Power-friendly Primary Frequency Control Method and System of Receiving-end Grid

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Abstract. With the rapid development of new energy sources such as wind power and photovoltaics, and the intensification of interconnected power grids, power fluctuation problem brings adverse influence on power grid frequency control. The stability of power grid frequency mainly depends on primary frequency compensation (PFC) of thermal power units. How to control and improve the PFC ability is the precondition to realize the safe and stable operation of power grid. By analyzing the PFC assessment system and standard of power grid, the problems in the current unit's PFC were pointed out. By dynamically correcting the current rotation difference according to the actual main steam pressure measurement value of the unit, it can fully compensate the grid power gap by using the unit's heat storage. The application results show that the power-friendly PFC method and system of receiving-end grid can effectively control the thermal power units to achieve the stability of power grid frequency.

1. Introduction

With the new energy grid connection, the growth of load and the increasing scale of the power grid, under the new situation of the interconnection of UHV power grids and large-area power grids, the grids at all levels are getting closer and closer, and the requirements of coordination between power grids and units is becoming more and more high. Because of dynamic characteristics of primary frequency control (PFC) significantly affect the system security and stability level, the PFC function becomes one of the effective means to stabilize the power grid[1,2]. The dynamic characteristics of PFC not only depend on the design of speed control system, but also depend on the design of unit coordinated control system. It is a typical cross-system integrated technology.

The PFC capability of unit is very important to frequency control and avoiding cascading tripping caused by sudden change of load and generator outages. The grid-connected power plant must be equipped with one frequency modulation function, and the primary frequency modulation investment/withdrawal signals should be connected to the power dispatching agencies. The artificial dead zone, the rate of change of the speed regulation system and the maximum adjustment load limit of the primary frequency regulation, and the speed control system of delay rate, response speed and so on should meet the requirements of the primary frequency regulation technology management of the regional grid[3-5]. Units running in the grid must be put into primary frequency modulation function, when the grid frequency fluctuations should automatically participate in frequency modulation, and the grid power plant must not withdraw from the unit's frequency modulation function.
Function of PFC is an inherent function of turbo-generator unit, mainly by adjusting the admission of digital electric hydraulic (DEH) control system damper, using the unit’s boiler heat storage. In the case of an abnormality in the power grid, the unit’s PFC quickly responds to the requirements of the power grid and stabilizes the grid frequency to compensate for the grid load gap, maintain the safety of the grid. PFC responds quickly to system frequency changes. According to IEEE statistics, the PFC characteristic time constant of the power system is generally about 10 seconds.

Since the PFC of the generator only acts on the valve position of the DEH system of turbine, it does not affect on the combustion system for coal-fired power units [6-8]. When the opening of turbine’s valve increases, the heat storage in the boiler temporarily changes the power of the turbine. Since the chemical energy in the combustion system does not change immediately, the power of the turbine will return to the original level with the decrease of heat storage. Therefore, the action of PFC is short and transient. For different types of thermal power generators, the operating time of PFC varies from 0.5 to 2 minutes due to different heat storage. The adjustment method adopted by the PFC of the generator is the differential characteristic method, which has the advantage that all unit adjustments are only related to one parameter (that is, related to the system frequency), and there is little interaction between units. Due to the need of China Grid, thermal unit need to take the responsibility of PFC.

2. Power Grid PFC Assessment System and Assessment Standards
The unit’s PFC performance assessment parameters in the power grid dispatching centre are derived from the scheduling plan and energy management system (EMS). The frequency, active power and other measuring point’s information of one unit are defined in the telemetry definition table on wide area monitoring system (WAMS) [9,10]. The frequency, active power, turbine rotation speed, before-PFC and after-PFC commands of the frequency disturbance calculation are obtained from the synchronous vector measurement device (PMU) real-time library according to the telemetry information defined in the WAMS.

2.1. Definition of Effective Disturbance
As required in the Chinese GB/T 30370 ‘Guide of primary frequency control test and performance acceptance for thermal power generating units’ standard etc., the dead band of primary frequency compensation is 50±0.033Hz, the response delay time is no more than 3 seconds, the stabilization time is less than 1 minute.

![Figure 1. Frequency fluctuation curve](image)

The power grid assessment system realizes the recognition of frequency disturbance and the calculation of performance index by defining effective disturbance. As shown in Figure 1, the blue curve 1 is the frequency of unit, the red curve 2 is the active power of unit. When the unit’s frequency is more than dead band (50±0.033Hz) after A point, unit’s active power begin to act according to frequency deviation. B point is the active power change point after frequency more than dead band 3 seconds. At C point, return to the dead band. It is an effective disturbance when the frequency exceeds the primary frequency dead band (50±0.033Hz) and lasts for 6 seconds or more, and the maximum frequency deviation reaches 50±0.038Hz.
2.2 Major assessment methods

There are two main modes of assessment of power grid PFC performance, speed governing droop method and integral power contribution index method.

According to the power grid standard, the speed governing droop of the thermal unit’s primary frequency modulation should be 3%-5%. The greater contribution of unit contributes to the power grid with the speed governing droop smaller. Calculation formula as follows

\[
L = \frac{\left| f_2 - f_n \right| - 0.033}{f_n} \times \frac{P_2 - P_0}{P_N}
\]  

In formula (1), \( P_0 \) is the unit’s power value at power grid frequency beyond the dead band in frequency disturbance process, \( P_2 \) is the unit’s maximum active power value after frequency beyond dead band 3 seconds, \( f_2 \) is the frequency value corresponds to \( P_2 \), \( f_n \) is the rated frequency 50Hz, \( P_N \) is the unit’s rated power.

The unit’s load response with large frequency fluctuations is shown in Figure 2. Among them, the curve 1 is the grid frequency, the curve 2 is the standard unit load output, and the curve 3 is the actual load output. The shadow area A is the integral area that the standard load output minus the initial load output on the assessment time. The shadow area B is the integral area that the actual load output minus the initial load output on the assessment time.

The integral charge contribution index is calculated by the following formula

\[
Q\% \times 100% = \frac{B}{A}
\]

\[
B = \int \frac{\Delta P(\Delta f, t) \Delta t}{3600} = \frac{1}{3600} \times \sum_t (P(t) - P_0)
\]

\[
A = \int \frac{\Delta P_N(\Delta f, t) \Delta t}{3600} = \frac{1}{3600} \times \frac{P_N}{f_n \times \delta} \times \sum_t \Delta f
\]

Among them, \( P(t) \) is the unit’s real time power value in one frequency disturbance; \( \Delta f \) is the frequency deviation value; \( \delta \) is the setting value of speed governing droop.

The value of integral charge contribution index needs to exceed 80% to meet the grid’s standard requirements. Because of the different heat storage capacity, the action time of PFC to different types of thermal power unit is 0.5 to 2 minutes inequality. PFC is adjusted by the control methods according
to differ characteristics. So, it is possible to meet the standard requirements by increasing the amount of load in the later period.

3. System Structure of Unit’s PFC
The typical schematic diagram of the conventional steam turbine PFC function is shown in Figure 3. The calculated rotation difference is sent to the side of coordinated control system (CCS) and the side of DEH respectively.

On the CCS side, the rotation difference passes through the speed governing droop function to generate the corresponding frequency-power setting value, which is superimposed on the unit power setting value to generate the unit power setting value.

By finding the difference between the setting value and the actual value, the valve position command signal is calculated by the power PID controller. On the DEH side, the rotation difference passes through the speed governing droop function to generate the corresponding comprehensive valve position increment, superimposed to the valve position command signal sent from the CCS side, and generates the comprehensive valve position command to control the turbine valve.

The increment of comprehensive valve position on the side of DEH directly affects the opening degree of turbine regulating valve, so the response speed on the DEH side is relatively fast, so as to meet the speed requirement of power grid frequency modulation. Parameters such as wind, coal and water are mainly adjusted on the CCS side to ensure stable power at the required target value.

4. Problems and Solutions

4.1 Problems
In the conventional steam turbine PFC method, since the rotation difference of frequency modulation needed is a fixed value and remains unchanged, so the existing PFC system performs frequency modulation according to the standard primary frequency power compensation setting required in the regulation. With the development of technology and the increase of unit capacity, the unit's primary frequency modulation capability has been improved. In actual operation, the unit's main steam pressure measurement value is often higher than the main steam pressure setting value, that is, the heat storage capacity of the unit is usually higher than constant power compensation value of procedures required. Therefore, the current PFC method is not conducive to give full play to the potential frequency modulation of the unit, which easily leads to energy waste of the unit.

4.2 Control method and System Structure
Based on the frequency of receiving-end power grid exceeds the unit’s frequency dead band, the actual power of the unit within the adjustable range and units have excess power compensation capacity, the project designed a kind of power-friendly PFC method of receiving-end grid. According to the main steam pressure deviation to calculate the excess compensation coefficient of unit, and then uses the coefficient to dynamically correct the current rotation difference of unit, obtain the corrected rotation difference slip in real time. Thereby, over-power compensation adjustment of PFC is made for the grid power gap.

The power-friendly PFC system of receiving-end grid mainly include grid frequency detecting module, main steam pressure deviation detecting module, excess compensation judgment module etc.

The grid frequency detecting module is configured to collect the grid frequency of the receiving-end grid, determine whether the grid frequency exceeds the range of the primary frequency dead band, and transmit the judgment result to the excess compensation processing module. The actual power detection module is used to collect the actual power of the unit and determine the actual power range of the unit. The main steam pressure deviation detecting module is configured to collect the main steam pressure measurement value and the main steam pressure setting value in the CCS side of unit, and obtain the main steam pressure deviation according to the main steam pressure measurement value and the main steam pressure setting value. The excess compensation judgment module is configured to determine whether unit has the excess power compensation capability according to the data of the grid frequency detecting module, the actual power detecting module and the main steam pressure deviation detecting module, and transmit the judgment result to the rotation difference correction module. The rotation difference correction module is used to calculate the corrected rotation difference based on the judgment result of the main steam pressure deviation and the excess compensation judgment module. The control module is configured to perform the frequency control on the receiving-end grid by using the corrected rotation difference.

4.3 Practical Application

Taking one 300MW supercritical, intermediate reheat unit as an example, it is clearly that the action amplitude of PFC get greatly increased after optimization of unit. As shown in Figure 4, the red curve is actual power of unit, it increased immediately with the main steam pressure change within 0.2MPa.

![Figure 4. The PFC amplitude after optimization](image)

According to the equation (1) and (2) to calculate, the speed governing droop L is 3.34% that less than 5%, the integral charge contribution index is 101.5% that more than 70% standard, the process data is shown in Table 1.

| Parameter            | Start Point | 3 Seconds | 15 Seconds |
|----------------------|-------------|-----------|------------|
| Rotation Deviation   | 0           | 6         | 6          |
| (rpm)                |             |           |            |
| Frequency Difference | 0           | 0.1       | 0.1        |
| (Hz)                 |             |           |            |
| Unit Load (MW) | 240.00 | 235.61 | 227.15 |
|---------------|--------|--------|--------|
| Main Steam Pressure (MPa) | 15.63  | 15.64  | 15.83  |
| Main Steam Temp. (℃) | 539.35 | 539.35 | 539.10 |
| Furnace Draft (Pa) | -11.06 | -50.35 | -82.01 |
| Condenser Vacuum (kPa) | 9.95   | 11.17  | 1.57   |

5. Conclusion
As an important technical means of frequency control of the power grid, PFC is of great significance to the frequency stability of power system. The proposed scheme can dynamically correct the current rotation difference according to the actual main steam pressure measurement value of the unit. By using the unit’s heat storage, the designed system can fully compensate the grid power gap without affecting the safe and stable operation of the unit. It is conducive to give full play to the potential of frequency modulation and make full use of energy. At the same time, the primary frequency regulation is adjusted in combination with the change of the main steam pressure. It can meet the requirements of the power grid on the basis of ensuring the PFC index of the unit, and can also release too much energy in the unit to maintain the main steam pressure tends to be stable, thereby further ensuring stable operation of the unit. It is conducive to improving the stability of the unit and achieving a win-win situation in the source and network.

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