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Research on Economic Effect of Wind Power Accommodation Based on Electric Boiler and Heat Accumulator

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Abstract: Facing serious wind power curtailments problem, the new economic analysis method of accommodating wind power based on electric boilers and heat accumulators with combined heat and power(CHP) is presented in the paper. Firstly, the cause of tremendous wind power curtailment in the north power grid of China is introduced. Secondly, thermoelectric characteristics of CHP is introduced. Thirdly, implement mode of advancing wind power accommodation based on electric boiler and heat accumulator is presented. Finally, economic benefits of increasing wind power accommodation are calculated and the meaningful conclusion is obtained by example analysis.

Keywords Wind power accommodation, CHP, Electric boilers, Heat accumulators.

INTRODUCTION

Wind power is an important resource for solving energy and environmental issues in recent years. In 2017 the accumulative installed wind power capacity in China reached 164 GW and has the largest installed wind power capacity in the world. Wind power capacity was the third power capacity that inferior to thermal power capacity and hydropower capacity in China. With rapid increase of wind power capacity, the problem of wind power curtailment becomes increasingly serious. According to National Energy Board counted, wind power curtailment of China are about 41.9 billion kWh and direct losses are 21.8 billion Yuan in 2017. Lack of the peak regulation ability of power system is one of the most important causes [Yuan, et. al., 2014] of tremendous wind power curtailments.

Northern China are major areas of wind power development and have 80% of the total installed wind power capacity. Its' power structures are coal-fired thermal power unit and load regulating capacity is insufficient. Confront by the technical difficulties of lack of accommodation capacity and external delivery capability of local power grid because of large-scale wind power locating the end of power grid in the areas. Combined heat and power units operating in the mode of forced power output determined by heat in order to meet the demand of heat load will further decrease the peak regulation ability of CHP and increase contradiction of lack of the peak regulation ability of the system. It causes lots of wind power curtailment.

In order to improve wind power accommodation, lots of measures were proposed by the domestic and foreign scholars. In [Yan, et. al., 2013], heat pump technology used to increase wind power accommodation at the supply side. In [Zheng, et. al., 2014], electric boilers used to increase wind power accommodation at the supply side. In [Xu, et. al., 2014 and Yuan, et. al., 2013], Heat accumulator technology and energy alternative technology are in focus considerable.

The paper focuses on decoupling the constraint of forced power output determined by heat by configuring large electric boilers and heat accumulators for CHP and calculating benefits and costs of the system that include electric boiler and heat accumulator for CHP units.

The following of the paper consists of four sections: the peak-load regulation principle of CHP is discussed in Section 2. wind power accommodation with the installation of electric boilers and heat accumulator is discussed in Section 3. A case considering an actual grid is presented to illustrate the proposed method in Section 4, followed by conclusions in Section 5.

THERMOELECTRIC CHARACTERISTICS OF CHP UNITS

Heating mode of CHP units and regional boilers operating collectively is adopted in winter heating period. Because of inefficiency and high pollution of regional boiler, heating mode of CHP becomes popular. CHP units include backpressure units and extraction condensation units. Coupling relation between electric power output and heating power output is called thermoelectric characteristics.

For backpressure units, backpressure exhaust of turbines transfer heat with heat supply network by heat exchanger and achieve supply heat for heat loads by heat supply network. Its' heating power and electric power present approximately coupling relation. Electric power of CHP units are decided by heating power and heat-to-electric ratio is confirmed. Backpressure units have not regulating capacity in order to meet heat load demands in heating period.

For extraction condensation units, a part of steams as heat source are extracted from intermediate pressure cylinder and low pressure cylinder of turbines for supplying heat. Heat-to-electric ratio of turbines are adjusted by accommodating steam extraction under the conditions of satisfying operation, therefore the relation of heating power and electric power can be commonly presented operating region. Electric power can be adjusted within limits for some heating power. When heat loads become higher, steam extraction increasing results in reducing adjustable range of electric power. If wind power become large, extraction condensation units need operate in minimum condensing condition in order to enough spaces for wind power. At present electric power of CHP units are decided by heating power and CHP units have not regulating capacity [Lü, et. al., 2014].

BOILER AND HEAT ACCUMULATOR WIND POWER ACCOMMODATION MODE BASED ON ELECTRIC BOILERS AND HEAT ACCUMULATORS FOR CHP UNITS

Power system and thermodynamic system are connected by CHP units in mains side. Since CHP units have thermoelectric characteristics constraint of forced power output determined by heat, it limits electric power. If CHP units can accommodate tremendous wind power curtailment by reducing forced power output result from forced power output determined by heat, insufficient heat supply of CHP units need be compensated. Since supply of heat by using electric boilers make high quality electric energy become low quality heat energy, electric boilers try to use wind power curtailment. If electric boilers supply heat without heat accumulator, electric loads of electric boilers are decided by heat loads and peak-load regulation ability of electric boilers are low. Therefore the project is composed that compensating supply heat and decoupling the constraint of forced power output determined by heat by configuring large electric boiler and heat accumulator for CHP units in the paper. The project can improve regulating capacity of CHP units.

When wind power is large and wind power curtailment appear, on the one hand electric boilers that installed in combined heat and power plant supply heat by consuming a part of wind power curtailment and electric power of CHP units are reduced by reducing heating power of CHP units, on the other hand electric power of CHP units are reduced by supplying heat of heat accumulators [Hedegaard, et. al., 2013]. The on-grid spaces of wind power are increased to accommodating wind power curtailment by reducing electric power and lack of supply heat are compensated by electric boilers and heat accumulators. Accommodating curtailed wind power effectively is achieved with ensuring heating level.

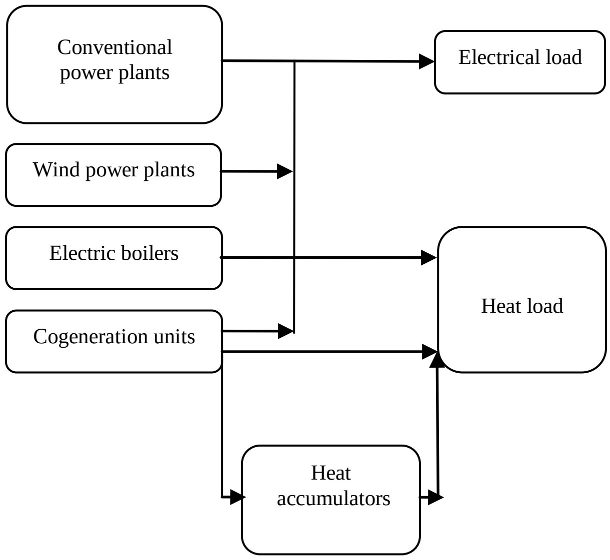

Figure 1 Diagram of accommodating wind power curtailment by combined heat and power plant

ECONOMIC BENEFITS OF WIND POWER ACCOMMODATION BASED ON ELECTRIC BOILER AND HEAT ACCUMULATOR

Benefits analysis of the project

According to the principle, benefit sources of accommodating curtailed wind power by electric boilers and heat accumulators include three parts: The first part is coal saving benefits of reducing consumption of coal by decreasing electric power of CHP units because of electric boilers supplying a part of heat instead of CHP units. The second part is coal saving benefits of reducing coal consumption by decreasing electric power of CHP units because of heat accumulators supplying a part of heat instead of CHP units. The third part is having a share in benefits of on-grid wind power owing to improving level of curtailed wind power by electric boilers and heat accumulators.

The first part benefit: saving consumption of coal per year Q_{EB} [Lü, et. al., 2014]by configuring electric boilers in combined heat and power plant:

$$Q_{EB} = 0.1228 \frac{C_{EB}\beta_{EB}\left(1+\gamma_{CHP}\right)}{\beta_{CHP}\gamma_{CHP}} h_{EB}$$

Where β_{EB} is heat production efficiency of electric boilers, β_{CHP} is fuel efficiency of CHP units, γ_{CHP} is heat-to-electric ratio of CHP units, h_{EB} is average operation hours per year of electric boilers.

If the price of standard coal equivalent is υ, coal saving benefits of electric boilers in combined heat and power plant:

$$B_{EB} = 0.1228 \frac{C_{EB}\beta_{EB}\left(1+\gamma_{CHP}\right)}{\beta_{CHP}\gamma_{CHP}} h_{EB}\upsilon$$

The second part benefit: when curtailed wind power that are accommodated by CHP is W_W , saving consumption of coal is:

$$Q_{HA} = 0.1228 \frac{\beta_{EB}\left(1+\gamma_{CHP}\right)}{\beta_{CHP}\left(\beta_{EB}+\gamma_{CHP}\right)} W_W$$

In view of increasing accommodation of curtailed wind power by supplying heat of heat accumulators similar to electric boilers, saving consumption of coal by heat accumulators increasing accommodation of curtailed wind power is calculated by formula (4). Coal saving benefits of heat accumulators per year:

$$B_{HA} = 0.1228 \frac{\beta_{EB}\left(1+\gamma_{CHP}\right)}{\beta_{CHP}\left(\beta_{EB}+\gamma_{CHP}\right)} W_W\upsilon$$

The third part benefit is environmental benefit: the environmental benefit is associated with the external and social benefit evaluations compared with the economic benefit based on coal costs in this system. The extra wind power accommodated by the power grid will replace a certain amount of thermal power generation. We define the reduction in pollutant and CO_2 emissions as the environmental benefit.

The environmental benefit of this project is based on Q_{EB} and Q_{HA} increasing (coal consumption decreasing) after the project is implemented. The environmental benefit evaluation model is given by:

$$B_{EH} = \left(Q_{EB}+Q_{HA}\right)\times\mu + \left(Q_{EB}+Q_{HA}\right)\times e_c\times\varepsilon$$

where μ is the pollutant emission cost per ton of coal, e_c is the CO2 emissions per ton of coal, and ε is the carbon emission cost.

The total benefits B per year of electric boilers and heat accumulators is:

$$B = B_{EB} + B_{HA} + B_{EH}$$

Costs analysis of the project

The costs consist of initial construction costs, operating and maintenance costs of electric boilers and heat accumulators. Initial construction costs consist of original equipment cost, construction cost and installation cost etc and are calculated refer to existing projects. Operating and maintenance costs consist of energy cost, operating personnel cost and quick-wear parts cost etc and are calculated by a certain proportion according to initial construction costs.

Supposing capacity of electric boilers is C_{EB} , capacity of heat accumulators is C_{HA} , construction cost per unit of electric boilers is u_{EB} , construction cost per unit of heat accumulators is u_{HA} , service life of electric boilers and heat accumulators are both N . In consideration of using curtailed wind power to supply heat for electric boilers, short-term cost of electric boilers is 0. Operating and maintenance costs of electric boilers and heat accumulators are respectively calculated by a certain proportion α and β . The total costs C per year of electric boilers and heat accumulators is:

$$C = C_{EB}\times u_{EB}/N + C_{EB}u_{EB}\times\alpha + C_{HA}\times u_{HA}/N + C_{HA}u_{HA}\times\beta$$

Example analysis

A 300MW extraction condensation unit is as research subject in North China in the paper. Capacity of electric boilers is 10MW. Construction cost per unit of electric boilers is 1 million Yuan/MW. Capacity of heat accumulators is 20MW. Construction cost per unit of heat accumulators is 03 million Yuan/MW. Maintenance costs ratio of electric boilers and heat accumulators are respectively 1% and 2%. Service life are both 20 years. Heat production efficiency of electric boilers is 99%. Fuel efficiency of CHP units is 0.7 because of operating under backpressure condition or minimum condensing condition for CHP during curtailed wind. Heat-to-electric ratio of CHP is 2. Average operation hours per year of electric boilers is 300h, 400h and 500h respectively. Coal price is 500 Yuan/t and amount to 715 Yuan/t of the price of standard coal equivalent. Pollutant emission cost per ton of coal μ is 80 Yuan/t. CO2 emissions per ton of coal e_c is 2.6 t. Carbon emission cost ε is 25 Yuan/t.

When average operation hours per year of electric boilers is 300h, 400h and 500h, comprehensive profits separately are 1673560 Yuan, 1897160 Yuan and 2121620 Yuan. When other conditions are not changed and average operation hours per year of electric boilers h_{EB} is changed separately from 300h to 400h, comprehensive profits increase by 1.13. When h_{EB} is changed from 300h to 500h, comprehensive profits increase by 1.27.

CONCLUSIONS

Aim at the problem of tremendous wind power curtailment in the north power grid of China, the method of decoupling the constraint of forced power output determined by heat by configuring large electric boiler and heat accumulator for CHP is proposed. By Economic benefits analysis of the project, there are significant benefits of coal saving by using wind power to supply power and heat instead of CHP units. Since some factors such as average operation hours per year of electric boilers h_{EB} and heat-to-electric ratio of CHP units γ_{CHP} dramatically influence economic benefits of the project, the project has priority to be applied to the conditions of large curtailed wind power, long curtailed wind time and small heat-to-electric ratio of CHP units.

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REFERENCES

Hedegaard, K.; Münster, M. Influence of individual heat pumps on wind power integration—Energy system investments and operation. Energy Convers. Manag. 2013, 75, 673–684.

Lü Quan, Jiang Hao, Chen Tianyou, Wang Haixia, Lü Yang, Li Weidong. Wind power accommodation by combined heat and power plant with electric boiler and its national economic evaluation[J]. Automation of Electric Power Systems, 2014, 38(1): 6-12.

Lü Quan, Chen Tianyou, Wang Haixia, Yu Ting, Li Qun, Tang Wei. Analysis on peak-load regulation ability of CHP with heat accumulator[J]. Automation of Electric Power Systems, 2014, 38(11): 34-41.

Xu Fei, Min Yong, Chen Lei, Chen Qun, Hu Wei, Zhang Weiling, Wang Xiaohai, Hou Youhua. Combined electricity-heat operation system containing large capacity thermal energy storage[J]. Proceedings of the CSEE, 2014, 34(29): 5063-5072.

Yan Gangui, Liu Jia, Cui Yang, Mu Gang, Li Junhui,Xu Guangxin. Economic evaluation on improving wind power scheduling scale by using energy storage systems[J]. Proceedings of the CSEE, 2013, 33(22): 45-52.

Yuan, J.; Sun, S.; Shen, J.; Xu, Y.; Zhao, C.Wind power supply chain in China. Renew. Sustain. Energy Rev.2014, 39, 356–369.

Yuan Xiaoming, Cheng Shijie, Wen Jinyu. Prospects analysis of energy storage application in grid integration of large-scale wind power[J]. Automation of Electric Power Systems，2013，37(1)：14-18.

Zheng Le, Hu Wei, Lu Qiuyu, Min Yong, Yuan Fei, Gao Zonghe. Research on planning and operation model for energy storage system to optimize wind power integration[J]. Proceedings of the CSEE, 2014, 34(16): 2533-2543.