Analysis of Primary Frequency Regulation Ability of Shandong Power Grid Thermal Power Unit

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Abstract: Shandong Power Grid is about to achieve the development goal of 30% of new energy power generation installed capacity, 30% of foreign power input into Shandong, and 30% of thermal power installed capacity. Neither new energy power generation nor external power has the ability to adjust primary frequency. Thermal power is the main force of primary frequency modulation of Shandong Power Grid. This article counts all primary frequency modulation remote tests of the Shandong Power Grid in 2020, analyzes the current status of Shandong Power Grid’s primary frequency modulation, gives an assessment method for the primary frequency modulation integral power, and summarizes three reasons for the unqualified primary frequency modulation. The reasons are analyzed separately, and optimization suggestions are given.

1. Introduction
According to the "Shandong New Energy Industry Development Plan (2018-2028)" issued by the Shandong Provincial Government on September 17, 2018, by 2022, Shandong Province will strive to achieve two 30%, that is, the installed capacity of new energy power generation will account for the entire province. The proportion of total electricity installed capacity reaches 30%, and the capacity that can accept incoming electricity from outside the province accounts for 30% of the province’s available electric installed capacity.

The new energy power generation and nuclear power in Shandong Province do not have the ability of primary frequency regulation, and the installed hydropower capacity is relatively small. Thermal power generating units are the main force of primary frequency regulation of Shandong Power Grid.

2. Primary frequency regulation assessment method
The primary frequency regulation is related to the safe and stable operation of Shandong Power Grid. In order to improve the supporting effect of the thermal power unit on the safe and stable operation of the power grid, the grid dispatching agency tests the primary frequency regulation capability of the thermal power unit through remote tests every month, units that fail primary frequency regulation remote test will be assessed.

The provincial dispatcher sends a frequency modulation remote signal to the power plant through the RTU. After the unit receives the remote control signal, the theoretical power compensation amount is calculated according to the magnitude of the frequency difference, and the generator power is increased or decreased according to the theoretical power compensation amount. After a genset frequency adjustment action, the generator power and other signals will be transmitted to the provincial adjustment through the RTU or PMU, and the provincial adjustment committee will calculate the assessed power of the unit according to the formula.
In order to quantitatively assess the unqualified units in a remote frequency modulation test, the Shandong Provincial Commission adopted the method of calculating integral electricity to assess the power plant.

The assessed power is:

\[ KO \times PN \times \alpha \]  

\( KO \): Comprehensive index for a frequency modulation assessment.
\( PN \): Unit rated power.
\( \alpha \): A frequency modulation coefficient, currently press 1 to execute.

The calculation method of the comprehensive index \( KO \) for a frequency modulation assessment is:

\[
Q\% = 0.55 \times \left( \frac{Q_{15\text{ actual}}}{Q_{15\text{ theory}}} \right) + 0.3 \times \left( \frac{Q_{30\text{ actual}}}{Q_{30\text{ theory}}} \right) + 0.15 \times \left( \frac{Q_{45\text{ actual}}}{Q_{45\text{ theory}}} \right)
\]  

\( Q_{15\text{ actual}} \): The actual generating capacity of the unit when the unit operates for 15s.
\( Q_{15\text{ theory}} \): The theoretical increase in generating capacity when the unit operates for 15s.
\( KO := 0 \) (\( Q\% > 70\% \))
\( KO := 1 - \frac{Q\%}{70} \) (\( 40\% < Q\% < 70\% \))
\( KO := 1 \) (\( Q\% < 40\% \))

3. Statistical analysis of primary frequency regulation remote test

For the convenience of statistics, as long as the unit's comprehensive assessment index for a frequency modulation is less than 70%, this remote frequency modulation test is unqualified.

According to statistics, Shandong Power Grid has conducted a total of 1,580 remote frequency modulation experiments on thermal power units in 2020. A total of 1,235 passes and 345 failures were passed in a frequency modulation remote test. The annual failure rate was 21.8%. The annual failure rate was 21.8%. The specific statistics of the remote test are shown in Figure 1.

![Figure 1. Statistics of a remote primary frequency regulation test](image)

It can be seen from Figure 1 that the failure rate of a FM remote test is high at both ends and low in the middle. The heating months in Shandong are January, February, March, November, and December. It is 28.94%, and the average failure rate in the non-heating season is 18.5%. This shows that the heat supply of the thermal power unit will reduce the primary frequency regulation capability of the unit.

4. Analysis on the Reasons of Unqualified Frequency Modulation

After analysis, this article summarizes the reasons for the unqualified remote experiment of the primary frequency modulation of the thermal power unit into three types, namely: the poor flow characteristics of the steam turbine valve, the large heat supply of the unit, and the TF control mode of the unit.
As shown in Figure 2, the number of unqualified remote FM tests caused by the poor flow characteristics of the gate is 146 times, accounting for 42.3%; the number of unqualified remote FM tests caused by the large heat supply of the unit is 183 times. It accounts for 53%; the number of unqualified FM remote tests caused by TF control mode is 16 times, accounting for 4.6%.

Figure 2. Proportion of three reasons that cause an unqualified frequency modulation test

4.1. The influence of the poor flow characteristics of the valve on the primary frequency modulation

The flow characteristic of a steam turbine valve refers to the corresponding relationship between the opening of the steam turbine regulating valve and the steam flow through the valve, which has typical nonlinear characteristics.

In order to realize the linear control of the output power of the steam turbine, it is necessary to set the valve flow function to control the total valve position command of the steam turbine regulating valve and the steam flow to be approximately linear. The valve flow function of a steam turbine refers to the corresponding relationship function between the total valve position command and the regulating valve.

The regulating valve flow characteristic function of a steam turbine is usually given by the steam turbine manufacturer. However, the maintenance, transformation, and replacement of the flow part of the steam turbine and the high pressure regulating valve may cause mismatch between the original flow function and the actual valve flow characteristics.

When the actual flow characteristics of the control gate do not match the original flow characteristics, the gate flow characteristic function cannot meet the requirements of the unit under all load conditions, which may cause the primary frequency regulation performance of the unit to fail to meet the requirements.

Figure 3. Primary frequency modulation response curve of a unit with poor valve flow characteristics
1- Active power, 2- Load order, 3- primary frequency modulation remote control value.
Figure 3 is a typical response curve of a failed remote test of frequency modulation caused by poor flow characteristics of the gate. Curve 1 is the unit's active power, and curve 2 is the unit's load command. It can be seen that the unit's active power increases slowly. After calculation, the unit's comprehensive assessment index for a frequency modulation is 32%, which does not meet the requirements.

Fig. 4 is the valve flow characteristic function of the unit. Before the test, the load of the unit is 102MW, the integrated valve position command is 81%, GV1, GV2, GV4 are fully open, GV5 opening is 70, GV6 opening is 10, GV3 is not open, the unit is adjusting the door. The opening is in the overlap zone of GV5 and GV6. Due to the long-term operation of the unit and the overhaul of the unit, the valve flow characteristic function of the unit does not match the actual flow characteristic of the valve, which caused the unit to fail a remote frequency modulation test.

4.2. The influence of heating on primary frequency modulation

The heating units are divided into extraction steam heating units and high back pressure heating units. There are 200 direct-regulated thermal power units in Shandong Province, including 133 extraction steam heating units and 33 high back pressure heating units.

The extraction steam heating unit extracts part of the steam from the medium pressure cylinder or the medium and low pressure cylinder connecting pipe or the reheating steam pipe for heating. Since the steam used for heating cannot be fully converted into electrical load, the extraction steam heating unit the frequency modulation capability is worse than that of non-heating units.

There are three methods for high back pressure heating of the unit:

(1) Cut off the low-pressure cylinder for heat supply and cut off the low-pressure cylinder's inlet steam. The heating technology refers to the removal of the low-pressure cylinder's inlet steam through the fully-sealed, zero-leakage heating butterfly valve shut-off function during the heating period, so that the low-pressure cylinder rotor is in high vacuum. It is a flexible operation technology for "idling" operation under conditions, high back pressure heating operation of high and medium pressure cylinders.

(2) The blades of the low-pressure cylinder rotor are removed. Some power plants adopt the method of removing the last three stages of the low-pressure cylinder or shortening the last few blades to increase the back pressure of the unit and enhance the heat supply capacity of the unit.

(3) The low-pressure cylinder replaces the rotor, which is a high back pressure heating method commonly used by units in Shandong Province. When operating under heating conditions, the unit uses a newly designed high back pressure and low pressure rotor with a relatively reduced number of moving and static blades, and uses circulating water for heating.

There are 36 high back pressure heating units in Shandong Province and 37 high back pressure heating units with low pressure cylinders for rotors. The second method has been eliminated. Regardless of the high back pressure heating method, the high back pressure heating unit improves the heating capacity of the unit through the low pressure cylinder or the low pressure cylinder. The high back pressure heating will affect the primary frequency regulation capability of the unit.

Both the extraction steam heating unit and the high back pressure heating unit affect the primary
frequency regulation capability of the unit because the heated steam does not fully perform work, but the power plant can overcome the heat supply by multiplying the coefficient of the theoretical compensation amount of primary frequency regulation (the coefficient is greater than 1) The impact on the primary frequency modulation of the unit. The main reason for the low pass rate of the primary frequency regulation of the heating unit is that the large amount of heat supply causes the steam turbine governing door to be fully opened, and the unit has no adjustment margin. When the heat supply unit provides a large amount of heat and the unit is not at full load, the steam turbine valve is fully opened, and the unit loses its ability to adjust the load upward. Figure 5 is the response curve of a frequency regulation of a 330MW heat supply unit. The load of the unit is 250MW. Because the unit heats up to 300T/h and the gate is fully opened, the frequency regulation test fails.

![Figure 5. Primary frequency modulation response curve of heating unit](image)

1- Load order, 2- Active power, 3- Extraction steam heating flow, 4- Master valve position command.

4.3. TF The influence of TF control mode on primary frequency modulation

The next frequency modulation control mode of the unit in the conventional coordinated control mode is DEH+DCS, that is, the difference between the rated speed (frequency) in the DEH and the turbine speed (grid frequency) is calculated by a certain function and the valve is directly actuated. DCS performs adjustment and compensation to ensure the unit The load meets the requirements of the grid.

When the unit is under the Turbine Follow (TF) control mode, the unit relies on DEH to respond to a frequency modulation, and the miracle master controls the main steam pressure of the unit. When the grid frequency is lower than the standard frequency 50HZ, DEH opens the valve of the large steam turbine to generate more electricity, and the main steam pressure drops due to the opening of the steam turbine valve. In order to control the main steam pressure to be equal to the set value, DCS will issue an instruction to close the small steam turbine valve.

In the TF control mode of the unit, DEH and DCS will issue opposite valve opening commands to reduce the unit's primary frequency adjustment capability. Fig. 6 is the response curve of primary frequency modulation under typical TF control mode. The load command changes from 213MW to 223MW, and the active power rapidly rises from 208MW to 220MW and then begins to decrease. After calculation, this unit is the primary frequency modulation of this remote frequency modulation test. The comprehensive assessment index is 23%, which does not meet the requirements.
5. Conclusion
Shandong Power Grid has conducted a total of 1,580 remote frequency modulation experiments on thermal power units in 2020. A total of 1,235 passes and 345 failures were passed in a frequency modulation remote test. The annual failure rate was 21.8%.

As the main force of Shandong Power Grid's primary frequency regulation, thermal power units need to be further improved. The main reasons for the poor primary frequency modulation capability of the thermal power unit are poor gate flow characteristics, large heat supply, and TF control methods.

If the flow characteristic of the control valve is poor, the flow characteristic curve of the unit control valve can be re-determined through the valve optimization test, so that the flow characteristic curve matches the actual flow characteristic of the control valve. When the heat supply of the unit is large and the regulating door is fully opened, the control logic can be optimized, and the heating extraction steam regulating valve can be briefly closed by using the thermal inertia of the heating network to enhance the unit's primary frequency regulation capability. The TF control method is not a common control method for power plants. Generally, this method is only used when the unit is just started. You can set the block and reduce conditions for the main control of the steam turbine through logic optimization. When the unit is in the TF control mode, a frequency modulation occurs. When the time, the main control of the steam turbine is locked down, and the regulating door is prohibited from closing down.

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