Dynamic Compensation Control Strategy of PFC Based on Real-time Calculation of Performance Index

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Abstract. The primary frequency control (PFC) performance of thermal power units were affected by the problems such as equipment delay, nonlinear valve flow characteristic curve and weak controller parameters etc. Combined with the new integral electricity contribution index method, one dynamic compensation adjustment method of PFC based on real-time evaluation of performance indexes are proposed. The method dynamically adjust the control parameter by calculating the amplitude of PFC at the relevant time and the integral electricity contribution in the corresponding time period. This method not only improves the PFC performance based on the safe operation of the unit, but also helps to improve the PFC performance. It satisfies the power grid’s standard and reduces the frequency fluctuation of the grid system.

1. Introduction
With the increasing scale of new energy and the rapid development of UHV power grid, power grids at all levels are increasingly closely connected, and the requirements for coordination and cooperation between power grid and units are increasingly high[1-3]. PFC in the coordination function of power source becomes one of the effective means to stabilize the power grid. In recent years, the synchronous vector measurement technology based on GPS technology has been gradually mature and developed, fundamentally solving the problem of synchronous data acquisition of different spatial positions, and realizing the synchronous acquisition of wide-area measurement information of the unit. At the same time, the PMU device distribution and measurement configuration within the scope of power grid is becoming more and more perfect and rich, which lays a good data foundation for the online monitoring and analysis of the PFC performance of the unit. PFC of thermal power unit is the main part of China's power grid and frequency modulation[4-6]. PFC is mainly by adjusting the inlet damper of digital electric hydraulic control system(DEH), using the boiler heat storage, rapid response to the requirements of the grid when the grid appear abnormal, the stability of power grid frequency, to make up for the gap between power load, so as to maintain the safety of power grid.

As an important means of frequency adjustment, PFC should be fast and effective. Rapidity refers to the rapid adjustment of unit output with the change of frequency to ensure the timely adjustment of power grid frequency. Effectiveness refers to that after the power grid frequency crosses the set dead zone, the unit output changes rapidly reach a certain range to ensure that the frequency can be significantly adjusted in the direction of the dead zone[7-9]. Therefore, each regional power grid has gradually carried out online monitoring and analysis of the primary frequency modulation performance of the unit based on PMU dynamic data, and comprehensively analyzed and evaluated
the primary frequency modulation performance of the unit by using output response index and power contribution index.

2. Grid Assessment Standard
Since the original fixed time point assessment method and the speed governing droop method cannot fully reflect the contribution of units to the power grid during the frequency disturbance, the current regional power grid gradually adopts the electricity contribution index method.

2.1. Actual electricity contribution
When the frequency variation exceeds the lower limit (or upper limit) of the dead zone of the PFC, the actual active power generation of the unit during the PFC operation period increases (or decreases) the part of the power generation before the PFC operation, that is, the actual compensation power of the unit during the PFC (if the time exceeds 60 seconds, it will be calculated by 60 seconds). High frequency less or low frequency more power generation is positive, high frequency more or low frequency less power generation is negative[10,11]. If the actual electricity contributed during the operation period of primary frequency modulation is positive, it is positive. Otherwise, it is the negative electricity contribution.

\[
Q_{\text{Actual}} = H = \int \Delta P(\Delta f, t) \Delta t \times \frac{1}{3600} \times \sum_{t} (P(t) - P_0)
\]

Where, \(Q_{\text{Actual}}\) is actual electricity contribution. \(P_0\) is the actual output of the power grid when the frequency variation exceeds the dead zone of primary frequency modulation. \(P(t)\) is the actual output of the unit during PFC operation period. \(\Delta f\) is the frequency deviation between the actual frequency and PFC dead zone (50±0.033Hz).

2.2. Ideal electricity contribution
Considering the actual load limit of the unit, the ideal PFC compensates the electricity from the time when the frequency deviation exceeds the dead zone (such as 0.033Hz).

\[
Q_{\text{Ideal}} = \int \Delta P_N(\Delta f, t) \Delta t \times \frac{1}{3600} \times \frac{P_N}{f_N \times \delta} \times \sum_{t} \Delta f
\]

Where, \(Q_{\text{Ideal}}\) is ideal electricity contribution. \(P_N\) is the unit rated power. \(f_N\) is the unit rated frequency 50Hz. \(\delta\) is the speed governing droop and its value is 4%~6%.

2.3. Electricity contribution index
The electricity contribution index refers to the percentage of the actual electricity contribution of the unit to the ideal electricity when the frequency change exceeds the lower limit (or upper limit) of the PFC dead zone and the unit's PFC response time.

\[
Q\% = \frac{Q_{\text{Actual}}}{Q_{\text{Ideal}}} \times 100\%
\]
As shown in Figure 1, curve 1 is the grid frequency value, curve 2 is the ideal operation amplitude of PFC, and curve 3 is the practical operation amplitude. The actual electricity contribution can be obtained from curve 2, and the ideal electricity contribution can be obtained from curve 3. The electricity contribution index should exceed a certain ratio square to meet the grid assessment requirements..

3. Existing Control Strategies and Problems

In the existing technology, PFC system sends the calculated speed deviation to coordination control system (CCS) side and DEH side respectively. On the CCS side, the variation is generated by the unequal rate function generator to generate the corresponding frequency modulation power, which is superimposed on the value of frequency modulation power to generate the set value of power of the unit. The difference between the set value of power of the unit and the actual power of the unit is calculated, and the valve position command signal is generated by PID operation of the power controller. On the DEH side, the slip is generated by the unequal rate function generator to generate the corresponding comprehensive valve position increment, and the comprehensive valve position increment is superimposed on the valve position command signal sent from the CCS side to generate the comprehensive valve position command, through which the steam turbine adjustment gate is controlled. Among them, the comprehensive valve position increment on the DEH side directly affects the turbine valve opening, so the response speed on the DEH side is fast to meet the fast requirement of power grid frequency modulation[12]. CCS side mainly adjusts wind, coal, water and other parameters to ensure that the power of the unit is stable at the required target value.

According to GB/T 30370, Q/GDW 669 and other relevant technical standards, the dead zone of conventional DEH control system is controlled within ±0.033Hz. The speed governing droop should be 4%–5%. The time when the load adjustment amount of coal-fired generating units reaches the target load variation range of 75% shall be no more than 15s, and the time when the target load variation range reaches 90% shall be no more than 30s. PFC mainly plays an important role in the early stage of power grid frequency fluctuation, and AGC (automatic generation control) of 15~20s units will play a role in secondary frequency modulation after the Generation of power grid frequency difference. The difference between primary frequency modulation and AGC is that there is no rate limit and the response speed is fast, but there is some difference adjustment, which needs to be eliminated by AGC. Therefore, for power network frequency control, primary frequency modulation needs to focus on the frequency modulation performance within 15~20s.

In actual operation of the unit, such as turbine valve itself inherent delay characteristics of the actuator, the turbine valve after long time running, astringent and flow characteristic changes caused by the nonlinear characteristics, and weaken the controller parameters, all can cause the low control precision of PFC. At the same time, the active variation indicators in the assessment of power grid cannot meet the standard, and monthly pass rate is lower than the specified value.
4. Optimization and Improvement
According to the actual needs of the unit, one dynamic compensation control strategy of PFC based on real-time calculation of performance index is designed. This strategy judge and record the starting point of the grid frequency beyond the limit, PFC amplitude and period corresponding action integral power whether meet the requirements of grid standards. Combined with the unit the important parameters and comprehensive judgment, the computing results of performance indicators for dynamic adjustment or run the alarm unit can be achieved.

The first step is to determine whether the grid frequency exceeds the range of PFC dead zone. The judgment standard for power grid frequency fluctuation beyond GB30370 duration exceeds a certain value, \( |f_N - f| > 0.033 \text{Hz} \) and \( T > n \text{s} \), \( f_N = 50 \text{Hz} \), \( n \) is more than 6. Specifically, it is when the difference between actual value and the grid frequency 50Hz is greater than 0.033, and lasting more than 6s, this is considered a effective power grid frequency disturbance, the unit need an frequency compensation.

The second step is to record the load value \( P_0 \) and \( t_0 \) at the starting point. Where, since the load value of the unit fluctuates in a small range in actual operation, to ensure the reliability of the value, \( P_0 \) takes the average value of the load value of 1 second before and after \( t_0 \), that is

\[
P_0 = \frac{P_{16} + P_{15} + P_{14}}{3}
\]

The third step is to calculate the relevant point PFC amplitude satisfies the requirement of grid evaluation standard or not. In accordance with the GB/T 30370 standard requirement and the actual demand, the system focus on the load adjustment \( P_{15} \) after 15s. \( P_{15} \) need to reach the 75% target load change, that is

\[
K_p = \left| \frac{P_{15} - P_0}{\Delta P} \right| \geq 75\%
\]

among them

\[
\Delta P = \begin{cases} 
-P_N \times \frac{f - f_N - 0.033}{f_N} \times \frac{1}{\delta\%}, f > 50.033 \text{Hz} \\
-P_N \times \frac{f_N - f - 0.033}{f_N} \times \frac{1}{\delta\%}, f < 49.967 \text{Hz}
\end{cases}
\]

The speed governing droop \( \delta\% \) value is 4%~5%.

The fourth step is to judge whether the main steam pressure deviation and the integrated valve position command value meet the requirements. When \( |\text{main steam pressure deviation}| < \Delta p \) and \( L < |\text{integrated valve position command value}| < H \), dynamic compensation adjustment can be made to the PFC motion amplitude of the unit. The range of H is set as 90%~99%, and L is determined by the unit's minimum stable combustion load, which is generally no higher than 50%. Otherwise, when the amplitude and integral electricity of PFC are not up to the standard, the alarm signal of ‘primary frequency modulation is not up to the standard’ will be issued.

The fifth step is, according to PFC amplitude and integral electricity dynamic compensation coefficient, the system focus on the first 15s actual action of PFC period the ratio coefficient. That is

\[
K_A = \frac{Q_{\text{Actual}}}{Q_{\text{Ideal}}} \geq R
\]

\[
Q_{\text{Actual}} = \int_{t_0}^{t_1} |P_t - P_0| \text{dt}, \quad Q_{\text{Ideal}} = \int_{t_0}^{t_1} |\Delta P(t)| \text{dt}
\]
In accordance with the assessment of the regional power grid frequency control rules, R value generally is 40%~55%.

The specific method of judging compensation is

If \( K_A \geq R \), it indicates that the actual operation integral electricity of the PFC reaches the standard, and the operation amplitude of the PFC also meets the requirements, without compensation, and the dynamic compensation coefficient \( K=1 \).

If \( K_p \geq 75\% \) and \( K_A < R \), it is mainly due to the insufficient initial integral electricity caused by the delay of the unit equipment, and it is necessary to increase the motion amplitude in the later stage to compensate for the deficiency generated in the early stage, and the dynamic compensation coefficient is \( K = 1 + \frac{Q_{\text{ideal}} - Q_{\text{Actual}}}{Q_{\text{ideal}}} \).

If \( K_p < 75\% \) and \( K_A < R \), the unit's PFC amplitude is not enough, it is necessary to improve the subsequent PFC amplitude to make up for the difference in the early stage, and the dynamic compensation coefficient is

\[
K = \frac{75\%}{\frac{|P_{15} - P_0|}{|\Delta P|}}
\]

The sixth step is to send to CCS and DEH side for dynamic compensation and adjustment of frequency modulation power fixed value and comprehensive valve position increment respectively.

5. Conclusion

The performance of PFC of grid-connected units directly affects the stability of power grid frequency. The dynamic compensation coefficient is calculated according to the PFC amplitude of the relevant time points of the unit and the operation integral electricity of the corresponding time period, which can adjust the variation of the PFC of the unit and improve the accuracy of the thermal power unit's response to the dispatching primary frequency modulation. The designed control strategy satisfies the power grid's demand for the power of the unit's PFC action, thus ensuring its frequency modulation ability and reducing the frequency fluctuation of the power grid system. At the same time, the system makes dynamic adjustment or operation alarm based on the important parameters of the unit, and gives consideration to the safe and stable operation of the unit and the demand of power grid for frequency modulation and peak regulation, so as to ensure the coordinated development of network sources.

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