Study on the Factors influencing the qualified Rate of Large Disturbances of the Primary Frequency Regulation on Heat Supply Units and the Improving Measures

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Abstract. At present, the major problem faced by heat supply thermal power units is not only to ensure the external heating demand, but also to meet the requirements of the power grid for the primary frequency modulation of units. The main types of heat supply units in Shandong power grid are introduced. And take a 600MW pure condensing heat supply unit as an example, the reasons that affect the test results of large disturbance of primary frequency regulation in the period of heat supply are analysed. The scheme of optimization and transformation is put forward, which has good effect and meets the requirement of primary frequency regulation of power grid.

1. Introduction
Power grid frequency is one of the three indexes of power quality. The stability of power grid frequency plays an important role in ensuring the normal operation of all kinds of electrical equipment and economic social development. With the rapid development of large-scale intermittent energy and the overall acceleration of UHV construction in China, higher requirements are put forward for the coordination between generator units and power grid [1-2]. At present, Shandong power grid has been connected with external grid through “three DC and four AC” UHV line, such as ±800KV Lugu DC UHV power grid, 1000KV Hequan AC UHV power grid. By May 2020, the proportion of external electricity connected to Shandong power grid has exceeded 30%. New energy accounts for about 30% of electricity generation. It forms a three-way situation with conventional thermal power.

Furthermore, Shandong province continues to promote energy conservation and emission reduction policies. All small thermal power and heating boilers have been shut down. Cogeneration mode is used for central heating. Large power generation enterprises in Shandong Province actively seize the heating market. By May 2020, the number of heating units in Shandong Province has accounted for 85% of all unified dispatching units. How the thermal power unit can meet both the heating parameters stability and the primary frequency modulation needs for the power grid has become an important problem to be solved urgently.

2. Primary frequency regulation and test method in Shandong power grid
According to the requirements of Guide of primary frequency control test and performance acceptance for thermal power generating units, the unit should be put into primary frequency regulation function under any operation mode. Daily indicators meet the requirements of the procedure. After the
transformation of primary frequency equipment was reformed in the maintenance of thermal power unit or the thermal power unit has been operated for five years, the primary frequency modulation test should be carried out. The performance management of primary frequency modulation is based on daily assessment and performance test. The daily assessment is strictly carried out in accordance with “The Two rules of Power Grid for North China”. Conventional performance verification is achieved by field primary frequency modulation test. But the field test is always affected by some objective factors, such as manual intervention by operators, forcing control logic, manual adjustment of thermal parameters. Test conditions are often manufactured artificially. Therefore, many tests cannot truly reflect the actual primary frequency regulation capacity of this unit. In view of this, Shandong power grid has used primary frequency modulation remote test device creatively to investigate the real large frequency difference of the unit under the real disturbance of primary frequency regulation. The frequency difference range of large disturbance test is 0.083Hz-0.15Hz. The whole set of large disturbance measuring device of primary frequency modulation is divided into three parts: master station in power dispatch control centre, sub-station in power plant and I/O channel system. On the one hand, the master station sends test signals through SCADA (Supervisory Control and Data Acquisition), and on the other hand receives signals uploaded by PMU (Phasor Measurement Units) through WAMS (Wide Area Measurement System). The sub-station in power plant receives the test instruction from the master station, switches to the on-line test mode of primary frequency modulation and adjusts the power according to the test frequency. At the same time, it uploads real-time frequency, power and other signals through PMU or RTU. The main station and the sub-station transmit safely through the data special communication network.

According to the 15s,30s and 40s actions of the unit, the composite index is calculated to evaluate the primary frequency modulation large disturbance test. Units that fail the test will be assessed. According to the test results of Shandong power grid in 2019-2020 in the heating season, the number of unqualified units in large disturbance test from November 2019 to January 2020 accounted for 43% of the total number of unqualified units in the whole year. It shows that the primary frequency regulation capacity of the heating unit is affected by the extraction steam, and the capacity decreases to different degrees.

3. Types of heating units in Shandong Power Grid

From statistics, there are three types of heating units in Shandong Power Grid, high back pressure units, bleeding back-pressure units, extraction condensing units respectively. In recent years, there are few new heating units in the province, so most of the heating units are transformed by equipment transformation. The transformation plan mainly includes: opening holes in the bridge pipe or exhaust pipe on HP and IP cylinder, installing heating butterfly valve for external heating, or transforming the unit into a high back pressure heating unit by changing the turbine rotor in winter, supplying hot water to external heating network.

Taking a Supercritical 600 MW steam extraction cogeneration turbine unit as an example, the IP cylinder is connected with 1~2 LP cylinders through two connecting pipes. Part of the middle pressure cylinder exhaust steam is used as the heat source of the heating network heater. This part of exhaust steam is divided into two parts, one part is divided into three circuits and sent to three heating network heaters in series, and the other part of exhaust steam is used as driving energy of heat supply network circulating pump, returning to heater for heat exchange after working. After the steam releases heat, it is sent to the deaerator through the heat network drain pump. Check valve, quick closing valve and isolation valve are installed on the three pipes before entering the heating network heater. The return water from the heat supply network is continuously heated by three heaters, and then boosted by the heat supply network circulating pump and sent to the heat supply network for heating. Figure1 show the heat supply system flow chart.
4. Factors affecting the primary frequency regulation capacity of cogeneration unit and optimization scheme

4.1 More invalid action times of primary frequency modulation and poor measurement accuracy of speed signal

Many units are at the end of Shandong Power Grid. The frequency often vibrates around the dead zone of ±2r/min. For a long time, it is easy to damage the high-pressure regulating valve. Moreover, the invalid action of primary frequency modulation will have a great influence on the operation index of AGC. As shown above, frequent fluctuation of primary frequency modulation instructions superimposed on AGC instructions, causing the reverse of their actual actions. Therefore, the AGC index of the unit is greatly reduced.

The accuracy of conventional turbine speed measuring device is poor. The speed difference signal shall be changed to the frequency difference signal consistent with the grid frequency. In view of the shortcomings of frequent primary frequency modulation invalid disturbance and poor speed signal accuracy, most units in Shandong power grid have been installed and used the intelligent primary frequency control device. This device uses dual channel redundancy design and embedded design. From PMU, PT signal is connected in parallel through hardwired to calculate grid frequency. CT signals are connected in series to calculate the load of the unit. The corresponding primary frequency regulation load command is calculated by the intelligent device and sent to DCS and DEH respectively. This intelligent device can effectively improve the acquisition accuracy of frequency, reduce a lot of unnecessary responses and improve the qualification rate of primary frequency regulation action. The figure below shows the comparison of the actual operation times of primary frequency modulation within two hours before and after the transformation of the device. The blue and red pulse curves respectively represent the times and amplitudes of the actual primary frequency modulation actions before and after the revamping of the device. So after modification, the number of invalid primary frequency regulation actions of the unit is obviously reduced. Signal acquisition becomes more accurate. After AGC-R mode is eliminated, the qualified rate of primary frequency modulation is as high as 95.63%.
4.2 Using heat storage of heat network to improve primary frequency regulation ability

For heating units, part of the steam is transferred to external heating. It will cause the reduction of the heat storage capacity and the decrease of load capacity of the unit itself. The central heating units supply the heat to the external users through the heat pipe network. Large quantities of heating pipes, heaters, heat exchangers, user heating devices and other metal equipment in the heat supply network. Heat supply network has large capacity to store heat energy. When the real primary frequency modulation disturbance occurs in the power grid or receiving the large disturbance test switch signal, we can use this part of the energy in the heat supply network. This part of heat directly entre IP and LP cylinders to do work. It greatly compensates the primary frequency modulation response ability of the unit after 10s. And it will not cause significant impact on external thermal energy users [3]. Most units use the fast closing valve with the same regulating function to regulate the external heating [4]. For heating units, the fuel supply, the opening of the high-pressure regulating valve and the opening of the quick closing valve are the main factors affecting the rapidity of the primary frequency modulation. There is a large lag from the change of fuel quantity at the beginning to the later adjustment of unit load.

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The action of turbine regulating valve is very fast, which can change the unit load quickly. But once the heat storage of the unit is completed, the load of the unit will gradually return to the initial value as the main steam pressure decreases in the later stage. The fast action of the quick closing valve can make up the energy demand of the unit in the later stage of the primary frequency regulation action by using the heat storage of the heat network.

As shown in Figure 4, the coordinated control scheme of unit with feed-forward signal of heat supply compensation is designed in the action of large disturbance of primary frequency modulation. The load corresponding to the large disturbance of primary frequency modulation is taken as the feed-forward signal of heating and superimposed on the opening instruction of quick closing valve. The unit will use the heat storage of the heat network to rapidly change the required energy. The load response rate of the...
unit can be greatly improved. The heating side adopts closed-loop control, ensuring that the heat supply matches the external demand.

4.3 Increasing the contribution of extraction steam and main steam pressure to primary frequency regulation

When the external heating load is high, the primary frequency regulation ability of the unit will be greatly restricted. In order to ensure the primary frequency regulation action effect of the unit under different extraction conditions, designing correction function \( K_1(x) \) of primary frequency modulation under different extraction steam flow in Table 1.

| Extraction steam flow (t/h) | 0   | 150 | 200 | 250 | 300 |
|----------------------------|-----|-----|-----|-----|-----|
| Correction factor          | 1   | 1.010 | 1.02 | 1.025 | 1.03 |

By analyzing the unqualified reasons of the large disturbance of primary frequency modulation and the results of primary frequency modulation test, the main steam pressure has a great influence on the primary frequency regulation performance of the unit \([5]\). We can reduce the influence of the fluctuation of the main steam pressure by designing the compensation function of the main steam pressure for the primary frequency regulation ability of the unit. We design the modified function \( K_2(x) \) of Table 2. When the main steam pressure is lower than the set value, the compensation of primary frequency modulation will increase.

| Deviation of main pressure (MPa) | 0   | 0.2  | 0.3  | 0.5  | 0.7  | 1.0  | 1.4  | 2.0  |
|---------------------------------|-----|------|------|------|------|------|------|------|
| Correction factor               | 1   | 1.010 | 1.02 | 1.025 | 1.03 | 1.05 | 1.08 | 1.11 |

5. Practical application

Through the detailed research and improvement of the large disturbance function of the primary frequency modulation. We contacted the dispatching control centre of the power grid to conduct remote primary frequency modulation large disturbance test for this unit again. Under the same operating condition, the comprehensive index of primary frequency regulation of this unit is increased from 58% (70% for passing) to 86%. Figure 5 shows the comparison of the two tests curve before and after.

6. Conclusion

Whether the primary frequency regulation action or test of the heating unit is qualified, the accuracy of frequency signal shall be ensured firstly. Then the fast valve closing command, fuel command, main steam pressure and other control logic are corrected by large disturbance signal of primary frequency modulation command. At the later stage of primary frequency regulation, the unit can make full use of the heat storage of heat network to compensate the energy demand of load. Moreover, it can avoid the large fluctuation of parameters such as the main steam pressure at the inlet of turbine. Therefore, the qualification rate of large disturbance in primary frequency modulation action can be greatly increased.
The successful implementation of the optimization scheme has a good reference for the same type of heating unit.

References

[1] CHANG Dongfeng, WANG Wei. (2018) Primary frequency modulation of multivariable co-optimization for 1000 MW units. Thermal Power Generation, 47:123-128

[2] TAO Qian, HE Ying, PAN Yang, et al. (2016) Characteristics of power system frequency abnormal distribution and improved primary frequency modulation control strategy. Power System Protection and Control, 44:133-138.

[3] Liu Xinping, Tian Liang, Wang Qi. (2014) A control method of rapid load change for heat supply units compensating wind power disturbance. Automation of Electric Power Systems, 38(6): 26-32.

[4] DENG Tuoyu, TIAN Liang, LIU Jizhen. (2015) A Control Method of Heat Supply Units for Improving Frequency Control and Peak Load Regulation Ability with Thermal Storage in Heat Supply Net. Proceedings of the CSEE, 35:3626-3633.

[5] WANG Wenkuan, SHI Dianzhong. (2016) Research and Optimize of Primary Frequency Regulation for On-line Unit. Shandong Electric Power, 43:49-51.

[6] A. Delavari and I. Kamwa. (2018) Improved Optimal Decentralized Load Modulation for Power System Primary Frequency Regulation. IEEE Transactions on Power Systems, 33:1013-1025.

[7] A. Ghafoori, J. Milimonfared and G. B. Gharehpetian. (2015) Coordinated Control of Distributed Energy Resources and Conventional Power Plants for Frequency Control of Power Systems. IEEE Transactions on Smart Grid, 6:104-114.

[8] LIU Jizhen, DENG Tuoyu, TIAN Liang. (2016) Analysis of nonlinear characteristics of heat supply unit’s coordinated control object. Journal of North China Electric Power University, 43:66–72.

[9] TAO Qian, HE Ying, PAN Yang, et al. (2016) Characteristics of power system frequency abnormal distribution and improved primary frequency modulation control strategy. Power System Protection and Control, 44:133-138.