary variable that denotes the on/off states of unit i in period t. $\alpha_{i,t} = 1$ means the generating unit is on, while $\alpha_{i,t} = 0$ means the generating unit is off.
P_i^{min}	Minimum stable generation of unit i
P_i^{max}	Power rating of unit i
$\Delta P_{i,up}$	Ramp-up limit of unit i
$\Delta P_{i,dn}$	Ramp-down limit of unit i
$X_{i,t-1}^{on}$	ON time of generating unit i in period $t-1$
$X_{i,t-1}^{off}$	OFF time of generating unit i in period $t-1$
T_i^{on}	Minimum ON time of generating unit i
T_i^{off}	Minimum OFF time of generating unit i
ST_i	Constant startup cost of generating unit i
SD_i	Constant shutdown cost of generating unit i
R_t	System spinning reserve requirement in period t
$\overline{PF}_k$	Positive transmission limits of interface k
$\underline{PF}_k$	Negative transmission limits of interface k
$\overline{P}_l$	Positive transmission limits of line l
$\underline{P}_l$	Negative transmission limits of line l
G_{l-i}	GSDF between node i and transmission line l
$D_{i,t}$	Load at node i in period t
SS_k	Set containing the transmission lines in interface k
E_i	Energy of generating unit i
M	Days of this month, in this study $M = 31$
M_i	Days when the unit state is ON

energy (Chen and Mei, 2015), carbon capture and storage (CCS) in the electricity sector (Chen et al., 2010), and electric vehicles (EVs) in the transportation sector (Ji et al., 2012; Hu et al., 2013; Yang et al., 2014; Ocran et al., 2005), respectively. This paper focuses on the electricity sector.

In the past decades, to encourage investors to build power plants and to protect the interest of investors, the Chinese government implemented a generation dispatch mode termed "average generation and utilization hours" (Ding and Yang, 2013), which is also known as "percentage-based dispatch". In the conventional generation dispatch mode, the annual utilization hours of similar types of generating units are nearly the same. Therefore, the annual generation quotas are nearly proportional to the unit capacity. However, this is obviously inefficient. For instance, the fuel consumption rate of an ultra-supercritical 1000-MW generating unit can be as low as 270 g of standard coal per kWh, while that of a 50-MW generating unit can be as high as 450 g of standard coal per kWh (Ding and Yang, 2013).

Under these circumstances, the Chinese government launched the energy-saving generation dispatch (ESGD) in 2007 (NDRC, MEP, SERC, and NEA, 2007). In the *Measures for Energy-Saving Generation Dispatching (Interim)*, the merit order table of the generating units in ESGD is shown in Table 1 (Gao and Li, 2010). Thermal generating units are dispatched based on fuel consumption rates from low to high. If the fuel consumption rates are identical, generating units will be further ranked by the pollutant emission intensities from low to high (Xu et al., 2009).

Fig. 1. The location of five ESGD pilot provinces in China.

Table 1
The merit order table of the generating units in ESGD.

Order	Types of the generating units
1	Renewable generating units with little adjustment capability including wind, solar, oceanic energy and run-of-river hydro generating units
2	Renewable generating units with adjusting capabilities including hydro generating units, biomass and geothermal energy generating units
3	Nuclear generating units
4	Combined cycle thermal generating units whose generation is decided by heating load and resource comprehensive exploitation generating units that specifically refer to waste power generating units
5	Gas-fired generating units
6	Other thermal generating units including a combined cycle thermal generating unit without heating load
7	Oil-fired generating units

The pilot work of ESGD was conducted in the provinces of Jiangsu, Henan, Sichuan, Guangdong and Guizhou in 2007 (Liu et al., 2010). The location of these provinces is shown in Fig. 1. Fuel consumption rate on-line monitoring systems are implemented in these pilot provinces, which can monitor the real-time fuel consumption of each thermal generating unit. The piloting experience showed that these pilot provinces, to some extent, reduced energy consumption and pollutant emissions (Ding and Yang, 2013).

1.2. New challenges emerge

However, two challenges emerge with the currently implemented ESGD. First, because the implementation of ESGD results in the re-allocation of financial interest distribution, the reform encounters great resistance. The large-capacity and highly efficient generating units, renewable energy generating units, and hydropower generating units will obtain substantial benefit, while the small-capacity and low-efficiency generating units will be faced with heavy financial burden. In fact, the annual generation quotas still widely exist. Additionally, the current generation dispatch mode focuses on the day-ahead generation schedules. The generation company is reluctant to shut down the generating unit