Calculation Method of PFC Assessment Index Based on Time Point Comprehensive Processing

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Abstract. With the increase of DC power supply scale and the increase of new energy output ratio, higher requirements are put forward for the PFC (primary frequency control) performance of thermal power units. Through the introduction of the inherent characteristics of PFC, aimed at the problems of insufficient adjustment range and unable to effectively maintain the adjustment load in the actual modulation process of thermal power units, one calculation method of PFC assessment index based on the comprehensive processing of time points is proposed. This method can calculate the multi-point speed difference rate in accordance with the national standard, improve the effectiveness and accuracy of primary frequency modulation assessment index, ensure that the unit meets the power grid's demand for the rapidity and stability of PFC action, and ensure the safe and stable operation of the power grid.

1. Introduction
With the increase of DC power supply scale and the increase of new energy output proportion, conventional units are largely replaced. The rotary inertia of DC multi-feed into the receiving end power grid and the sending end power grid with a high proportion of new energy continues to decrease. The frequency over-limit and the risk of stability failure of the power grid increase, and the power grid’s frequency regulation ability decreases. In steady state, the frequency of power system is the consistent operating parameter of the whole system. When the total output and the total load are unbalanced, the frequency deviation will occur. Because the load is often changed, the load change at any place will cause the power imbalance of the whole system, thus resulting in the fluctuation of the system frequency. Therefore, one of the important tasks in power system operation is frequency monitoring and regulation.

In Chinese GB/T 30370 ‘Guide of primary frequency control test and performance acceptance for thermal power generating units’ and other technical standards clearly required, the speed difference rate of thermal power unit should not be more than 5%, the response time of the unit participating in primary frequency modulation should be less than 3s. The PFC load response speed of the unit shall meet the following requirements: the time for the thermal unit to reach 75% of the target load shall not be more than 15s, and the time for reaching 90% of the target load shall not be more than 30s[1-3]. How to effectively ensure the unit to achieve this goal is the key to ensure the frequency drop range of the power grid, which requires reasonable and effective monitoring means.
2. Characteristics and Standards of PFC

PFC refers to the capacity inherent in the frequency characteristics of the speed regulation system of the generator set to automatically adjust the frequency with frequency changes[4,5]. The characteristic is that the frequency is adjusted fast, but the adjusted quantity is different from the generator set.

2.1. Characteristics

Suppose that there is only one generator set and one integrated load in the system, and their static frequency characteristics are shown in figure 1 and figure 2 respectively. These characteristic curves are approximately replaced by straight lines. The slope $K_G$ of the frequency characteristic of the generator’s prime mover is referred to as the unit regulation power of the generator, which indicates the decrease or increase of the power with frequency, which can be tuned. The static frequency characteristic of integrated load also has a slope $K_L$, which is called the unit adjustment power of load. It indicates that the power consumption decreases or increases with the rise and fall of frequency load, which cannot be set.

![Figure 1. Generator static frequency characteristics](image1.png) ![Figure 2. Load static frequency characteristics](image2.png)

The intersection point O of the frequency characteristics of the prime mover of the generator and the frequency characteristics of the load is the original operating point of the system, as shown in figure 3. The sudden load increase $\Delta P_{L0}$ in the point O, namely load frequency characteristics of the sudden move up $\Delta P_{L0}$, sudden increase is due to the load is not changed in time, the output of unit will slow down, the system frequency will drop. And at the same time that the system frequency drops, the unit will increase output under the adjustment of the governor, the power of the load will be reduced because of its own adjustment effect. The former increased along the frequency characteristics of the generator, which cut down the frequency characteristics of the load, after a shock attenuation process reached a new equilibrium, namely in figure 3 O’ point, the corresponding frequency offset $\Delta f=f_0-f_0'$. According to the geometric relationship in figure 3, it can be seen that

$$\Delta P_{L0} = BO + AB = (K_G + K_L)\Delta f = K_S \Delta f$$

(1)
KS refers to the unit regulation power of the system, which depends on the unit regulation power of the generator and the unit regulation power of the load. KS indicates the increase or decrease of system frequency under the combined action of generator and load when system load increases or decreases.

2.2. Assessment Standard

The unit’s load response with large frequency fluctuations is shown in figure 4. Among it, the curve 1 is the frequency, the curve 2 is the standard unit load output, and the curve 3 is the actual unit 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.

Figure 4. Schematic of integral charge contribution index

The integral charge contribution index is calculated by the following formula

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

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

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

Among them, \( P(t) \) is the 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 70%-80% to meet the grid’s standard requirements[6-8]. Because of the unit’s different heat storage capacity, the action time of PFC to different types of 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. Problems and Solutions

3.1. Existing Problems

In actual operation, it is found that when the grid frequency difference occurs in the early stage, if the unit has no action or slow operation, and the unit load reaches the specified requirements, the
frequency modulation action performance of the unit will cause the frequency of the grid to fall too much at the initial stage, which will cause the system unstable and oscillates. It will cause the distance protection to malfunction. If it is more serious, it will directly lead to system unwinding. Or the grid frequency difference occurs in the early stage, the unit load increases rapidly, but can not maintain the specified load value, then the frequency modulation action performance of this type of unit is not conducive to the rapid return of the grid frequency to 50Hz.

The above two cases, whether calculated according to the speed governing droop or the primary frequency integrated power, the calculation results may be qualified, and can not truly reflect the frequency modulation performance of the unit. In this regard, one calculation method of frequency modulation evaluation index based on time point comprehensive processing is proposed. This method can calculate the multi-point speed unequal rate according to the national standard, improve the validity and accuracy of the primary frequency measurement index, and ensure the unit. It satisfies the rapidity and stability requirements of the power grid for the work of primary frequency modulation, and ensures the safe and stable operation of the power grid.

3.2. Solutions

According to the Chinese GB/T 30370 and other technical standards clearly required, combined with the real-time power value and frequency value collected from the power grid, the speed governing droop L3, L15 and L30 at the three time points were calculated respectively. Then, the maximum value Lc of the three speed governing droop were selected, and was taken as the speed governing droop in the PFC performance index of the unit for assessment.

First, according to the power value and frequency value of the power grid, the speed governing droop L3 of the unit at 3s is calculated. If the power grid frequency is less than 50Hz, that is, the unit needs to increase the load to make up for the power gap of the power grid. If the load change value of the unit is greater than 0, L3 is directly assigned to 5%, that is, the qualified value. If the load change value of the unit is not greater than 0 at this time, the operation is unqualified. L3 is assigned with a value greater than 5%, such as 6%, that is, the unqualified value. The calculation formula of L3 is

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

If the power grid frequency is greater than 50Hz, that is, the unit needs to reduce the load to reduce the excess power of the power grid and maintain the balance between supply and demand of the power grid. If the change value of the load of the unit is less than 0, the direct value of L3 is 5%, that is, the qualified value. If the load change value of the unit is not greater than 0 at this time, the operation is unqualified. L3 is assigned with a value greater than 5%, such as 6%, that is, the unqualified value. The calculation formula of L3 is

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

Second, according to the power value and frequency value of the power grid, the speed governing droop L15 of the unit at 15s is calculated. The calculation formula of L15 is

\[ L_{15} = \frac{50}{P_{15} - P_0} - \frac{0.033}{50} \]

Third, according to the power value and frequency value of the power grid, the speed governing droop L30 of the unit at 30s is calculated. The calculation formula of L30 is

\[ L_{30} = \frac{50}{P_{30} - P_0} \]

Fourth, according to the power value and frequency value of the power grid, the speed governing droop of the unit at 45s is calculated. The calculation formula of L45 is

\[ L_{45} = \frac{50}{P_{45} - P_0} \]
The final speed governing droop of the unit, that is, the maximum value is
\[
L_{30} = \frac{|f_{30} - 50| - 0.033}{\frac{50}{P_0} - \frac{0.9}{P_N}}
\]

The final speed governing droop of the unit, that is, the maximum value is
\[
L_C = \max\{L_3, L_{15}, L_{30}\}
\]

If \(L_C\) is less than 5%, the PFC is qualified. If \(L_C\) is greater than 5%, the PFC is unqualified. This method can be used to calculate the multi-point speed governing droop in accordance with the national standard, improve the effectiveness and accuracy of the PFC assessment index, ensure that the unit meets the power grid's demand for the speed and stability of the PFC action, and ensure the safe and stable operation of the power grid.

4. Practical Application

According to the regulations for the grid-connected operation and management of power plants in the North China region, take one 300MW unit as an example. The power grid conducts frequency perturbation test through the D5000 system and set 49.9Hz frequency value, that is, the frequency is lower than the standard 50Hz frequency, and the unit needs to immediately increase the load to make the power grid frequency return to the standard 50Hz.

At this time, \(P_0 = 240.0\) MW, \(P_3 = 242.2\) MW, \(P_{15} = 244.4\) MW, \(P_{30} = 248.5\) MW, \(P_{\max} = 249.9\) MW, \(f_{\max} = f_0 = f_{15} = f_{30} = 49.9\) Hz. As shown in figure 5, if the formula of speed governing droop in the original standard is followed
\[
L = \frac{|f_{\max} - f_N| - 0.033}{P_{\max} - P_0} = \frac{49.9 - 50 - 0.033}{249.9 - 240.0} = 4.47\%
\]
the calculated results are qualified.

If the calculation method proposed in this paper is followed. Since it is less than 50Hz, the unit needs to increase the load to make up for the power gap in the power grid. The actual power deviation
measured by the unit at this time $P_3 - P_0 = 242.2 - 240.0 = 2.2 > 0$, $L_3$ can be directly assigned as 5%, that is $L_3 = 5\%$.

$$L_{15} = \frac{|f_{15} - 50| - 0.033}{P_{15} - P_0} = \frac{50}{244.4 - 240} = 7.53\%$$

$$L_{30} = \frac{|f_{30} - 50| - 0.033}{P_{30} - P_0} = \frac{50}{248.5 - 240} = 4.68\%$$

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

Because $L_C$ is greater than 5%, the PFC of this time is unqualified. It can be clearly seen from figure 5 that during this PFC operation, the unit's early reaction is slow, which does not meet the requirements of the grid for frequency modulation rapidity. However, since the later load adjustment exceeds the specified requirements, it is qualified if the speed governing droop is calculated according to the original large value or the proportion of the operation area of the PFC is calculated, but it is actually unqualified. Therefore, the calculation method proposed can effectively identify the rapidity and effectiveness of the unit's PFC action.

5. Conclusion

The paper introduced the characteristics of PFC, analyzed the existing problems of current assessment methods, and put forward one calculation method of PFC assessment index based on the comprehensive processing of time points. According to the real-time power and frequency value of the unit, the speed governing droop $L_3$, $L_{15}$ and $L_{30}$ at the three time points are calculated respectively. The maximum value $L_C$ is taken as the speed governing droop in the PFC performance index for assessment. This method can improve the effectiveness and accuracy of the PFC assessment index, ensure that the unit meets the power grid's demand, and ensure the safe and stable operation of the power grid.

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