ENERGY SAVING OPTIMIZATION OF THERMAL POWER CO-GENERATION AUTOMATION SYSTEM IN POWER PLANT

by

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In order to establish a new optimal load distribution between CHP units and wind turbines and realize a new type of energy-saving dispatching, the authors proposed a dispatching system based on smart grid. The author proposed that the heat pump with electric drive air conditioning should share part of the heating load of the hot water radiator, accordingly, the supply of heating water is reduced, increase heating power load. This directly leads to the increase of the total power load in the grid and the decrease of the total heating and hot water load, changing the proportion of thermal power load. Based on the new heating water and power load constraints, a mathematical model of optimal scheduling is established, the energy-saving dispatching of cogeneration units and wind turbines is realized. The simulation results show that using the new energy-saving scheduling method, 342.4 MWh of fuel can be saved per hour, and the energy saving benefit is about 8.83%. If the calorific value of standard coal is 29271 kJ/kg, this means that the fuel consumption savings per hour is about 42.14 ton standard coal. The calculation results show that the higher the value is, the more economically feasible the feed-in price of wind power is. In conclusion based on the current electricity price and heating heat price, in order to ensure that the economic benefits of each participant are not changed, the feed-in price of wind power is discussed, and the economic feasibility of the method is proved.

Key words: *smart grid, combined heat and power generation, wind turbine, energy saving, scheduling, electricity price, power load*

Introduction

In the 21st century, the world's most potential for large-scale development of power generation for wind power generation. Large-scale development of wind energy resources is one of the main measures to reduce coal consumption, alleviate environmental pollution, improve the overall resource structure and promote the rational development of society [1]. By the end of 2012, the country has a total installed wind power capacity of 44.84 GW, overtook the USA in the world's total installed wind power capacity for the first time, reached number one. The installed capacity of wind power connected to the grid in China exceeds 30 GW, of which the *three north* (Northeast, northwest, North China) region accounts for more than 90%, the total annual wind power generation accounts for 1.4% of the total electricity consumption in China, about 50 TWh. According to the data of the total grid-connected capacity of wind power in Northeast China in 2012, the grid-connected capacity of wind power

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in Heilongjiang, Jilin, Mengdong, and Mengxi all exceeded 20% of the maximum load of the system in the region. However, compared with the abundant wind energy resources, the existing development capacity does not even reach 5% of the total development potential of wind energy, so the development space of wind power is still large. Load characteristics of power grid are important basis for power grid dispatching. In recent years, the power demand in the *three North* (Northeast, North and Northwest) regions in winter increases slowly in the trough of the grid, but rapidly in the peak. In addition, the demand for heat load on the heating side in these areas is generally small during the day and large at night, while the wind power output is large at night and small during the day, resulting in the peak-valley difference of the power grid increasing year by year, for example, the maximum peak-valley difference of Northeast power grid, in 2009, it was 10.674 million kW, in 2010, it was 12.18 million kW, and in 2011, it exceeded 13.12 million kW. With the continuous increase of the peak-valley difference of the grid load in the *three-north* area, the peak regulating capacity of the grid further declined.

Literature review

The *detailed rules for the implementation of energy-saving power generation scheduling measures* stipulates that *wind energy without adjustment capacity in the power grid has the first priority for power generation*. However, in the actual operation of the power grid, a large number of shutdowns and abandonment of wind have occurred. Due to the simultaneous existence of a large number of cogeneration units and wind turbines in the Inner Mongolia power grid, a large number of wind turbines must be stopped when the grid load is low to ensure the combined heat and power. Production unit heating operation needs. This is due to the definite operating condition constraints between the heat supply and the power generation of the co-generation unit. The aforementioned phenomenon is common in the northern heating areas of my country, and it is suggested to solve the problem by establishing a regionally interconnected transmission network to supply wind power.

In recent years, scholars have studied the use of thermal inertia to improve wind power consumption. Massaoudi *et al*. [2] aimed at the problem of unco-ordinated electric heating network in the combined electric heating system, by introducing the inertia model of solid electric heat storage boiler into the system, a co-ordinated electric heating operation model with multiple thermal inertia of the thermal system is established, which effectively realizes the electric pyrolysis coupling. Zahedi *et al*. [3], further studied the quasi-dynamic equation of heat energy transport, analyzed the quantitative method of the difference between heat network monitoring data and energy transport model, and then established the thermal inertia uncertainty model under robust optimization. Cao *et al.* [4] in order to solve the contradiction between the continuity of heat energy transmission and the dispersion of scheduling period, the flow segmentation method was used to accurately model the inertia of heat network, and a model considering various thermal inertia of source, network and load was established. Kallio and Siroux [5] considered the actual physical model of heat storage and release in the heat network, and applied the inertia model of the heating area to the scheduling, the heat dissipation in the heating area is taken as the control variable and the wind abandonment is absorbed through the inertia of the heating area. The simulation results show that, the improved dispatching model is beneficial to improve the system economy and the capacity of wind power consumption. At present, for the study of electrothermal combined system, it mainly focuses on the inertia of heat network and the heat storage characteristics of heat load, for example, the inertia of heat network and the heat storage characteristics of heat load are used to improve the acceptance capacity of wind power. However, these studies lack the analysis of the influence of the structure of the thermal load itself on inertia, and only regard the thermal load as a heat storage device with adjustable heat. Sun *et al*. [6], when heating a heat load, the heat load is only regarded as a load point controlled by the radiator and outdoor temperature, without considering the influence of building structure on the heat storage capacity of the heat load. Latif *et al*. [7] based on the autoregressive moving average model, the coupling relationship between multiple time periods of the heating power system was established, and the heat load was regulated in terms of heating quantity and time, the feasibility of the co-ordinated thermoelectric scheduling model of the micro-grid was verified by simulation.

This study points out that the existing grid dispatching cogeneration units and wind turbines are based on the principle of *determining electricity by heat*. First, ensure that the heating load is borne by the hot water output by the cogeneration unit, which is equivalent to determining the heating constraints. However, under the determined heating output, the adjustable range of the power generation output of the cogeneration unit is limited, which leads to the difficulty of dispatching the wind turbine and the occurrence of the phenomenon of shutdown and abandonment of wind.

This study further points out that the proportion of cogeneration units in the power grid in the north of China is high, changing the proportion of hot water consumption and electricity consumption in the heating terminal load can change the proportion of the hot water load and the total power load of the grid at the same time, thus, a new optimal load distribution is established between CHP units and wind turbines to realize a new energy-saving scheduling. The author focuses on the energy-saving benefits of this method [8].

Research methods

Based on smart grid technology, some researchers have proposed remote control systems and methods for both cogeneration units and terminal heating users [9]. A dispatching system for cogeneration units and a control system for end-user heating mode management are presented.

New energy-saving scheduling system

The remote monitoring and control system of a provincial power grid cogeneration unit has been built and operated, as shown in fig. 1. According to the requirements of *Electric Power Secondary System Safety Protection Regulations*, the system network design and safety protection measures are designed. On-site real-time data are collected by the power plant through RTU and then connected to the database through EMS [10]. The method proposed by the author only uses the system to monitor and control the three physical quantities of generation output, heating output and fuel input of the cogeneration unit.

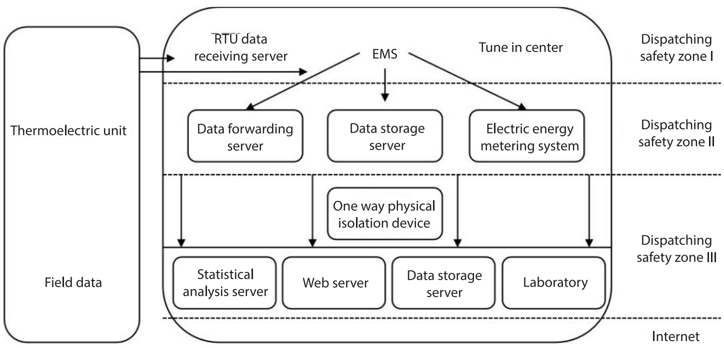

Figure 1. Block diagram of remote monitoring and control system for CHP unit

The remote monitoring of end-user heating load and the remote management system of heating mode in the dispatch center are shown in fig. 2. The system has been built in several smart residential areas.

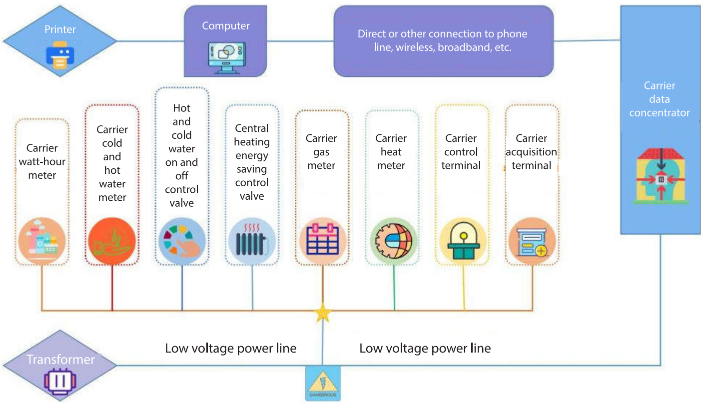

Figure 2. Intelligent terminal system diagram for remote control and management of resident users

The system uses the power line carrier communication and control terminal to control the heating energy-saving control valve. The heat pump switch of the corresponding air conditioner is controlled by single and three phase watt-hour meter. According to the heating mode of end users, demand-side management is carried out, so that the heating load of end users can be converted between heating hot water and power supply, so as to realize remote open and close hot water heating radiator and open and close corresponding air-conditioning heat pump heating [11, 12].

New energy-saving scheduling method

Under the new energy-saving dispatching method, the heating load H^*_{CHP} is jointly undertaken by the heating and hot water produced by the cogeneration unit and the electric-driven air-conditioning heat pump:

$$H^*_{\mathrm{CHP}} = \sum_{i=1}^{I} \left(Q_i \eta_i^q \right) + C_{\mathrm{OP}} E_{\mathrm{EHP}} \tag{1}$$

where C_{OP} is the heating coefficient of end-user air-conditioning heat pump heating and E_{EHP} – the power consumption load of air-conditioning heat pump heating under the new energy-saving scheduling mode, which is a non-negative variable.

Equation (2) indicates that under the new energy-saving dispatching method, the increased total power load needs to be shared by the cogeneration unit and the wind turbine:

$$P^*_{\mathrm{sum}} + E_{\mathrm{EHP}} = \sum_{i=1}^{I} \left(E_i \eta_i^e - Q_i E_{\mathrm{HR}} \right) \eta_{\mathrm{GBD}} + E_{\mathrm{WIND}} \eta_{\mathrm{WIND}} \tag{2}$$

where E_{WIND} is the power generation output of the wind turbine and η_{GBD} – the power supply efficiency of the wind turbine, calculated as 0.95.

The cogeneration unit needs to operate under certain working condition constraints:

$$0 \le Q_i \le Q_i^{\max} \tag{3}$$

$$E_i^{\min} \leq E_i \leq E_i^{\max} \tag{4}$$

where $Q_i^{\max}$ is the maximum allowable heating output of the i^{th} co-generation unit under the new energy-saving scheduling mode, $E_i^{\min}$ and $E_i^{\max}$ are the minimum and maximum heating output of the i^{th} co-generation unit under the new energy-saving scheduling mode, respectively, power output.

Equation (5) is a new energy-saving scheduling method using heating management, which can obtain energy saving compared with the existing scheduling method of *setting electricity by heat*:

$$\Delta F = \frac{F_{\text{CHP}}^{*} - F_{\text{CHP}}}{F_{\text{CHP}}^{*}} \times 100\% \tag{5}$$

where ΔF is the energy saving benefit.

New energy-saving scheduling method

Based on the aforementioned hardware system, the integrated energy-saving scheduling of cogeneration and wind turbines can be realized through the demand-side management of heating mode for end users [13]. The specific scheme is described:
- Reduce the output of hot water for heating of cogeneration units and close some end users' hot water heating radiators, turn on the air-conditioning heat pump heating of the corresponding end user, which changes the proportion of the heating load, respectively borne by the hot water radiator and the electric air-conditioning heat pump.
- For the new heating hot water load, heating electric load and existing non-heating electric load, carry out the optimal load distribution and dispatch between the wind turbine and the CHP unit.
- The essence of this method is: In order to find the optimal heating water and power load heat power ratio, with the changed heating hot water load and power load as constraints, the optimal output of cogeneration unit and wind turbine unit is, respectively found [14].

Result analysis

Mathematical model of cogeneration unit

Because in reality, the two systems of urban heating and power supply are independent of each other, the scheme proposed by the author cannot be tested in the actual system for the time being, but the energy saving and economic feasibility of the method can be tested by simulation calculation.

A total of 12 C135/N150-13.24/535/535/0.400 turbine CHP units and 100 MW wind turbines are used as examples. Based on the actual monitoring data of the CHP unit, eqs. (6)-(8) are the operating conditions of the CHP unit:

$$E^{\max} = -0.297Q + 151.90 \leqslant Q \leqslant 153 \tag{6}$$

$$E^{\max} = \begin{cases} -0.344Q + 92.06 & 0 \leqslant Q < 85 \\ 0.33Q + 35.32 & 85 \leqslant Q \leqslant 153 \end{cases} \tag{7}$$

$$F = 0.68Q + 2.45E + 9.590 \leqslant Q \leqslant 153 \tag{8}$$

In the simulation calculation, it is assumed that the total power load of a regional power grid is 878 MW and the total heating load is 1781 MW. Assuming that the unit operation time is 1 hours, each CHP unit in the current *heat to fix electricity* dispatching mode produces 153 MW heating output and 85.9 MW power generation output. The 100 MW wind turbine was forced to shut down and abandon the wind, and the grid-connected power generation output was 0. According to the energy efficiency limit value and energy efficiency level of room air conditioners, the existing energy efficiency ratio of heating and heating of air conditioners ranges from 1-6 [15]. If we take 4 as the C_{OP} value of the energy efficiency of the room air conditioner, using non-linear programming (NLP), the optimization calculation results are shown in tab. (1). Computing environment: GAMS software, the CPU is Intel Core2 Duo 2.66 GHz, and the memory is 4 GB. The 357 seconds.

Table 1. Comparison between the new energy-saving scheduling and the traditional scheduling MWh

Unit composition	The output way	The traditional way	A new way
Combined heat and power unit	Heating quantity	1836	408
	Power generation	1030.8	1284
	Amount of fuel	3880.8	3538.4
Wind turbines	Power generation	0	100
other	Air conditioning heat pump power	0	3572

As shown in tab. 1, the new energy-saving scheduling method is adopted, the fuel can be saved 342.4 MW per hour, and the energy saving benefit is about 8.83%. If the calorific value of standard coal is 29271 kJ/kg, this means that the fuel consumption savings per hour is about 42.14 tons standard coal.

Simulation results

Table 2 shows the current electricity price and heating price.

Table 2. Current heating price and electricity price [Yuan per MWh]

Species	Price	Species	Price
$\varepsilon_e^{\mathrm{end}}$	500	ε_q	100
$\varepsilon_e^{\mathrm{end}}$	300	ε_f	100

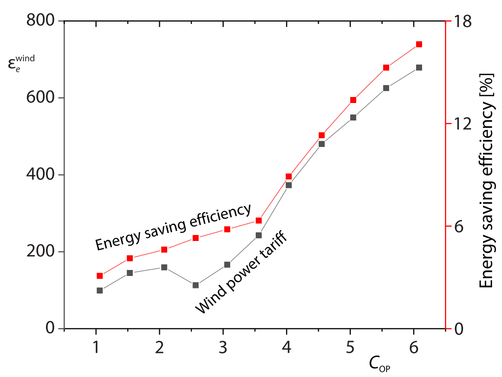

Figure 3. Energy saving benefits and wind power economic benefits brought by the new energy saving scheduling

If the energy efficiency ratio of heating and heating of room air conditioner is considered to change from 1-6, energy saving and economic benefits obtained under different C_{OP} values are shown in fig. 3. In the figure, the energy saving efficiency represents the energy saving benefit brought by the new dispatch mode, and the on-grid price can be obtained by wind power, which proves the economic feasibility of the new dispatch mode.

As shown in fig. 3, different C_{OP} values produce different energy saving benefits, the larger C_{OP} value is, the greater energy saving efficiency is, the higher the technical feasibility, the higher the feed-in tariff for wind power. This calculation of wind power feed-in price, compared with the four-level wind power electricity price 510, 540, 580, 600 yuan per MWh stipulated in the Notice on Improving the Policy of Wind Power Feed-in Price of National Development and Reform Commission, it is economically viable. The calculation results show that the higher the C_{OP} value is, the more economically feasible the feed-in price of wind power is.

In the new energy-saving dispatching mode, the benefits ΔC_{END}, ΔP_{CHP}, and ΔP_{GRD} of terminal heating users, CHP units and power grid that need to be adjusted, respectively are shown in fig. 4. That is, compared with the existing scheduling method of *determining electricity by heat*, the new scheduling method leads to the necessary adjustment of the interests of all parties involved.

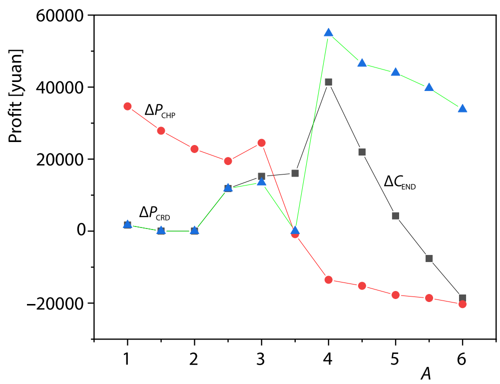

Figure 4. Interest adjustment of supply and demand parties under the new energy-saving scheduling mode

As shown in fig. 4, ΔC_{END} has a critical value, that is, when the heating C_{OP} is greater than a certain critical value, user expenditure will be reduced and users themselves will get economic benefits. If ΔP_{CHP} and ΔP_{GRD} are greater than 0, it means that the new energy-saving dispatching method can bring more profits to the thermal power plant and the power grid than the current dispatching mode. All three are assumed to remain unchanged through various means of administrative policy. Profits greater than zero are subsidized to wind turbines to improve the economic viability of their feed-in tariffs. Otherwise, wind turbines are needed to subsidize end-user expenditures, thermal power plant profits and grid profits.

Conclusions

The author presents a new energy saving dispatching system and method for power grid using heating management. The system and method are based on smart grid technology, through the management and regulation of the heating mode of end users, the heating output of cogeneration unit is controlled to realize grid-connected power generation of more wind turbines, so as to achieve the purpose of energy saving dispatch. The system is based on smart grid technology, firstly, a remote control system for end-user heating is constructed to manage the end-user heating mode. Secondly, a remote monitoring and dispatching system for cogeneration units has been established, co-operate with the grid to increase the grid-connected power generation of wind turbines. The simulation results show that the method is feasible in energy saving and economy, are as follows.

- Reduce the use of cogeneration central heating by regulating end-user heating patterns, increase the use of electric air conditioning heat pump heating. Change the ratio of heating hot water load and power load to realize the heating demand side management.
- According to the new heating hot water load and grid power load constraints, establish the optimal load distribution and dispatch between CHP units and wind turbines. The simulation results show that under the new energy-saving scheduling method, the energy-saving benefit increases with the increase of C_{OP}.
- With the increase of C_{OP} value, the feed-in tariff obtained by the wind power plant also increases. The electricity price has sufficient economic feasibility compared with the cur-

rent wind power feed-in price established by the state. At this time, it can ensure that the economic interests of thermal power plant, power grid and end users are consistent with the current dispatching mode.

- Under the new energy-saving scheduling mode of heating management, the economic benefits of thermal power plant and power grid end users need to be adjusted, make it comparable to the current *heat based electricity* scheduling system, in order to ensure the smooth development of the new energy-saving scheduling, with sufficient economic feasibility.

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