Emergency Coordinated Frequency Control Strategy for Multi-DC Infeed Receiver Network

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Abstract. For the receiver network with multiple DC feed-in, the DC locking fault seriously affects the safe and stable operation of the receiver network. This paper presents a frequency emergency coordinated control system which takes into account three measures: DC coordinated control, pumping and storage pump, and cutting off interruptible load. Two control strategies are developed, which are quick action from afar and frequency action on the spot. Both schemes have their own fault criteria. Finally, the two control strategies are analyzed and compared through the simulation of East China Power Grid.

1. Introduction

East China is the most economically active and developed region in China, with dense population and developed industry. Therefore, the demand for power load in East China is also very strong. But at the same time, East China is a region with very poor primary energy resources, and regional resources can hardly meet their development needs. For a long time, East China has been the region of electricity income, and the supply of electricity is extremely dependent on external input¹.

East China Power Grid has received seven rounds of hydroelectric direct current from the central and western regions, with a total capacity of 31,760 MW. From the northern region into the four tempering power DC, the total capacity of 38000MW. With the rapid increase of UHVDC scale in East China Power Grid, East China Power Grid presents the characteristics of "strong DC and weak AC"². The stability problem caused by DC locking has become one of the most important risks faced by East China receiving power grid.

On September 19, 2015, Jin-Su DC bipolar block caused a loss of 4.9 million kilowatts of power to East China Power Grid at the receiving end, causing the power grid frequency to drop to 49.58Hz, which sounded the alarm for the safe operation of large power grids³.

With the rapid development of UHV DC project, China will have several large-capacity and multi-DC feed-in receiver-end grids in the near future. For the large-capacity and multi-DC feed-in receiver-end grids, the frequency stability control problem and challenge will be faced⁴. If multiple DCs are lost at the same time, the phenomenon of multiple rounds of low-frequency load reduction will exist in the power grid, and a large number of loads will be removed, and even the system frequency will collapse, resulting in the possibility of large-scale power failure in the whole network⁵. Measures should be taken to solve the problem. In general, the low-frequency load shedding of the third line of defense is used to...
deal with the power loss of the power grid, but the low-frequency load shedding cannot meet the problem of DC blocking. DC emergency coordinated control, pumping and storage pump, and interruptible load provide a new technology for fast and precise control of large DC feed terminals, besides low frequency load reduction. In this context, this paper studies the frequency emergency coordinated control strategy, which is of great significance to the safe and stable operation of UHV multi-DC receiving power network.

2. Frequency emergency control system composition

The traditional frequency stability control technology usually works in the second or third line of defense to solve the problem of frequency imbalance. Moreover, each defense line is independent of each other and completely depends on off-line pre-decision, which has the shortcoming of insufficient coordination.

Fig. 1 Conventional frequency stability control diagram

In this paper, the frequency emergency coordinated control strategy for the occurrence of DC locking fault is studied, and between the traditional emergency control triggered by DC fault and the third line of low frequency load reduction control, the integrated configuration of DC modulation, pump and storage pump, interruptible load control, etc. The stability of frequency coordination control system is improved.

Fig. 2 East China Power Grid Frequency Emergency Control System

The main function of the frequency emergency coordinated control system is to detect the real-time running state of each DC system, each pumping and storage power plant and controllable load, and to carry out emergency coordinated control of frequency according to the established control strategy when the single or multiple cross-region DC is lost at the same time or one after another, which brings power shortage to the power grid.
2.1. **DC coordinated control**

HVDC transmission system has multiple overload capacity, which is very important to improve the stability of power grid. When one or more DCs of the multi-DC receiver network are lost at the same time, the DC coordinated control system can be used to assume part or all of the power deficiency. The stability of the system is achieved by direct current lifting. In general, the higher the overload lifting multiple of DC power is, the shorter the sustainable time of overload is. In general, the maximum sustainability time of 1.5 times overload can reach 3s, the maximum sustainability time of 1.35 times overload can reach 10s, the maximum sustainability time of 1.25 times overload can reach 2h, the maximum sustainability time of 1.1 times overload can last for a long time.

The short-time modulated power capacity of DC is very strong, but its time is too short to support the continuous stable state of the power grid. DC long time modulated power capacity is relatively weak, but can last for a long time, can continue to bear a small part of the gap. According to Equation (1) below, the stability of the system can be improved by changing the transmission power of the DC line in normal operation through configuration rate, including frequency emergency lifting and fallback.

\[
P_{dc}^e = P_{dc} + K(t_e - t_s)
\]  

On the type, \(P_{dc}\) is the initial operating power of DC line; \(P_{dc}^e\) is the DC power after operation; \(t_e\) is the end of DC modulation; \(t_s\) is the start time of DC modulation; \(K\) is the rate of power rise or fall set.

2.2. **Pumping storage pump**

In addition to DC modulation, the large-scale pumping and storage power stations of the grid also have the advantages of large regulation capacity, fast response speed, flexible switching adjustment of units and strong climbing ability. Pumping and storage stations can be regarded as special loads. Pumping and storage stations can cut off pumping pumps simultaneously or in multiple rounds to release loads. In case of emergency, the pumping and storage stations can even be transformed into power stations, which is equivalent to doubling the power of the pumping and storage stations in a short time. Each pumping and storage power station is relatively independent, and when pumping the storage and cutting pump, the whole number of the pump is removed, so the power of the storage and cutting pump is improved faster. Each pumping and storage power station is relatively independent, and when pumping the storage and cutting pump, the whole number of the pump is removed, so the power of the storage and cutting pump is improved faster.

At present, East China Power Grid has 8 pumping and storage power plants and 33 pumping and storage units, with a total installed capacity of 8900MW.

2.3. **Interruptible load**

Currently connected to the East China power grid emergency coordination control strategy system of interruptible load is engineering, precision cutting of Jiangsu power grid load in the application of interruptible load under control of the emergency source network interactive coordination technology, marketing interruptible load control system of large user load as the main object of control, in order to prevent the migration trend of electric power system.

The precision load cutting project capacity of Jiangsu Power Grid has reached 2,750 MW. It is expected that a large number of interruptible loads will be connected in Anhui, Zhejiang and Shanghai in the next 1 to 2 years.

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3. **Failure criteria and control strategies**

3.1. **Failure criterion**

Fast and accurate fault identification is the premise of correct action of control system. The two control strategies mentioned in this paper: remote action and local frequency action correspond to two control
criteria respectively. The criterion of local frequency is mainly to detect whether the grid frequency is lower than the preset threshold value, which is similar to the existing automatic frequency load shedding criterion and will not be repeated in this paper. For remote action, the DC converter fault criterion is used. Its logical schematic diagram is shown in Figure 3.

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3.2. Frequency emergency control strategy

As shown in Fig. 4, the power balance diagram of the receiving end of the grid shows, in case of DC B1 lockout, system A will instantly produce power deficiency, while system B will produce excess power. At this time, it is the safest measure for the two systems to increase the B2 power of the same receiving end. If the tie line conditions of system B and C allow, increasing the DC power of C1 and C2 at the same time will help to transfer the excess power. For system A, to remove pumping state pump storage power station is the most efficient and economic measures, residual power gaps should be done by spinning reserve, if appear rotation response is slow, in order to prevent the worsening of system frequency, the DC modulation and resection can consider to remove the smoke storage load, but the removal of the load economic cost is higher. To sum up, the principle of various measures is as follows: no emergency control shall be taken for the maximum DC monopole blocking fault; DC modulation and pumping storage and cutting pump shall be adopted for the blocking fault greater than the power gap; and interruptible load removal shall be taken for the power gap that may touch the low-frequency load shedding.

![Fig. 3. Logic diagram of DC blocking criterion](image)

![Fig. 4. Control measures and strategy coordination of frequency control system in receiving power network](image)

![Fig. 5. Priority of various measures of the frequency emergency coordinated control system](image)
4. Simulation analysis of control strategy

4.1. Set the scene
Taking East China Power Grid as simulation scene, this paper simulates the improvement effect of frequency emergency control system in Xiagao mode when Jiquan DC and Fufeng DC have bipolar block fault by using the strategy of quick action from afar and local frequency action respectively.

The capacity of the pumping and storage and cutting pump is 0 in the summer peak, the operating threshold of the system is 3900MW, and the operating threshold of the interruptible load quick cutting is 8400MW. Jiquan bipolar locking fault was set in the simulation. At this time, the power loss on the ground side of East China Power Grid was 11160MW, and the maximum DC modulation capacity was reduced to 3300MW. Therefore, all DC modulation power was needed, and about 2760MW needed to be removed for accurate load control.

4.2. The simulation analysis
According to the simulation, when the frequency control system does not act after the DC bipolar block in Jiquan, the system frequency will reach the lowest point at 49.2651Hz in 18s. When the frequency emergency control is used to command the fast action in the distance, the system frequency will reach the lowest point of 49.7137Hz at 10s. As shown in Fig. 6, when the system adopts frequency emergency control to issue fast action in the distance, there is an obvious pullback trend in the frequency decline, the lowest frequency increases by 0.4487Hz, and the frequency recovery speed also significantly increases.

![Fig. 6 Frequency response of the system after DC locking (quick action by remote command)](image)

![Fig. 7 Frequency response of the system after DC locking (local operation according to frequency)](image)

When the frequency emergency control is adopted to operate according to the local frequency, when the system frequency drops to 49.65Hz, DC modulation is started with the maximum modulation amount of 3300MW. After DC modulation, the lowest frequency of the system reaches the lowest point of 49.5600Hz in 13s, which is higher than the action threshold value of 49.25Hz of the precision load control system, so the precision load control does not act. As shown in Fig. 7, when the system adopts frequency emergency control to operate according to the local frequency, the frequency decreases with a pullback trend, the lowest frequency increases by 0.4487Hz, and the frequency recovery speed also increases.

From the simulation results, it can be seen that using the remote quick action can act quickly and accurately according to the power gap before the actual frequency drop, so the response time of the system is shorter, the load system can be invested in advance to avoid further system drop, and the recovery effect of the lowest point of the system frequency after an accident is relatively good. When the system frequency drops to the threshold, it triggers the device to act. When the system frequency
does not drop to 49.25Hz, the action of load cutting can be avoided. However, its response effect to the lowest frequency of the system is not as good as that of quick command from afar.

5. Conclusion
In order to solve the problem of frequency stability control in the receiving power network with multiple DC feed-in, this paper introduces the frequency emergency coordinated control system of East China Power Grid, and takes Jiquan DC bipolar block fault of East China Power Grid as the simulation scenario. By using the two control strategies of fast action from afar and frequency action on the spot, good results of frequency recovery are obtained. By comparing the two results, it is verified that the fast action from afar is better than the frequency action on the spot.

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