Research on Optimal Control of PFC of Thermal Power Units in DC UHV Grid

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Abstract. By analyzing the change of grid frequency during direct current(DC) ultra high voltage(UHV) faults this year, it is found that the use of conventional primary frequency control(PFC) technology in thermal power units cannot suppress the occurrence of extreme frequency of the power grid, and the conventional PFC method can no longer adapt to the frequency control of the power grid. By analyzing the control signals and control logic of the unit participating in the frequency regulation of the power grid, the PMU(phasor measurement unit) frequency signals that are closely connected to the power grid are introduced, and the second-order differential feed-forward is used to achieve overshoot compensation, which makes the frequency modulation action faster and more accurate, ensuring the power grid’s safe and stable operation.

1. Introduction
At present, China is implementing a global energy internet strategy. The construction of ultra high voltage(UHV) power grids, especially direct current(DC) UHV transmission projects, is rapidly advancing. China’s power grids are developing from regional power grids to cross-regional power grids. Among them, at the 21:58 Jinsu DC bipolar blocking fault on September 19, 2015, the system frequency dropped from 49.97Hz to 49.563Hz, and the maximum deviation of the grid frequency was -0.407Hz (about -24.42rpm), the total time below 0.333Hz is about 6 minutes. In the past, the view that the frequency change of the power grid was ±0.2Hz was impossible[1]. Now the current operating conditions of the power grid have become reality, and the deviation is so large that it takes longer than expected and seriously threatens the safe operation of the power grid.

At present, the power supply side of China’s power grid is increasingly diversified, and its power sources include thermal, nuclear, hydro, and wind power. However, due to various reasons, nuclear power cannot be adjusted quickly, and hydro power is not guaranteed. The only thing that can rely on is thermal power generation[2,3]. Thermal power generators have been transformed from sub-critical drum boilers to super-critical direct-blow-through boilers. The control method has also changed from direct energy balance to indirect energy balance. Drum boilers have large heat storage, which can make full use of their heat storage to complete PFC, while super-critical boilers without steam drums have small heat storage, which is an effective PFC scheme for upwards of drum boilers, and cannot be achieved in super-critical boilers good control effect[4,5]. At the same time, one DC UHV line is equivalent to one super power station. Judging from the actual situation of the bipolar blocking fault in the actual DC UHV, the frequency change after the action is far greater than ±0.2Hz, the action time reaches 5 minutes, and the frequency modulation starts slowly. Power changes, and the large
frequency difference change has occurred 5 seconds after the occurrence of the bipolar blocking fault in the DC UHV. The use of conventional PFC technology cannot suppress the occurrence of extreme frequency of the power grid. The conventional PFC method has been unable to adapt to the power grid. Under the new characteristics of new energy wide-area absorption and UHV AC-DC hybrid power grid, frequency control mode and control performance evaluation method should be changed.

2. Analysis of PFC

The grid frequency is determined by the value of generated energy and electricity consumption. The PFC has the characteristics of high frequency of action and small amplitude of motion.

2.1. Characteristic of PFC

PFC is fast response to the changes of grid frequency. Because of the different heat storage capacity of different types of thermal power unit, the action time of PFC is 0.5 to 2 minutes. The advantage of PFC is the adjustment of all units only with the related system frequency, the interaction of units is small. According to the characteristics of PFC, it’s known that the function of PFC control is, to automatic balance the load error, namely those fast, amplitude smaller, random load, and to buffer the abnormal situation of load mutation. According to the Q/GDW 669-2011 Guide of primary frequency compensation test for thermal power generating units, steady-state speed regulation is 5%. When the rated power(Pn) is less than 250MW, the max frequency compensation load is 10%Pn. When Pn is more than 250MW and less than 350MW, the max frequency compensation load is 8%Pn. When Pn is more than 350MW and less than 500MW, the max frequency compensation load is 7%Pn. When Pn is more than 500MW, the max frequency compensation load is 6%Pn. Assume that only one unit in a power grid, when power grid frequency reduced from 50Hz to 49.8Hz, after unit’s PFC, frequency stabilizes at 49.9Hz finally. When power grid frequency reduced from 50Hz to 49.6Hz, after unit’s PFC, frequency stabilizes at 49.8Hz finally. The reason is that PFC is droop control, the grid frequency cannot return to 50Hz. Depend on the relationship between speed difference and loads of PFC, the frequency only increase half of the frequency deviation.

2.2. Control Strategy

Generally speaking, the PFC in domestic most power plants adopts coordinated control system(CCS) and digital electric hydraulic(DEH) control strategy. DEH is implementation stage, open loop control, ensure frequency compensation’s rapidity. CCS is correction stage, no difference, closed loop control, ensure the accuracy and persistent of frequency compensation.

In CCS side, turbine speed deviation signal is converted to the corresponding frequency modulation power through the function generator f(x), and added to the unit load after load changing rate, and after load high and low limit, forms the final actual load demand, ensure frequency compensation demand quickly, correctly and accurately.

In DEH side is shown, turbine speed deviation of rated speed and mid-valve of actual speed represents the frequency deviation. After the operation of f(x) that have dead zone, power increment of the unit frequency modulation can be achieved. Through the load amplitude limit, the valve position demand is generated, to be added directly in steam flow demand of valve, it is to be delivered to the valve of turbine satisfy the quickness of frequency modulation.

3. Existing 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. This can ensure the relative stability of the grid frequency. The UHV line is one super power plant. Once the fault occurs, the amount is large and sudden. Conventional methods cannot deal with it at all, and it cannot effectively suppress the occurrence of low-frequency or high-frequency power grids[6,7]. The controlled parameters include the turbine speed, generator frequency and grid frequency. The assessment of the power grid is based
on the frequency of the grid where the network is located, or the frequency that the unit’s PMU uploads to the power grid. In addition, the turbine speed is not synchronized with the grid frequency, and the grid frequency is in Hz units and the speed unit is revolutions per minute.

The grid-connected power plants of various regional power grids in China have basically the same regulation for PFC. The grid assesses the integral electricity contribution index of the first 60s of the unit during frequency fluctuations. Therefore, the unit needs to adjust the load quickly to meet the needs of frequency changes.

At present, thermal units are basically super-critical units, and the coordinated control method is indirect energy balance. Among them, the super-critical units have the problem of water and coal decoupling. The simple feed-forward of steam valve position cannot effectively ensure the safety of the unit. It must have the cooperation of PFC coal feed-forward and PFC water feed-forward to complete a qualified PFC action[8,9]. At the same time, the PFC power must be linear and constant. The PFC steam valve position feed-forward, the PFC coal feed-forward and the PFC water feed-forward can be non-linear.

4. Optimal Control of PFC

4.1. Optimization of Frequency Control Signals

The ultimate purpose of PFC is to stabilize the frequency of the power grid, so the control signal should be the frequency of the power grid or the frequency signal synchronized with the power grid. Considering the impartiality of the power grid assessment and the time space characteristics of the frequency distribution, the frequency signal sent by the PMU to the power grid can be introduced as the control signal. However, when the quality of the frequency signal is deteriorated, the speed of the steam turbine should be selected. At the same time, the difference in magnitude between the frequency and the speed of the turbine should be considered, so it is necessary to switch to correspond.

4.2. Optimization of Feed-forward Control

Feed-forward control is that the control part sends an instruction to the controlled part to perform some kind of activity, and at the same time sends a feed-forward signal to the controlled part through another fast way.

When the controlled part receives the instruction of the control part to perform the activity, it receives the feed-forward signal is regulated, so the activity can be more accurate. Compared with feed-forward control, feedback control need a longer time, because the control part can only issue a command to correct the activity of the controlled part after receiving the feedback signal of the activity of the controlled part, so the activity of the controlled part may occur larger fluctuation. Feed-forward is equivalent to a predictive control, and feedback should be a compensation control. Feed-forward and feedback control is to make the controlled object move according to the expected target.

According to the characteristics of the unit’s PFC, fast and accurate control of the unit is required, so feed-forward control is used to adjust the wind, coal and water of the unit. The feed-forward control
logic is shown in Figure 2. A second-order differential feed-forward is constructed by using two lag modules and a subtraction module to achieve fast response of frequency modulation. The time constant of the lag module LAG2 is variable, it can be switched by the analog selector AXSEL. When performing one frequency adjustment, the time constant becomes smaller to achieve a rapidly changing demand. At the same time, in order to ensure safety, a high and low limit module HLLMT was added to control the output range of the feed-forward. In addition, according to the size of the selected speed, a correction factor is generated by the function F4(x) to correct the feed-forward.

![Figure 2. Feed-forward control logic](image)

5. Conclusion

Through the analysis, it can be found that after 5 seconds from the occurrence of the bipolar blocking fault in the DC UHV, a large frequency difference has occurred. The use of conventional PFC technology cannot suppress the occurrence of extreme frequency of the power grid. The conventional one-frequency frequency modulation method can no longer adapt to the frequency control of the power grid. By analyzing the control signals and control logic of the unit’s participation in frequency regulation of the power grid, the PMU frequency signals that are closely connected to the power grid are introduced, and the secondary differential feed-forward is used to achieve overshoot compensation, which makes the primary frequency modulation action more precise and satisfies the unit’s stable operation. The requirements of response enable the unit’s primary frequency adjustment to achieve optimal control and ensure the safety of the power grid.

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