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To cite this article: Jun Li et al 2018 J. Phys.: Conf. Ser. 1087 042060

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Primary frequency optimization control method of thermal power unit based on safe and stable operation

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Abstract. With the rapid development of energy-saving and clean new energy, power fluctuations bring great challenges to frequency control of power grid. The main ways of dealing with the instantaneous power gap depends on primary frequency compensation (PFC) of thermal power units. The characteristics and questions of automatic generation control (AGC) and PFC were analyzed, and the optimization of unit control were offered. It can ensure that the frequency modulation and peak shaving capacity of the thermal power unit meets the requirements of power grid standards, and effectively ensure the priority of the PFC action when the grid frequency fluctuates, improve the coordinated operation of the AGC and PFC.

1. Introduction
With the construction of smart grids such as UHV power grid interconnection and new energy grid-connected power generation, the power grid takes high requirements on the peaking and frequency regulation capability of thermal power units. In order to ensure the safe and stable operation of power grids, all large thermal power generating units require AGC function. Large-scale thermal power units are often operated in a wide load range, generally ranging from 50% to 100% of the rated load, and require the unit to have fast, accurate, and stable response load change requirements. At the same time, the related regulations of the state grid regulate the frequency of responding to grid frequency changes after a frequency adjustment requires the unit to be connected to the grid.

Since the frequency adjustment of the power system is treated differently according to the period and magnitude of the load change, the frequency adjustment is generally divided into primary, secondary and tertiary adjustments. That is also known as the PFC, AGC and the unit plan to generate electricity¹². Among them, primary frequency modulation and AGC are automatically adjusting the output of the unit according to the control requirements of the power grid, and thus occupy an important position in the frequency regulation of the power grid. The primary frequency modulation function of the generator set is an inherent function of the steam turbine generator set. The main function is to adjust the steam inlet valve of the DEH system and use the boiler heat storage to respond quickly to grid requirements and stabilize the grid frequency in the event of an abnormal grid condition, to make up for the difference in grid load and maintain the safety of the grid. The one-time adjustment responds quickly to changes in the system frequency³⁴⁵. According to IEEE statistics, the time constant of the primary regulation characteristic of the power system synthesis is generally about
ten seconds. Since the chemical energy in the combustion system does not change, the generator will decrease with the decrease of the stored heat amount. The power will return to the original level.

2. AGC and PFC Performance Evaluation Standard

PFC and AGC is the main form of power grid frequency adjustment. PFC is differential control which has static frequency deviation. AGC is no difference adjustment, and ultimately achieve balance between supply and demand.

2.1. Unit’s AGC Control Performance Evaluation Standard

The AGC commands from EMS will be sent to remote terminal unit (RTU) of power plant side, then by the RTU via hard-wired to send to unit’s coordinated control system (CCS), to complete the adjustment task of unit's AGC system[6,7]. As shown in figure 1, it is a set point control process of a typical AGC unit. \( P_{\text{min},i} \) is the lower limit of the unit adjustable output, \( P_{\text{max},i} \) is the upper limit of its adjustable output, \( P_{Ni} \) is its rated output, \( diP \) is a critical power point of its start and stop grinding.

The whole process can be described as, \( T_0 \) time ago, the unit work stably near the output \( P_1 \). At \( T_0 \) time, AGC control program sent power command \( P_2 \) to unit, the unit start up. To the time \( T_1 \), unit reliable across the \( P_1 \) adjustment dead zone, and to the \( T_2 \) time, unit work into the rev grinding range. Until \( T_3 \) moment, the rev grinding process is over, the unit continues to raise its power. To \( T_4 \) time, unit first time work into the dead zone adjustment range, then near \( P_2 \) unit adjust slightly and has a stable value. Until \( T_5 \) time, AGC control program sent a new unit set point command, the power is \( P_3 \), unit began to a new work.

![Figure 1. Typical AGC unit set point control process](image)

According to the rules of power grid, the AGC must to be run in accordance with the scheduling curve. The rate, accuracy and response time of adjustment are three main criteria of AGC assessment. In general, the adjustment rate of thermal power units with intermediate storage pulverizing system is 2% of unit’s rated active power, circulating fluidized bed coal-fired units is 1%, supercritical once-through boiler unit is 1.5%. Adjustment accuracy is the difference between the actual output of unit and the set point when unit work stably after a AGC response, permissible deviation is 1% of unit’s rated active power. Response time refers to, after the EMS system send AGC commands, on the basis of the original output point, the time that the output of generating unit reliably adjust to across adjusting dead zone to need. AGC response time of thermal power unit should be less than one minute.

2.2. Unit’s PFC Control Performance Evaluation Standard

The primary frequency regulation, refers to the grid frequency deviation, control unit in the power grid automatically to increase or decrease the unit active power, to limit the changes of grid frequency, so that to maintain the stability of grid frequency.
As shown in figure 2, it's the load response of one unit when grid frequency in the fall. Among them, 1 is grid frequency, 2 is ideal load output, and 3 is actual load output. The shadow area A is the integral area that the ideal 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.

![Figure 2. Schematic of PFC's Assessment Criteria](image)

\[ A = \int_{t_0}^{t} [P_i(t) - P_0] dt \]
\[ B = \int_{t_0}^{t} [P_r(t) - P_0] dt \]

\( t_0 \) is the starting time that the frequency deviation over of the dead band, frequency deviation dead band generally taken to be 0.033Hz. \( P_0 \) is the unit load at moment. \( P_i(t) \) is the unit actual load curve. \( P_s(t) \) is the unit ideal load curve. Calculated \( P_i(t) \) as following formula

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

Among them, \( R_i \) represents the unit ramp rate. After calculating the shadow area A and B, PFC assessment indicators equal to

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

Unit PFC assessment rules as follows, if \( \eta > 0 \), it’s determined to be correct FM operation. If \( \eta \geq \eta_{min} \), \( \eta_{min} \) is the threshold value, it is determined to meet the requirements of PFC performance.

3. Influence of AGC on PFC

Due to the overlap between AGC and PFC time scale, there is an influence between the two. A typical 300MW subcritical boiler in the North China region was taken out as an example. It’s single load adjustment of AGC mode is 3MW, and ratio is 1.5% rated load. Adjust the speed calculation, the time required for a single load adjustment is

\[ t = \frac{3}{300 \times 1.5\%} = 0.667 \text{ min} = 40 \text{ s} \]

According to the PFC assessment, the effective disturbance is defined as the frequency exceeding 50±0.033Hz and continues to be in the 6s and above, while the maximum frequency deviation is 50±0.038Hz. Therefore, there is the possibility that PFC and AGC direction is opposite, which affects AGC and PFC index. Therefore, the unit needs to have a certain reaction time for the single AGC regulation, and the length of the action is greater than the length of the time of the PFC. Because the working time of the AGC is longer than that of the PFC, and because the priority of the operation after
the rate limiting is lower than that of the PFC, in some cases in actual operation, the PFC and AGC actions are reversed, resulting in that the amplitude of the PFC action does not reach the frequency. On the one hand this will cause the PFC assessment of the power plant to fail to reach the standard and affect the actual economic efficiency of the power plant. On the other hand, the lack of the magnitude of the PFC response of the unit is not conducive to the stability of the power grid frequency.

In practice, the reverse processing logic of PFC and unit load instruction is added in the thermal power unit to ensure the action priority and qualification of PFC. When the unit is increasing load and PFC is required to reduce load, the increase instruction of the PID controller of the closed steam turbine. When the unit is reducing load and the PFC requires increasing load, the reduction instruction of the PID controller of the closed steam turbine.

The above control method can effectively ensure the effect of PFC and AGC in most of the time. However, due to the transient and random nature of PFC, there is a long-term small-frequency oscillation condition of the grid frequency in a certain period of time. This will cause PFC to take a long time blocking the main control commands of the steam turbine, at this time, the load command increases in reverse, and the deviation between the load command value received by the steam turbine PID controller and the actual power value is continuously increased as a result of the lockout, as shown in figure 3, when the PFC blocking action signal When it disappears, the load deviation value is released, and the output command of the steam turbine PID controller will change significantly, causing the unit main steam pressure, main steam temperature and load to fluctuate violently, affecting the safe and stable operation of the unit.

![Figure 3. The curve of load control deviation increased with PFC blocking](image)

4. PFC Optimization Control Strategy

In order to solve the above problems, PFC optimization control method based on safe and stable operation of the thermal power unit is proposed. This method ensures the priority of the PFC operation when the frequency of the power grid fluctuates, and at the same time considers the safety of the unit due to blocking during rapid adjustment of the unit load. The unfavourable effects can not only guarantee the unit PFC action, but also improve the coordinated operation of the unit AGC and PFC, thus ensuring the safety and stability of the unit.

During the normal load adjustment of the unit, if the deviation between the command value of the load after the speed limit and the measured value of the load does not exceed the specified range, the turbine controller locks up when the unit increases the load and the load is reduced by the PFC, the load shedding and the PFC load increase At the time, the turbine controller locks off. If the deviation between the speed limit post-load command value and the load actual value exceeds the specified range, the turbine controller is no longer locked up or down.

The optimized system structure is shown in figure 4. After the unit speed limit, the load command value and the load measured value are respectively connected to the subdivide module DEV, and the difference value is sent to the high-low alarm module HLALM. High and low alarm module HLALM,
the High alarm signal and the Low alarm signal are respectively connected to the switch selector DXSEL1 and the switch selector DXSEL2. The output of the switch selector DXSEL1 is connected to the PID controller of the turbine, and the output of the switch selector DXSEL2 is connected to the PID controller of the turbine. The unit is operated in AGC mode. When the grid frequency is not stable, one frequency difference $\Delta f$ will be generated between the frequency measurement value and the frequency standard value of 50Hz. Assume that the deviation is $|\Delta f| > 0.033$, which is set according to the requirements of the national grid. After the primary compensation value function $F(x)$ is calculated, a load compensation amount $\Delta P$ is generated, sent all the way to the CCS side and superimposed on the load command value to generate a new load command value, which is adjusted by the steam turbine PID controller; all the way to the DEH side, After linear conversion into the corresponding valve opening change, superimposed to the original valve opening command to generate the final valve opening command value, adjust the valve actuator opening.

Figure 4. Optimal control schematic diagram

5. Conclusion
The PFC performance of the grid-connected generating unit directly affects the stability of the grid frequency, and the invention can ensure the priority of the PFC action when the grid frequency fluctuates, and at the same time considers the adverse effect caused by the blockage on the unit safety during rapid adjustment of the unit load. It can ensure that the frequency modulation and peak shaving capacity of the unit meets the requirements of dispatching assessment standards. The optimized system can effectively ensure the priority of the PFC action when the frequency of the power grid fluctuates. It can also improve the coordinated operation of the AGC and PFC of the unit. For one thing, it can maintain the safe operation of the unit. For another thing, it can further improve the stability of the
frequency of the power grid and reduce the power grid system. The frequency fluctuations, in turn, ensure the safe and efficient operation of electrical equipment and power equipment for a wide range of users.

References

[1] D.E. Seborg, T.F. Edgar, D.A. Mellichamp 2004 Process Dynamic and Control (New Jersey : John Wiley & Sons)
[2] YIN Feng 2005 Test and research on CCS-joined primary frequency regulation of thermal power units Electric Power 38(3)
[3] Liu Nian, Xie Chi. Teng Fusheng 2004 Study of safety and stability problems for power system Sichuan Electric Power Technology Vol.1 p1-6
[4] ZHU Wei, TAN Xi-yi, TANG Ying-jie 2008 Analysis and research on primary frequency modulation of the turbine generation unit Automation of Electric Power Systems 32
[5] CHEN Liang, CHEN Hui-kun 2007 Analysis on primary frequency regulation of generator units in Guangdong Power System Guangdong Electric Power 21(8)
[6] 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) pp57-61
[7] WANG Zhen-yi, XIE Yi-gong, YIN Cheng-quan 2007 Research on the coordination of AGC and primary frequency regulation based on CPS Power System Protection and Control 37(19)