**Influence of back-to-back VSC-HVDC project on the operation characteristics of Hubei power grid**

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**Abstract:** The synchronous interconnection between Chongqing and Hubei power grid is planned to be unsynchronised by back-to-back voltage source converter based high-voltage direct current (VSC-HVDC) project, which has great impact on the operation characteristics of Hubei power grid. In this study, the basic information of back-to-back VSC-HVDC project was introduced. The influence of this project on the operation characteristics of Hubei power grid was analysed in detail, including power flow, short-circuit current, transient stability and frequency characteristic. The corresponding grid reinforcement measures were proposed to solve power flow over-limit and transient instability problems caused by this project. The study has some reference value for the planning and operation of Hubei power grid and the design of other similar HVDC transmission projects.

1 **Introduction**

The concept of voltage source converter based high-voltage direct current (VSC-HVDC) was first proposed in 1990 [1]. Since then, it has attracted widespread concern of academia and engineering. The VSC-HVDC technology is based on VSC, self-turn-off device and pulse width modulation. It has several advantages, such as independent control of active power and reactive power, no commutation failure risk, no reactive power compensation problem, powering passive network, no communication between converter stations, easy to form multi-terminal DC system and small occupation area and so on. The VSC-HVDC technology can be applied to the interconnection among AC power systems, renewable energy access and power supply to urban or remote areas [2].

This technology has been officially named as VSC-HVDC by International Council on Large Electric Systems (CIGRE) and Institute of Electrical and Electronics Engineers (IEEE) in 2004. ABB, Siemens and Alstom Company named this technology as HVDC Light, HVDC Plus and HVDC MaxSine, respectively. In China, it is usually referred to as HVDC Flexible [3]. Some representative VSC-HVDC projects are introduced as follows [4-6]. The first VSC-HVDC industrial pilot project – Hellson project was put into operation in 1997. The ±200 kV/400 MW Transbay project using modular multilevel converter (MMC) was brought into operation in 2010. The ±30 kV/20 MW Shanghai Nanhui project was put into service in 2011, which is the first MMC demonstration project in China. The world’s first five-terminal ±200 kV/1000 MW Zhoushan MMC-HVDC project was come into use in 2014. VSC-HVDC is a promising technology for constructing a flexible, robust and efficient power grid and making full use of renewable energy. It represents the development trend of the HVDC technology and becomes a key technology in the smart grid [7].

The back-to-back VSC-HVDC project connecting Chongqing and Hubei power grid is planned to put into operation in 2018 by State Grid Corporation of China (SGCC). It is the first 500 kV VSC-HVDC project in China, whose transmission power capacity is 5000 MW. This project has the highest voltage level and transmission power capacity in the world. At present, Chongqing and Hubei power grid are connected by four-circuit 500 kV AC transmission lines, including 500 kV Juquan to Longquan and Zhangjiaba to Enshi two-circuit transmission lines. The power capacity transported from Chongqing to Hubei power grid is generally about 2800 MW during summer. Hubei power grid will be subjected to 5000 MW power by this transmission section after the operation of back-to-back VSC-HVDC project. So power flow of west to east power transmission section in Hubei power grid will increase. Evacuation pressure of power flow in the Three Gorges area will increase. In addition, the connection between Hubei and Chongqing power grid is going to change from synchronous to asynchronous, which would weaken the electrical link between Hubei power grid and external power grid, and moment of inertia of central east four provinces’ power grid will decrease, including Hubei, Henan, Hunan, Jiangxi. Thus, this project will have a great impact on power flow and stability characteristics of Hubei power grid.

In this paper, the basic situation of back-to-back VSC-HVDC project connecting Chongqing and Hubei power grid is proposed. The influence of this project on the operation characteristics of Hubei power grid is analysed in detail, including power flow, short-circuit current, transient stability and frequency characteristic. The corresponding grid reinforcement measures are proposed to solve the power flow over-limit and transient instability problems caused by this project.

2 **Basic information of back-to-back VSC-HVDC project**

It is necessary to implement southwest power grid and central east four provinces’ power grid asynchronous networking. The asynchronous networking can bring many advantages, such as achieving the reasonable consumption of seasonal hydropower in Sichuan province, giving full play to the power transmission line capacity, optimising AC power system structure, improving the controllability of power grid operation and reducing the risk of security and stability operation of power grid. The construction of back-to-back VSC-HVDC project can build southwest synchronous power system, which covers Sichuan, Chongqing and Tibet power grid. This project can realise asynchronous interconnection between...
southwest power grid and central east four provinces’ power grid, as shown in Fig. 1. This project can also reduce the short-circuit current in Three Gorges area.

The converter unit of this project adopts symmetrical unipolar connection. Each station has two converter units. The capacity of converter unit is 1250 MW, and its DC voltage is ±420 kV, which are the first in the world. The converter valve uses half-bridge modular multi-level scheme and adopts water cooling. The valve tower installs by grounding support way.

The back-to-back VSC-HVDC project includes north channel converter station (Longquan station) and south channel converter station (Shanshuyuan station). North channel converter station is located in southwest side of Longquan converter station, Xiangyansi village, Longquan town, Yiling district, Yichang city, Hubei province. South channel converter station is located in Shanshuyuan village, Gaoleshan town, Xianfeng county, Enshi city, Hubei province. The current construction is two 1250 MW back-to-back VSC-HVDC converter units and the total back-to-back size of this period is 2500 MW at each converter station.

The 500 kV two-circuit transmission line from Jiupan to Longquan will link with north channel converter station by π connection. The length of new single circuit transmission line built is 4.5 km. The 500 kV two-circuit transmission lines from Zhangjia to Enshi will link with south channel converter station by π connection. The length of new two-circuit transmission line is 10.4 km.

### 3 Influence of the project on the operation characteristic of Hubei power grid

#### 3.1 Power flow

The influence of this project on the power flow of Hubei 500 kV power grid is illustrated by four typical load operation modes, including summer peak, summer valley, winter peak and winter valley load operation mode. Partial topology structure of Hubei 500 kV power grid is shown in Fig. 2.

The power received by Hubei 500 kV power grid from southwest power grid will increase from the original 2800 to 5000 MW by this project in the summer. The power flow transmission direction of Hubei 500 kV power grid is still from west to east, and Three Gorges hydropower is transported to the east, south and north three directions. The pressure of power flow transmission from west to east and power flow evacuation in the Three Gorges area will increase. In the winter, Hubei power grid supplies 3000 MW power to southwest power grid, which can reduce the pressure of power flow transmission from west to east.

During summer peak load operation mode, three-circuit transmission line 1-2 delivers 3030 MW power, which exceeds its thermal stability limitation of 2200 MW. The power transmitted by three-circuit transmission line 2-3 and three-circuit transmission line 3-4 is 4450 and 4600 MW, respectively, which is significantly larger than the situation before back-to-back VSC-HVDC project and is hard to control. Three-circuit transmission line 10-11 delivers 5260 MW power, which seriously exceeds its thermal stability limitation of 4000 MW. Due to the power increase of three-circuit transmission line 10-11 and some power plant projects put into operation, the power transmitted by transmission section composed of line 10-12 and line 10-13 is 2890 MW, which exceeds its thermal stability limitation of 2800 MW.

During summer valley load operation mode, the redundant power of Enshi 220 kV power grid transmitted to Hubei 500 kV power grid by substation 1 will further increase compared with summer peak load operation mode. The power transmitted by three-circuit transmission line 1-2, three-circuit transmission line 2-3 and three-circuit transmission line 3-4 is increased to 3500, 4950 and 5160 MW, respectively, which means severely over-limit. In order to relieve the evacuation pressure of power flow in the Three Gorges area, new hydropower transmission channel from southwest to east in Hubei should be built, combined with the planned 500 kV Enshi East substation. The power transmitted by transmission section composed of line 10-12 and line 10-13 will increase to 2990 MW.

During winter peak load operation mode, the transmission section from west to east is mild. The power transmitted by three-circuit transmission line 3-4 and transmission section composed of line 10-12 and line 10-13 is 1120 and 2400 MW, respectively. The power flow directions of three-circuit transmission line 1-2 and three-circuit transmission line 10-11 are contrary to the one during summer load operation mode, which are from substation 2 to substation 1, and from substation 10 to substation 11. The power transmitted by three-circuit transmission line 1-2 and three-circuit transmission line 10-11 is 2040 and 250 MW, respectively.

During winter valley load operation mode, power flow of transmission sections from west to east and from north to south in Hubei eastern power grid maintains at a low level. However, if 1700 MW power delivered from Hunan power grid to Hubei power grid, which can reduce the pressure of power flow transmission from west to east.
power grid is considered, line 3-7 will easily overload when line 5-7 has fault. Thus, the output of power plant P1 and P2 needs to be increased, and power delivered from Hunan power grid to Hubei power grid should be controlled.

3.2 Short-circuit current

Short-circuit current of 500 kV buses in Hubei power grid will reduce in different degrees after back-to-back VSC-HVDC project put into operation and the average reduction value is 1.29 kA. Table 1 shows short-circuit current of some 500 kV buses before and after this project put into operation. There are eight 500 kV buses whose short-circuit current reduction is more than 1 kA after this project. Short-circuit current of 500 kV buses in Hubei western power grid has an average decline of 2.17 kA. Short-circuit current of 500 kV buses in Hubei eastern power grid has an average decline of 0.18 kA. Short-circuit current of 500 kV buses in the Three Gorges area (including buses 2, 3, 5, 6, 7, 8, 9, 10, 11, 18, 19 and 20) have an average decline of 2.47 kA. After back-to-back VSC-HVDC project put into operation, short-circuit current of 220 kV buses in Hubei power grid reduces in different degrees, and the average decline is 0.25 kA. The operation of back-to-back VSC-HVDC project makes southwest power grid and central east four provinces’ power grid show asynchronous interconnection pattern. Due to interrupting of AC channel between Chongqing and Hubei power grid, southwest power grid no longer supplies short-circuit current to Hubei power grid. Therefore, short-circuit current level of AC power system of Hubei power grid is generally decreased, and the decline value is related to the electrical distance of the short-circuit point to the VSC-HVDC project placement.

3.3 Transient stability

Before the back-to-back VSC-HVDC project put into operation, Hubei 500 kV power grid can maintain transient stability when 500 kV transmission line occurs N–1 fault. Under the circumstance of large hydroelectric power output of the Three Gorges plant and Hubei province, when part of transmission lines of the Three Gorges substations and two-circuit transmission line 14-15 has N–2 failure, power system is transient instability and the corresponding lines will be seriously overloaded. This problem can be resolved by existing stability control measures. Hubei 500 kV power grid can maintain transient stability when the rest of 500 kV transmission line occurs N–2 fault, which considers two lines on same tower and the same transmission channel.

After the back-to-back VSC-HVDC project put into operation, the AC channel between Chongqing and Hubei power grid is interrupted, which makes the equivalent moment of inertia of central east four provinces’ power grid decrease. The power of transmission channel from west to east increases. The transient stability of 500 kV Hubei power grid will deteriorate. The N–1 fault of any transmission line of 500 kV line 1-2, 9-10, 10-12 and 10-14 would cause the power angle between generators of Hubei western power grid and Three Gorges generators to fluctuate greatly and decay slowly as well as bus voltage to fluctuate greatly.

3.4 Frequency characteristic

The operation of back-to-back VSC-HVDC project interrupts the AC channel between Chongqing and Hubei power grid, which makes southwest power grid and central east four provinces’ power grid show unsynchronised interconnection. Central China synchronous power grid is changed from five provinces (including Hubei, Hunan, Jiangxi, Henan and Sichuan) and one city (Chongqing) to four provinces (including Hubei, Hunan, Jiangxi and Henan). So the equivalent moment of inertia of central China power grid will decrease, which will have great impact on the frequency characteristic of central China synchronous power grid.

Before the operation of back-to-back VSC-HVDC project, the load level of a typical load operation mode in central China synchronous power grid is shown in Table 2. The total load is 11,4850 MW. When spinning reserve is not considered and power shortage of central China synchronous power grid is 4150 MW, the lowest frequency of central China synchronous power grid is 49 Hz. When power shortage of central China synchronous power grid is 3280 MW, its lowest frequency is 49.25 Hz. When spinning reserve is considered and power shortage of central China synchronous power grid is 5970 MW, its lowest frequency is 49 Hz. When power shortage of central China synchronous power grid is 4950 MW, its lowest frequency is 49.25 Hz.
In order to solve the problems of power flow over-limit and transient instability of Hubei 500 kV power grid after the operation of back-to-back VSC-HVDC project, grid reinforcement measures need to be implemented.

(i) 500 kV Enshi East substation is proposed to build ahead of schedule and synchronize with back-to-back VSC-HVDC project. Its original scheme of access to power system needs adjust.

The specific scheme of 500 kV Enshi East substation access to power system is proposed as follows: (i) 500 kV Enshi East substation links first circuit transmission line of line 1-2 with network, and the line 2 to Enshi East stays outage, which makes substation 2 have one free interval to build another one-circuit transmission line of line 2-6. (ii) Double circuit transmission line from 500 kV Enshi East substation to 500 kV Chaoyang substation is built. (iii) In order to meet the needs of power transmission, the original transmission channel of Gedajiang is required capacity-increasing transformation. (iv) 500 kV transmission line Enshi to Enshi East fault would cause overload of multiple transmission lines of Enshi 220 kV power grid, so adding a new 500 kV transmission line from Enshi to Enshi East is recommended.

When above grid reinforcement measures are implemented, the power transmitted by two-circuit transmission line Enshi to Enshi East is about 1300 MW during summer valley load operation mode. The power transmitted by two-circuit transmission line 1-2, three-circuit transmission line 2-3 and three-circuit transmission line 3-4 is about 1900, 3400 and 3700 MW, respectively. The power flow of these lines above is within the control limits.

As the first and second circuit transmission lines are on the same tower, there is the risk that one-circuit transmission line of 500 kV line 1-2 and line Enshi to Enshi East trip at the same time. This risk will cause 220 kV line Qifengba to Enshi East overload easily, which is LGJ-300 wire. So the suggestion is to replace 220 kV line from Qifengba to Enshi East with largescale-cross-section wire.

1. The fourth circuit transmission line 10-11 is suggested to construct to increase transmission capacity to 6400 MW, which can solve the problem that power flow of line 10-11 is far beyond the existing control limits.
2. Line 13-16 is suggested to construct to mitigate the power transmission pressure of transmission section composed of line 10-12 and line 10-13.

With grid reinforcement measures mentioned above, Hubei 500 kV power grid can maintain transient stability when 500 kV transmission lines occur N−1 fault in all operation modes in 2018.

After the operation of back-to-back VSC-HVDC project, the load level of a typical load operation mode in central China synchronous power grid is shown in Table 3. The total load is 94,830 MW. When spinning reserve is not considered and power shortage of central China synchronous power grid is 3150 MW, the lowest frequency of central China synchronous power grid is 49 Hz. When power shortage of central China synchronous power grid is 2650 MW, its lowest frequency is 49 Hz. When spinning reserve is considered and power shortage of central China synchronous power grid is 5100 MW, its lowest frequency is 49 Hz. When power shortage of central China synchronous power grid is 4500 MW, its lowest frequency is 49.25 Hz. The frequency characteristic of central China synchronous power grid before and after this project is compared in Table 4.

| Province       | Load, MW |
|----------------|----------|
| Hubei          | 19,380   |
| Hunan          | 16,000   |
| Henan          | 44,070   |
| Jiangxi        | 8400     |
| Sichuan        | 20,400   |
| Chongqing      | 6600     |
| central China  | 114,850  |

| Province       | Load, MW |
|----------------|----------|
| Hubei          | 20,810   |
| Hunan          | 16,500   |
| Henan          | 48,360   |
| Jiangxi        | 9160     |
| central China  | 94,830   |

### Table 2 Load level of a typical load operation mode in central China synchronous power grid in 2017

| Province       | Load, MW |
|----------------|----------|
| Hubei          | 19,380   |
| Hunan          | 16,000   |
| Henan          | 44,070   |
| Jiangxi        | 8400     |
| Sichuan        | 20,400   |
| Chongqing      | 6600     |
| central China  | 114,850  |

### Table 3 Load level of a typical load operation mode in central China synchronous power grid in 2018

| Province       | Load, MW |
|----------------|----------|
| Hubei          | 19,380   |
| Hunan          | 16,000   |
| Henan          | 44,070   |
| Jiangxi        | 8400     |
| Sichuan        | 20,400   |
| Chongqing      | 6600     |
| central China  | 114,850  |

### 4 Improvements and suggestions

In order to solve the problems of power flow over-limit and transient instability of Hubei 500 kV power grid after the operation of back-to-back VSC-HVDC project, grid reinforcement measures need to be implemented.

1. The fourth circuit transmission line 10-11 is suggested to construct to increase transmission capacity to 6400 MW, which can solve the problem that power flow of line 10-11 is far beyond the existing control limits.
2. Line 13-16 is suggested to construct to mitigate the power transmission pressure of transmission section composed of line 10-12 and line 10-13.

With grid reinforcement measures mentioned above, Hubei 500 kV power grid can maintain transient stability when 500 kV transmission lines occur N−1 fault in all operation modes in 2018.

### Summary

The back-to-back VSC-HVDC project connecting Chongqing and Hubei power grid is planned to put into operation in 2018, which has the highest voltage level and transmission power capacity in the world. This project will have great impact on the operation characteristics of Hubei power grid, including power flow, short-circuit current, transient stability and frequency characteristic.

This project makes Hubei power grid receive much more power from southwest power grid in summer, which increases the pressure of power flow transmission from west to east and power flow evacuation in the Three Gorges area. The power transmitted by some 500 kV lines exceeds the thermal stability limitations, including line 1-2 and line 10-11. The AC channel between Chongqing and Hubei power grid is interrupted by this project. Short-circuit current level of Hubei power grid is generally decreased. Transient stability of Hubei 500 kV power grid is deteriorated. When part of 500 kV lines occur N−1 fault, transient instability would happen and the corresponding stability control measures are insufficient. The decrease of the total load and moment of inertia makes the reduction of power shortage corresponding to decrease the frequency of 1 Hz of central China synchronous power grid.
grid. To make sure that Hubei power grid is under safe and stable operation, some grid reinforcement measures are proposed to be implemented.

6 References

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