Electrical Power and Energy Systems 57 (2014) 135–140

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Joint optimization model of generation side and user side based on energy-saving policy

Tan Zhong-fu [a], Song Yi-hang [a,*], Zhang Hui-juan [a], Shi Quan-sheng [b], Xu Jun [a]

[a] North China Electric Power University, Beijing, China
[b] Shanghai University of Electric Power, Shanghai, China

ARTICLE INFO

Article history:
Received 18 September 2012
Received in revised form 20 November 2013
Accepted 25 November 2013

Keywords:
Time-of-use price
Energy-saving
Unit commitment
Joint optimization

ABSTRACT

China is actively promoting energy saving policies to achieve the commitments promised in Copenhagen. Meanwhile, the relevant energy-saving programs are being implemented in the upstream and downstream of the electric power industry, including energy saving dispatching in the power generation side, and Time-of-Use (TOU) price mechanisms in the user side, etc. In order to optimize the energy efficiency of the power industry chain, it is necessary to implement joint optimization of the generation side and user side. In this paper, considering the constraints such as the user demand for electricity and benefits of the grid company, the joint optimization model of generation side and user side is built, with objective function of minimizing the coal consumption. In the user side, the TOU price is implemented and the fluctuation level of the load curve is reduced by adjusting the tariff of the peak periods and valley periods. In the power generation side, the electricity demand load optimized by TOU in the user side will be balanced in accordance with the principle of energy saving generation dispatching. Optimization results indicate that the response of demand load to TOU price will contribute to achieving energy saving benefits in the generation side.

1. Introduction

In 2011, China's total coal consumption reached 1.84 billion tons oil equivalent, having increased by 9.7% of the last year. Compared with other countries, China's coal consumption accounted for 49.4% of the world's total consumption, far higher than the consumption of the United States who is the global second biggest coal consumer, accounting for 13.5% of the world's total. But in China, proven coal reserves only account for 13.3% of the world's total, lower than 27.6% of the United States and 18.2% of Russian. Considering the reserve-production ratio of the coal, the coal reserves in China can only meet its demand in the next 33 years, lower than the world's average of 112 years, and far lower than the coal reserve-production ratio of the economic giants such as the United States and Japan [1].

The above statistics fully reflect the situation of energy shortage in China, and the national energy security is facing unprecedented challenges. The power industry is an important part of the coal supply chain, and the coal consumption of power industry accounts for 48.4% of the national total coal consumption, therefore, the way power industry was operated decides the energy pattern of the whole nation. In order to promote the development of clean energy and improve the fossil energy utilization efficiency of power system, the State Council of China [2,3] promulgated the "Energy-Saving Scheduling Approach of Power Generation" in 2007, which requires priority scheduling of clean energy and regulates that the scheduling of coal-fired units are ordered according to their energy consumption parameters. The energy-saving dispatching of power generation is a unit commitment (UC) problem in nature, which should fully consider the unit technical constraints, such as start-up, shut-down and ramp up/down, and then pursuit the optimization goal of the lowest coal consumption at the background of energy-saving power generating. Scholars have used kinds of algorithm to optimize the UC problem to achieve different optimization objectives, including artificial bee colony algorithm [4], mixed integer quadratic constraint programming (MIQCP) [5], the imperialist competitive algorithm [6], particle swarm optimization [7], gravitational search algorithm [8], hybrid Taguchi-ant colony system algorithm [9] and rank-constrained semidefinite program [10], etc. These studies indicate that the energy-saving scheduling of power generation can use optimization algorithm to make the scheduling strategy, with the goal of the minimum total coal consumption, and then propose specific compensation policy to ensure the implementation of energy-saving power generation dispatching [11,12].

The above studies mainly focus on the power generation side, while on the demand side, various demand-side management tools can also be used to affect the electricity consumption behaviors and achieve adjustment of the load distribution, such as Time-of-Use (TOU) price, interruptible load price, and multistep residential

* Corresponding author.
E-mail address: allensoon@163.com (Y.-h. Song).

0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.11.042

electricity tariff [13,14]. In literature [15], a joint optimization model of interruptible load price and TOU tariff was built to reduce the difference between peak and valley load through demand-side management. In order to further research on the relationship between electricity load optimization and the energy efficiency of the generation side, literature [16] established an multi-objective optimization model for TOU design, which targeted at minimum peak load and minimum difference between peak load and valley load, and analyzed the coal consumptions of power generation before and after TOU optimization. They found that the implementation of TOU helps to reduce the coal consumption of power generation. Oriented by energy-saving dispatching, Literature [17,18] build the optimization model of the TOU implementation both on the generation side and demand side in order to reduce the coal consumption of the power generation, with the precondition that the benefits of generators, grid and consumers were guaranteed, and then the model was solved by genetic algorithm. Literature [19] centered on the grid reliability, and a joint unit commitment model of the generation side and the demand side was constructed, with the goal of seeking optimal grid reliability and decision variables of the TOU tariff adjustment range.

Based on above research, this paper focuses on the transmission effects of TOU power price in the demand side on coal consumption in the generation side. A joint optimization model of TOU price and energy-saving power generation dispatching is developed to pursuit the minimum total coal consumption of power generation, unit start-up and unit shut-down under different price adjustment proportions of peak load period and valley load period.

2. Energy-saving generation dispatching model of units on power generation side

According to energy-saving power generation dispatching policy, based on the premise of security check which is a measure guaranteeing the load flow distribution within the limit, the dispatching center will dispatch the following units in turn: the renewable energy units, nuclear power generators, the comprehensive utilization of resources units such as cogeneration units, gas-fired units, coal-fired units and oil-fired units. At present, installed capacity of new energy generation, include wind power and photovoltaic power generation, accounts for less than 5% of the total power generation capacity in China. Under the condition that it is difficult for clean energy generation units to meet the system load demand, clean energy power generation will be wholly accepted by the grid as long as the security check requirements were met. The dispatching of coal-fired units should closely combine with the units' energy consumption parameters, and gradually transits from using factory consumption parameters to the measured value. Guided by the goal of minimum total coal consumption of power generation, energy-saving generation dispatching model (P_1) of units on the generation side before the implementation of TOU can be built as follows:

$$MINz_1 = \sum_{t=1}^{T}\sum_{j=1}^{J}\left[u_{jt}f_j(g_{jt}) + u_{jt}(1-u_{j,t-1})SC_{jt} + u_{j,t-1}(1-u_{jt})SD_{jt}\right]$$

$$\text{s.t.} \sum_{j=1}^{J} u_{jt}g_{jt}(1-\theta_j) = G_t^{(0)} \tag{1}$$

$$\sum_{j=1}^{J} g_j^{max}(1-\theta_j) \geqslant G_t^{(0)} + R_t^{(0)} \tag{2}$$

$$f_j(g_{jt}) = a_j g_{jt}^2 + b_j g_{jt} \tag{3}$$

$$u_{jt}g_j^{min} \leqslant g_{jt} \leqslant u_{jt}g_j^{max} \tag{4}$$

$$\Delta g_j^- \leqslant g_{jt} - g_{j,t-1} \leqslant \Delta g_j^+ \tag{5}$$

$$\left(T_{j,t-1}^{on} - MT_j^{on}\right)(u_{j,t-1} - u_{jt}) \geqslant 0 \tag{6}$$

$$\left(T_{j,t-1}^{off} - MT_j^{off}\right)(u_{jt} - u_{j,t-1}) \geqslant 0 \tag{7}$$

In the objective function, z_1 is the total coal consumption before TOU, u_{jt} is the state variable of unit j at the time t, which is 1 at the start-up state and 0 at the shut-down state; g_{jt} is the output of unit j at the time t; $f_j(g_{jt})$ is the units' total coal consumption function, with corresponding parameters a_j and b_j; SC_{jt} And SD_{jt} are the coal consumptions of unit's start-up and shut-down. Eq. (1) is the balancing constraint of the power system; $G_t^{(0)}$ is on-grid active power of all units of the region in the period of t before the implementation of TOU; θ_j is the station service power consumption rate of the unit j. Constraint (2) is the reserve constraint of the system; g_j^{max} is the maximum output of unit j; $R_t^{(0)}$ is the system reserve demand in time t before the implementation of TOU. Constraint (4) is the unit output constraint; g_j^{min} is the minimum output of the unit j. Constraint (5) is the ramp up/down constraint of the unit; Δg_j^- and Δg_j^+ are the response speed limits for unit ramping up and down. Constraint (6) is the shortest start time constraint of unit j; $T_{j,t-1}^{on}$ is the running time of unit j during the period $t-1$; MT_j^{on} is the minimum running time of unit j. Constraint (7) is the shortest shut-down time constraint of unit j; $T_{j,t-1}^{off}$ is the shut-down time of unit j during the period $t-1$; MT_j^{off} is the minimum shut-down time of units.

3. TOU price response model on the user side

Before the implementation of TOU, the relationship between electricity demand of electricity customers of different categories and voltage levels in each period and the on-grid active power of regional power source meet the following equation:

$$G_t^{(0)} = \sum_{i=1}^{I}\left[D_{it}^{(0)}/(1-l)\right] \tag{8}$$

where $D_{ikt}^{(0)}$ is user's power demand of category i in the period of t; l is the integrated transmission and distribution line loss rate.

After the implementation of TOU, the power load will be changed in each period:

$$D_{it} = D_{it}^{(0)} + \Delta D_{it} \tag{9}$$

where D_{it} is the customers' power demand after the implementation of TOU; ΔD_{it} is the change range of power load in the relevant period. The relationship between the user's demand elasticity and change ranges of various power load and power price is shown as follows [20,21]:

$$e_{ist} = \frac{\Delta D_{is}/D_{is}^{(0)}}{\Delta P_{it}/P_{it}^{(0)}} \tag{10}$$

where e_{ist} is the user's demand elasticity of category i, indicating the affection of price change in the period of t on the power demand in period s; ΔP_{it} is the adjustment range of power price in the period of t after TOU was implemented; P_{it} is the electricity price before TOU was implemented. When $s = t$, e_{ikst} indicates the affection of price change on the power demand in present time (self-elasticity); when $s \neq t$, e_{ikst} indicates the affection of price change in present time on the power demand in other period of time (cross-elasticity). The power demand period in one day can be divided into three periods as peak, flat, and valley, and the demand elasticity matrix of category i will be:

$$E_i = \begin{bmatrix} e_{ipp} & e_{ipf} & e_{ipv} \\ e_{ifp} & e_{iff} & e_{ifv} \\ e_{ivp} & e_{ivf} & e_{ivv} \end{bmatrix} \tag{11}$$