Calculation method of PFC assessment index of thermal unit based on time point comprehensive treatment

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Abstract. With the rapid development of clean new energy, power fluctuations bring great challenges to power grid frequency control. The main ways of dealing with the instantaneous power gap depends on primary frequency control (PFC) of thermal units. Based on the analysis of the problems and shortcomings of the current two assessment methods of PFC, one method for calculating the assessment index of PFC of thermal unit based on time point comprehensive treatment is proposed. The efficiency and accuracy of the examination index of PFC are improved by calculating the multi-point speed governing droop based on the national standard, so as to ensure that the unit can meet the demands of the power grid for the speediness and stability of the PFC action, and ensure the safety and stability operation of power grid.

1. Introduction
In recent years, China is the country with the fastest development of new energy such as wind power and photovoltaics. The power grid of all levels is increasingly closely connected through the UHV grid engineering[1,2]. The coordination control between power grid and thermal units is increasingly demanding. Primary frequency control (PFC) has become one of the effective ways to stabilize the frequency of power grid. The PFC function of the thermal unit is an inherent function of the turbo generator unit. It is mainly used to quickly respond to the load requirements of the power grid, stabilize the system frequency to make up the load gap of the power grid, and maintain the security of the power grid by adjusting the steam inlet regulating gate of the digital electric hydraulic control (DEH) system and the boiler heat storage. In order to ensure the safe operation of their power grids and grid-connected generator sets, to improve the power quality and to standardize auxiliary service management, the regional power grids in North China, Central China, and Northwest China are all based on the Regulations on Electricity Regulations and Regarding the Opinions on Printing and Distributing the Opinions of Power Plants on Grid Operation Notice (Electric Supervision Market 2003 No.23) and other relevant regulations and rules, formulated the implementation rules for regional power plant grid-connected operation management and regional grid-connected power plant auxiliary service management implementation rules, and clarified the assessment and management of the frequency regulation operation of the thermal unit at PFC, conduct the corresponding overhaul acceptance test and PFC action performance assessment[3-5].

2. Existing PFC Performance Evaluation Standard
In the existing PFC performance assessment technology, the calculation parameters of the thermal power unit by the power grid dispatch management basically come from the dispatch plan and energy
management system (EMS). Among them, the measurement point information corresponding to the unit such as frequency and active power is defined in the wide area monitoring system (WAMS) telemetry definition table, and according to the telemetry information of WAMS. The telemetry data include frequency, turbine speed, active power, and instruction before and after the PFC disturbance calculation are come from the real-time library of synchronous vector measurement device (PMU)\cite{6-8}. In the case of power grid frequency fluctuation, it is required that the speed governing droop of the unit should not be 4%-5% or the PFC integral power should be more than the specified percentage 70% or more.

2.1. Integral Power Evaluation Standard

As shown in Figure 1, the unit automatically adjusts the active power according to the power grid frequency fluctuation. For example, it is required in the technical management regulations for PFC of Northwest power grid that the percentage of the total monthly integral electric quantity of the PFC of the unit to the theoretical monthly integral electric quantity, that is, the monthly average qualified rate of the PFC shall not be less than 60%.

![Figure 1. Schematic of PFC’s Integral Power Assessment Criteria](image)

In figure 1, it's the active power response of one thermal unit when grid frequency has a sudden power drop. The shadow area A is the integral power based on the normal active power and the initial active power on the assessment time. The shadow area B is the integral power based on the actual active power and the initial active power on the assessment time.

\[
A = \int_{t_0}^{t_f} [P_N(t) - P_0] dt
\]

\[
B = \int_{t_0}^{t_f} [P_A(t) - P_0] dt
\]

\(t_0\) is the starting of assessment time which the frequency deviation over of the dead band 0.033Hz. \(P_0\) is the unit active power at \(t_0\) time. \(P_N(t)\) is the normal active power curve of unit. \(P_A(t)\) is the actual active power curve of unit. The formula of calculated \(P_i(t)\) as following

\[
P_N(t) = P_0 + (t - t_0) \times R_i, \quad t - t_0 \leq \frac{P_{max} - P_0}{R_i}
\]

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

Among them, \(R_i\) is the unit load changing rate. According to the calculated shadow area A and B, PFC assessment indicators can be obtained

\[
\xi = \frac{A}{B} \times 100\%
\]
Assuming $\xi_{\text{min}}$ is the assessment threshold value of correct operation, if $\xi \geq \xi_{\text{min}}$, it is meet the standard. If $\xi < \xi_{\text{min}}$, it is not up to the standard.

2.2. Speed Governing Droop Evaluation Standard

The turbine speed governing droop in GB/T26863 is defined in this way, the turbine control system static characteristic curve slope, usually in the corresponding empty load and full load speed difference divided by the rated speed to obtain the ratio percentage. It is required in the detailed rules for the operation management of thermal power plants connected with the grid in North China region that the speed governing droop is less than 5%. Calculation formula is

$$L = \frac{f_n}{P_n - P_0} \left( f_t - f_n \right) - 0.033$$

Among them, $P_0$ is the unit’s actual load value when power grid frequency beyond dead band 0.033Hz in frequency disturbance process, $P_t$ is the maximum load value after frequency beyond dead band 3 seconds, $f_t$ is the frequency value corresponds to $P_t$. $P_n$ is the unit’s rated power, $f_n$ is the rated frequency 50Hz.

The speed governing droop is an important index to measure the quality of the regulating system. It reflects the change of the steam turbine speed due to the change of load. The higher the rotation rate is, the steeper the static characteristics are. Conversely, the static characteristic curve is flatter. The turbine speed governing droop with base load should be more than with peak load, but the so-called base load and peak load is also relative, it is with the increase of the power of the network and change, so generally hope that the speed governing droop is designed to be continuously adjustable, can be adjusted according to the operation.

3. Existing Problems

As required in the Guide of primary frequency control test and performance acceptance for thermal power generating units(GB/T 30370) standard etc., the unit’s load response speed of PFC should meet the requirements: the control dead band is 50±0.033Hz, the response delay time is less than 3 seconds, the stabilization time is no more than 60 seconds. the time that the unit reach 75% target load should be less than 15 seconds, and the time that the unit achieve 90% target load should be less than 30 seconds.

Existing technology found in the actual operation, the following problems: when power grid frequency difference appears early, if no action unit or slow, late load at specified requirements, the class of the unit, PFC performance early will cause power grid failure frequency drop too much, can cause system instability, oscillation occurs, will lead to distance protection misoperation. If the frequency difference of the power grid appears that the load of the units increases rapidly in the early stage, but cannot be maintained at the specified active power value, then the PFC performance of such units is not conducive to the rapid regression of the power grid frequency to standard 50Hz. If the above two situations happen, the calculated results may be qualified and cannot reflect the unit’s PFC performance.

4. PFC Performance Evaluation Standard Optimization

Based on time point comprehensive treatment calculation method of the evaluation index of PFC, according to the regulations of the state standard of GB/T 30370-2013 and Q/GDW asked in 669, the real time collected unit according to the power grid main frequency value and power value, calculate 3s speed governing droop L3, 15s speed governing droop L15, 30s speed governing droop L30, then
to choose the big speed governing droop. The maximum value L is taken as the speed governing droop in the performance index of the unit’s PFC to evaluate whether the PFC is qualified or unqualified.

If the grid frequency is no more than 50Hz, the unit should need to increase the active power to make up the grid’s power gap, and the calculation formula of the speed governing droop L3 is

$$L_3 = \begin{cases} 5\%, & P_3 - P_0 > 0, \quad f < 50Hz \\ 6\%, & P_3 - P_0 \leq 0, \end{cases}$$

If the grid frequency is more than 50Hz, the unit needs to reduce the active power to reduce the power grid’s excess power and maintain the balance between the power grid supply and demand, and the calculation formula of the speed governing droop L3 is

$$L_3 = \begin{cases} 5\%, & P_3 - P_0 < 0, \quad f > 50Hz \\ 6\%, & P_3 - P_0 \geq 0, \end{cases}$$

According to the national standard, the time for the unit to reach 75% target load should be less than 15 seconds, and the time for the units to reach 90% target load should be no more than 30 seconds, the calculation formula of speed change rate L15 and L30 are

$$L_{15} = \frac{f_{15} - 50}{P_{15} - P_0} \cdot 0.033$$

$$L_{30} = \frac{f_{30} - 50}{P_{30} - P_0} \cdot 0.9 \cdot \frac{0.75}{P_N}$$

Unit’s comprehensive speed governing droop is

$$L_c = \max\{L_3, \ L_{15}, \ L_{30}\}$$

If $L_c$ is less than 5%, the PFC’s performance is qualified. If $L_c$ is more than 5%, the PFC’s performance is unqualified.

5. Specific Case

Taking Shandong Power Grid as an example, the dispatch management agency realizes the frequency disturbance test function of 100MW or above directly regulated thermal units in the D5000 system, and the DCS system of the power plant receives trigger signals and realizes the PFC response. If the frequency fluctuates of power grid within a month, the assessment will be conducted based on the calculated results of the actual frequency disturbance of power grid. If there are no frequency fluctuation occurs, the test system in D5000 will be used for the test and assessment.

![Figure 2. PFC Disturbance Test Action Curve](image)
One 330MW sub-critical, primary intermediate reheat and natural circulation drum furnace unit in Shandong power grid is taken as an example. The frequency disturbance test of the power grid is carried out through D5000 management system, and the frequency value of 49.9Hz is issued, that is, the frequency is lower than the 50Hz of 0.1Hz, and the thermal unit shall quickly carry out active power growth to promote the frequency of power grid to return to the 50Hz standard value.

\[ P_0 = 240.0 \text{ MW}, \quad P_3 = 242.2 \text{ MW}, \quad P_{15} = 244.4 \text{ MW}, \quad P_{30} = 248.5 \text{ MW}, \quad P_{\text{max}} = 249.9 \text{ MW}, \]  
\[ f_{\text{max}} = f_0 = f_{15} = f_{30} = 49.9 \text{ Hz}.\]

If the conventional calculation formula is followed, the calculation results are as follows

\[
L = \frac{|f_{\text{max}} - f_N| - 0.033}{P_N - P_0} = \frac{|49.9 - 50| - 0.033}{249.9 - 240.0} = \frac{50}{330} = 4.47% \]

4.47%<5%, so the calculated result is qualified.

According to the design method, because it is no more than 50Hz, the unit needs to increase the active power to make up for the grid’s power gap. Because of the actual active power deviation measured at this time is \( P_3 - P_0 = 242.2 - 240.0 = 2.2 > 0 \), L3 can be assigned to 5%, i.e.

Because \( P_0 = 240.0, P_{15} = 244.4 \), so

\[
L_{15} = \frac{|f_{15} - 50| - 0.033}{0.75} = \frac{50}{244.4 - 240} = \frac{0.75}{330} = 7.53% \]



Because \( P_0 = 240.0, P_{30} = 248.5 \), so

\[
L_{30} = \frac{|f_{30} - 50| - 0.033}{0.9} = \frac{50}{248.5 - 240} = \frac{0.9}{330} = 4.68% \]

\[
L_C = \max\{L_3, L_{15}, L_{30}\} = 7.53% \]

Because \( L_C \) is greater than 5%, the PFC’s performance is unqualified. It can be clearly seen from figure 2 that during the PFC action process, the early load reaction of the unit is slow, which does not meet the requirements of the PFC standard. But, because the later load regulation exceeds the specified value requirements, if the original value is taken to calculate the speed governing droop or the ratio of the area of PFC operation is qualified, it is actually unqualified. Therefore, the proposed scheme can effectively judge he unit's PFC action speed and effectiveness, and meet the requirements of relevant national standards.

### 6. Conclusion

Unit’s PFC performance is good or bad directly affects the stability of power grid frequency, through the design plan can be carried out in accordance with the provisions of the state standard of multipoint calculation speed governing droop, improve the effectiveness and accuracy of the assessment index of PFC, to ensure that the work of power grid to PFC unit of rapidity and stability requirements, guarantee the safe and stable operation of power grid, solve the existing technology of caused due to
the large power grid fault initial frequency drop system instability, oscillation, and even lead to distance protection misoperation. Targeted in the system of examination by PFC power variation related indicators, it can effectively monitor the performance of the unit of PFC and improve the accuracy of the thermal power unit for scheduling PFC response. The practical application shows that it can effectively reduce the amplitude of power grid frequency fluctuation and ensure the stability of power grid frequency.

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