Research and application of PFC control based on command extra compensation

Jun Li¹ , XiangRong Meng¹, WenDong Zhang², Song Gao¹

¹State Grid Shandong Electric Power Research Institute, Jinan, China
²State Grid Shandong Electric Power Company, Jinan, China

Email: lijun_sdu@hotmail.com

Abstract. Based on the analysis of the unit’s PFC (primary frequency control) operation process, combined with the grid performance assessment standards, it was concluded that the inherent delay and inertia of the unit equipment caused PFC action to fail. Aiming at the problem of lack of turbine speed dead-band estimation for the PFC performance evaluation of thermal power units, by constructing the correlation domain between the turbine speed difference and the actual power difference of the unit’s daily operating data, the turbine speed dead-band of the unit was estimated. An optimization control method based on command extra compensation for PFC was proposed to improve the qualified rate of unit’s PFC operation.

1. Introduction

With the integration of wind power, photovoltaic and other new energy, and the increasing scale of the power grid, the power grids at all levels are becoming closer and closer. The requirements for coordination and coordination between power grids and generating units are increasing high. The PFC in the coordination function of power grid has becomes one of the effective means to stabilize the power grid frequency. The PFC is an inherent function of the turbo-generating unit. In the event of an abnormality in the power grid, it can quickly respond to the grid requirements and stabilize the grid frequency[1,2]. It is mainly through adjusting the inlet control valve of the DEH system and using the boiler heat storage.

The response of PFC to the power grid frequency change is fast. According to IEEE statistics, the time constant of the PFC comprehensive adjustment characteristic is generally about 10 seconds. Because the single adjustment of the unit only affects the valve position of the turbine, when the valve opening of the combustion system of the unit is increased, it is the heat storage in the boiler that temporarily changes the power. Because the chemical energy in the combustion system has not changed, the power of the turbine decreases as the heat storage decreases and return to the original level. Therefore, the action time of the thermal unit’s PFC is short[3,4]. Due to the difference in heat storage, the time of different types of thermal unit’s PFC is 0.5 to 2 minutes.

2. Analysis of Unit’s PFC Operation Process and Performance Assessment Standard

2.1 Unit’s PFC Operation Process

In order to improve the stability of the unit and avoid frequent adjustments when the frequency changes slightly, the speed dead zone D is set near the rated speed of the unit. The frequency is not
adjusted once within the dead zone. In general, the rated speed of the thermal power unit is set to 3000r/min, and D is usually required to be set to 2r/min(0.033Hz).

The response lag time of the PFC of the generator set shall not exceed 3 seconds. In order to ensure that the unit can be stabilized at the new load point as soon as possible after participating in the primary frequency modulation, it is stipulated that the stabilization time of the PFC of the generator unit should not exceed 60 seconds\(^{[5]}\). The speed inequality of the unit participating in the PFC, which is the slope of the static characteristic curve of the steam turbine control system, reflects the effectiveness of the PFC. It is usually expressed as a percentage of the ratio of the speed difference between the corresponding idle load and the full load to the rated speed. The speed inequality of PFC of thermal power unit should not exceed 5%.

2.2 Performance Assessment Standard

The PFC refers to the grid frequency deviation, control the operating unit automatically to increase or decrease the active power, to meet the requirement changes of frequency and maintain the stability of grid frequency. As shown in figure 1, it's the load response of the thermal unit when grid frequency is in the fall. Among them, 1 is the grid frequency, 2 is the ideal active power output, and 3 is actual active power output. The shadow area A is the integral area that the ideal active power output minus the initial active power output on the assessment time\(^{[6,7]}\). The shadow area B is the integral area that the actual active power output minus the initial active power output on the assessment time. The assessment time usually takes less than 60 seconds.

\[
A = \int_{t_0} \left[ P_i(t) - P_0 \right] dt
\]

\[
B = \int_{t_0} \left[ P_s(t) - P_0 \right] dt
\]

\(t_0\) is the starting time that the frequency deviation over 0.033Hz. \(P_0\) is the unit active power at \(t_0\) moment. \(P_i(t)\) is the unit actual active power curve. \(P_s(t)\) is the unit ideal active power curve. Calculated \(P_i(t)\) as following formula

\[
P_i(t) = P_0 + R_i \left( t - t_0 \right), t - t_0 \leq \frac{P_{\text{max}} - P_0}{R_i}
\]

\[
P_s(t) = P_{\text{max}}, t - t_0 > \frac{P_{\text{max}} - P_0}{R_i}
\]

\(R_i\) represents the unit ramp rate. PFC assessment indicators equal to

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

Unit PFC performance assessment rules as follows, if \(\eta < \eta_{\text{min}}\), this PFC is judged to be unqualified. If \(\eta \geq \eta_{\text{min}}\), \(\eta_{\text{min}}\) is the threshold value, it’s typically between 60% and 80%.
3. Problems of PFC

The power grid and power supply are interdependent. The root cause of frequency changes is the imbalance between the power generation and the energy consumption, and the energy change in the electricity consumption is random and uncertain. At present, the calculation parameters of PFC performance assessment of power grid dispatching management come from dispatching plan and EMS (energy management system). The corresponding frequency, active power and other measurement points of the unit are defined in the telemetry definition table of WAMS (wide-area monitoring system). According to the telemetry information defined in WAMS, the telemetry data of frequency, active power, turbine speed, and commands before and after PFC disturbance are obtained from the real-time library of PMU (synchronous vector measurement device).

It is stipulated in the performance assessment standard of power grid that the frequency exceeds the dead band of PFC and lasts for 10 seconds or more, and the maximum frequency deviation reaches 50±0.04Hz, which is defined as an effective disturbance. In the actual operation, the measurement of turbine speed or frequency signal, with 4-20mA current signal to DCS (distributed control system), then DCS control turbine valve action to make the active power change, there are signal transmission time delay and valve action needs certain reaction time, and rapidity and transient characteristics of PFC, so that the PFC action is unqualified. As shown in figure 2, it was one unit’s active power response when grid frequency changed. Among them, 1 is the grid frequency, 2 is the ideal active power output, and 3 is actual active power output. It can be seen that the response of the actual active power of the unit lags behind the change of the ideal active power, and the total amount of work done is less than the prescribed requirements.

4. Optimization and Application

In the daily operation process, there are certain difference between the dead zone of the PFC and the set value. It need to establish dead band of PFC estimation system, regular check the unit’s parameters of frequency modulation.
The optimized system structure is shown in figure 3. PFC optimization control method based on overshoot compensation is designed. When the absolute value of unit speed error signal $\Delta n$ is in the range of set, namely scheduling system assessment action value has not been achieved, the system output is the standard speed deviation $\Delta n$ after the frequency modulation signal compensation function $f(x)$ amount of compensation. The compensation of active power is $\Delta P_1$. When the unit speed error signal $\Delta n$ is beyond the scope of the absolute value, which meet the scheduling system assessment action, according to the setting speed error signal $\Delta n$ amount of positive or negative to overshoot power compensation $\Delta P_1$. The setting range is determined by the turbine speed deviation of the dispatching examination. When the unit speed deviation signal $\Delta n$ is beyond the scope of the absolute value of setting, if $\Delta n>0$, then the system output for $\Delta P_1$ and overshoot compensation quantity superimposition value, namely $\Delta P_1$ add A2 setting values. If $\Delta P_1 < 0$, then the system output for $\Delta P_1$ and overshoot compensation after the superposition of negative value, namely the set values for $\Delta P_1$ minus A2 setting values.

Figure 4. Optimized Unit’s PFC Active Power Response

Figure 4 shows the PFC action curveafter the unit's technical solution is implemented. It can be seen from the figure that the actual active power amplitude and response time of the unit’s PFC have been significantly improved, which can exceed the requirements of the power grid assessment standards.

5. Conclusion
The unit’s PFC performance directly affects the stability of the grid frequency. The proposed design scheme can improve the pass rate of PFC, effectively reduce the adverse effects caused by delay and lag factors such as the conversion calculation of each system during the actual frequency modulation reaction, improve the fastness and accuracy of the unit’s response to the frequency change of the power grid, and ensure the unit’s frequency modulation capability meets the requirements of the assessment standard. At the same time, by judging the magnitude of the speed deviation, different responses to the frequency fluctuations of the power grid are achieved, which not only ensures that the unit does not operate frequently, but also ensures the safe and effective operation of electrical equipment and power equipment of the majority of users.

References
[1] Shan Xin, Wang Yiyu, Jin Yiding, etal. (2018) Scheme and application of integrated monitoring and fault co-disposal technology of UHV interconnected power grid. Automation of Electric Power Systems, 42(2): 84-91.
[2] Zheng Tao, Gao Fuying,(2009) On-line monitoring and computing of unit PFR characteristic parameter based on PMU. Automation of Electric Power Systems, 33(11) :57-61.
[3] M. Zhuang, D.P. Atherton. (1993) Automatic tuning of optimum PID controllers. IEE ProcD, 140:216-224.
[4] Chen Guoping, Li Mingjie, Xu Tao. (2018) System protection and its key technologies of UHV AC and DC power grid. Automation of Electric Power Systems, 42(22): 2-10.
[5] Yu Daren, Mao Zhiwei, Xu Jiyu. (1996) Dygmic characteristic of primary frequency
regulation of turbo-generator. Proceedings of the CSEE, 16(4) :221-225.

[6] Dai Yiping, Zhao Ting, Tian Yunfeng. (2007) Research on the primary frequency control characteristics of generators in power system. Second IEEE Conference on Industrial Electronics and Applications, 569-574.

[7] Li Duanchao, Chen Shi, Chen Zhongyuan. (2004) Real-time measurement and reward method of the efficiency of generator unit primary frequency regulation. Automation of Electric Power Systems, 28(2):70-72.