Prediction technology and application of primary frequency regulation capability of thermal power unit

Song Gao1, Jin Wang2, Ming Wang2, Qing Yan1, Qingbin Yu1, Enren Liu1, Yuanyuan Li1, Xiangrong Meng1

1 State Grid Shandong Electric Power Research Institute, Jinan, Shandong, China.
2 Shandong electric power dispatching control center, Jinan, Shandong, China.
*Corresponding author’s e-mail: redblack9@163.com

Abstract. As one of the important functions of grid connected thermal power generation units, the primary frequency regulation function aims to increase and decrease load rapidly when the grid frequency changes, so as to achieve the stability of grid frequency [1-4]. According to the statistics of the power dispatching department, every time the frequency fluctuation of the power grid causes the primary frequency regulation action of all thermal power generating units, a considerable part of the thermal power generating units have insufficient primary frequency regulation capability. After the accident, the power dispatching department will impose economic punishment on the thermal power generating units that do not meet the requirements [5-7].

The primary frequency regulation test shall be carried out for the newly built thermal power generating unit or the thermal power generating unit after major main maintenance. The test is carried out under ideal test conditions, which can generally meet the requirements of relevant regulations. However, the real action of primary frequency regulation often occurs in the sudden situation of power grid frequency change. The primary frequency regulation capacity of the unit is easily affected by the current main parameters of unit operation and equipment operation mode, which will lead to the phenomenon of insufficient primary frequency regulation capacity [8-10].

If the capability of primary frequency regulation can be predicted in real time, the operation parameters and equipment operation mode of thermal power generation unit can be changed in time,
so as to avoid the situation of insufficient capability of primary frequency regulation when the grid frequency changes.

This paper focuses on the prediction technology of primary frequency regulation capability of thermal power units. The rest of this paper is organized as follows. Section 2 introduces the basic principle of primary frequency regulation of thermal power units. Section 3 gives the main technical methods and steps of primary frequency regulation prediction. Section 4 provides industrial case studies to illustrate the effectiveness of the proposed method. Section 5 makes concluding remarks.

2. Principle of primary frequency regulation

The main principle of the primary frequency regulation function of thermal power unit is shown in Figure 1. In the Coordinated Control System (CCS) control loop of the unit, the change of the set value of the active power is calculated through the speed unequal rate function according to the deviation of the grid frequency, and then is added to the original unit load command to realize the real-time adjustment of the active power of the unit with the fluctuation of the grid frequency. At the same time, in order to ensure the fast response, in the Digital Electro-Hydraulic (DEH) control loop of the unit, the deviation signal of power grid frequency is also used to calculate the change amount of turbine valve command through a speed unequal rate function, which is directly added on the turbine valve command, so as to achieve the purpose of rapid response.

The speed unequal rate functions A and B are generally set according to the requirements in Figure 2. The grid frequency deviation within ±0.033 Hz is the control dead zone, and the primary frequency modulation does not respond. If the grid frequency deviation exceeds the dead zone, the primary frequency regulation capacity will be calculated according to the function settings.

Figure 1. The principle of primary frequency regulation.

Figure 2. The functions of primary frequency regulation.
3. Prediction technology of primary frequency regulation capability

In order to solve the above problems, a prediction method of primary frequency modulation capability based on the allowable deviation of main steam pressure is provided. Through the real-time prediction of the primary frequency regulation capability of the thermal power generation unit, the operation parameters and equipment operation mode of the thermal power generation unit can be changed in time, so as to avoid the lack of primary frequency regulation capability when the grid frequency changes. In order to achieve the above purpose, the following technical steps is adopted.

Step 1: Obtain real-time unit parameters from distributed control system of thermal power unit, including unit rated load, set value of main steam pressure, measured value of main steam pressure, rated main steam pressure, measured value of main steam temperature, rated main steam temperature, rated unit back pressure, measured value of unit back pressure.

Step 2: determine two calculation factors $k$ and $\delta$, where $k$ is the unit correction factor, $\delta$ is the allowable deviation of the unit main steam pressure. The unit correction factor is related to the heat storage capacity of the unit and is a function of furnace type and boiler capacity grade. The correction factor is 0.1666 for 125MW, 0.1333 for 300MW and 0.1 for 600MW and above. According to practical experience, the allowable deviation of main steam pressure of the unit can be set to ±0.6MPa in the process of unit load change.

Step 3: using the parameters of step 1 and step 2, equation (1) can be used to calculate the primary frequency regulation capacity of thermal power units.

$$
\Delta N = N_0 \times k \times \left[ \delta - \left( P_s - P_t \right) \right] \times \left( \frac{P_t}{P_0} \right)^{1/2} \times \left( \frac{273 + t}{273 + t_0} \right)^{1/2} \times \left( \frac{P_{B0}}{P_B} \right)^{1/2}
$$

Where, $\Delta N$ is the predicted primary frequency regulation capacity of the unit, $N_0$ is the rated load of the unit, $\Delta N$ is the unit correction factor, $\delta$ is the allowable deviation of the main steam pressure of the unit, $P_s$ is the set value of the main steam pressure, $P_t$ is the real-time value of the main steam pressure, $P_0$ is the rated main steam pressure, $t$ is the main steam temperature, $t_0$ is the rated main steam temperature, $P_{B0}$ is the rated back pressure of the unit and $P_B$ is the real-time back pressure of the unit.

Step 4: set reasonable primary frequency regulation capacity limit $N_H$. In the actual production process, the maximum opening of the turbine control valve of the unit is 100%, which means that the primary frequency regulation capacity of the unit can not be increased infinitely, and it is necessary to set reasonable limiting. equation (2) can be used to calculate the primary frequency regulation capacity limit $N_H$ of thermal power units.

$$
N_H = N \times \frac{100 - TM}{100}
$$

Where, $TM$ is the control command of steam turbine valve and $N$ is the current load value of thermal power unit.

Step 5: return to step 1 to continue.

The flow chart of prediction technology of unit primary frequency regulation capacity is shown in Figure 3.
4. Application case
An industrial case of 330 MW thermal power unit is shown in this section. According to the calculation steps given in the third part, the calculation result of the unit's primary frequency regulation capacity $\Delta N$ is shown in Figure 4.
Through the real-time prediction of the action compensation amount of the primary frequency regulation function of the thermal power generation unit, it can timely change the operation parameters of the thermal power generation unit and the operation mode of the equipment before the primary frequency regulation action caused by the sudden fluctuation of the grid frequency, so as to avoid the occurrence of the insufficient action compensation amount of the primary frequency regulation during the actual action of the primary frequency regulation.

5. Conclusion
This paper focuses on the prediction technology of primary frequency regulation capability of thermal power units. The paper introduces the basic principle of primary frequency regulation of thermal power units, and gives the main technical methods and steps of primary frequency regulation prediction. The effectiveness of this method is verified by its implementation on a typical 330 MW thermal power unit.

References
[1] Li, J., & Li, W. W. (2013). Research and optimization of thermal power unit's automatic control based on frequency regulation ability of power grid. Applied Mechanics & Materials, 330, 606-610.
[2] Zorchenko, N., V., Rezinskikh, V., F., Suslov, & Yu, S., et al. (2011). Evaluating the effect of frequency regulation modes on the reliability and economic efficiency of thermal power generation units. Power Technology & Engineering, 45(2), 132-136.
[3] Kai, S., Jiang, X., & Zhou, N. (2016). Performance optimization of primary frequency regulation based on modeling of turbine and its governing system. Control Conference.
[4] Liang, Z. Y., & Li, S. S. (2013). Research on influence factor of primary frequency regulation performance for thermal power plant. Applied Mechanics & Materials, 448-453, 2040-2044.
[5] Lin, L., Wang, J., Jiang, Y., Meng, N., Tian, S., & Yang, R., et al. (2014). Experimental study on enhancing the quality of AGC and primary frequency regulation based on heat system accumulation. Electric Power, 14(2).
[6] Sun, X., Liu, X., Cheng, S., Duan, N., Chu, Y., & Zhang, L., et al. (2017). Actual measurement and analysis of fast frequency response capability of pv-inverters in northwest power grid. Power System Technology.
[7] Su-Xia, M. A., Qing-Zhong, M. A., & Zhang, L. Y. (2010). Study of the primary frequency-modulation characteristics of an intermediate reheat unit. Journal of Engineering for Thermal Energy & Power, 25(1), 72-76.
[8] Wu, H. X. (2014). Research on the primary frequency regulation of the large capacity thermal power units. Applied Mechanics & Materials, 608-609, 915-919.
[9] An, Y. K., Zheng, L., Song, J. Y., Ye, Z., & Cheng, W. Q. (2015). A multi-objective assessment for primary frequency of generator. Applied Mechanics & Materials, 740, 325-330.
[10] Huang, W. J., Zhang, X., Chen, S. H., & Chen, R. M. (2011). Enhancing response speed of primary frequency regulation in thermal power unit. Electric Power.