DStudy on small interference analysis and transmission capacity of UHVAC loop power grid of Shandong–Hebei

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Abstract. This paper studies the main operation characteristics, small interference analysis and transmission capacity of UHVAC in Shandong-Hebei loop power grid. It mainly includes the small interference characteristics and section transmission limit analysis of the certain area under the typical mode and maintenance mode, then the operation limit would be defined, so as to provide basic work for the safety and stability calculation of the loop network in the next stage.

Keywords: UHVAC, small signal stability, transfer capacity, safety control.

1. Introduction
During the 13th Five-Year-Plan period, Shanghaimiao-Linyi, Zhalute- Qingzhou and other UHVDC projects were put into operation. Power grid in Shandong will become "strong DC and weak AC system". The operation will be at great risk. In order to optimize the structure of North China power grid, and improve the security and stability of power system in Shandong, it is necessary to strengthen Shandong UHVAC power grid. After the UHVAC project of Shandong-Hebei loop network is put into operation, it can meet the safety and stability needs of UHVDC access and ensure the safe and stable operation of multi-infeed UHVDC, improve the ability of Shandong power grid to withstand serious accidents, strengthen the structure of Shandong and North China UHV AC grid.

In order to ensure the reliable operation of the project, it is necessary to comprehensively evaluate the small interference characteristics and the power receiving capacity of Shandong AC section. Then put forward comprehensive safety and stability control measures and strategies to ensure the stability of the system.

According to different operation modes, the small interference characteristics and the power receiving capacity of the section of Shandong-Hebei UHVAC loop network system is analyzed in this paper.

2. Brief introduction of Shandong-Hebei loop network UHVAC project
Shandong-Hebei UHVAC loop network includes five 1000kV substations in Shijiazhuang, Jinan, Weifang, Linyi and Heze. The geographical wiring diagram and detailed configuration diagram are as follow:
3. Analysis of grid characteristics

3.1. Small interference analysis
According to the main oscillation modes of the North China Power Grid in 2019, as shown in the table below, there are oscillation modes from Mengxi to North China in both the abundant and the withered modes, with damping ratios of 6.3% and 4.9% respectively; there are oscillation modes from North China to central China in both the abundant and the withered modes, with damping ratios of 12.1% and 15.8% respectively; there are also oscillation modes from Shanxi and Mengxi units to Shandong and from Mengxi to Shanxi in the withered mode. As well as the oscillation modes of Hengshan, Ordos, Shanxi, Hebei South grid, Beijing Tianjin Tangshan, the damping ratios are 14.5%, 4.6% and 8.8% respectively, all of which are strong damping.

**Table 1. Main oscillation modes of North China Power Grid in 2020**

| Mode            | Frequency (Hz) | Damping ratio (%) | Oscillation mode                   |
|-----------------|----------------|-------------------|------------------------------------|
| 2020 Heavy-load | 0.421          | 6.3               | Mengxi–Huabei                      |
| 2020 Heavy-load | 0.113          | 12.1              | Huabei–Huazhong                    |
| 2020 Heavy-load | 0.420          | 4.9               | Mengxi–Huabei                      |
| 2020 Light-load | 0.162          | 15.8              | Huabei–Huazhong                    |
| 2020 Light-load | 0.530          | 14.5              | Shanxi, Mengxi–Shandong            |
| 2020 Light-load | 0.514          | 4.6               | Mengxi–Shanxi                      |
| 2020 Light-load | 0.896          | 8.8               | Hengshan–Shanxi, Southern Hebei     |

The modal diagram of each oscillation mode is as follows:
(1) Heavy-load mode
   1) Mengxi North China oscillation mode, frequency 0.421hz, damping ratio 6.3%, strong damping mode.
Figure 2. 2020 heavy-load diagram of the oscillation mode Mengxi-North China

2) North China Central China oscillation mode, frequency 0.113hz, damping ratio 12.1%, strong damping mode.

Figure 3. 2020 heavy-load diagram of the oscillation mode North China-Middle China

(2) Light-load mode
1) Mengxi North China oscillation mode, frequency 0.420hz, damping ratio 4.9%, strong damping mode.

Figure 4. 2020 light-load diagram of the oscillation mode North China-Mengxi
2) North China Central China oscillation mode, frequency 0.162hz, damping 15.8%, strong damping mode.

![Figure 5](image_url)

**Figure 5.** 2020 light-load diagram of the oscillation mode North China-Middle China

3) Shanxi and Mengxi units ~ Shandong oscillation mode, frequency 0.530hz, damping 14.5%, strong damping mode.

![Figure 6](image_url)

**Figure 6.** 2020 light-load diagram of the oscillation mode Shanxi/Mengxi-Shandong

4) Mengxi Shanxi oscillation mode, frequency 0.514hz, damping 4.6%, strong damping mode.

![Figure 7](image_url)

**Figure 7.** 2020 light-load diagram of the oscillation mode Shanxi-Mengxi
3.2. Receiving capacity of Shandong AC power grid

When calculating the AC receiving limit, the arranged DC power of Lugu and Zhaoyi is 10000MW, and the arranged DC power of Yindong is 4000MW.

### Table 2. Comparison of calculation results of different receiving power of Shandong Power Grid

| Haihe-Quancheng | Xingtai-Quancheng | Xinliao | Huabin | Total receiving | Stability |
|-----------------|-------------------|--------|--------|-----------------|----------|
| 1639.3          | 1896.9            | 2657.7 | 1973.7 | 8167.6         | Voltage collapse after Quancheng-Changle N-2 |
| 1230.4          | 1523              | 1742.4 | 1625   | 6120.8         | Voltage collapse after Quancheng-Changle N-2 |
| 991.4           | 1238.3            | 1468.6 | 1386   | 5084.3         | After Quancheng-Changle N-2, continuous Commutation failure happen at the low-terminal of Lugu DC between 192-384.5 cycles |
| 848.3           | 1089.8            | 1331.9 | 1226.7 | 4496.7         | After Quancheng-Changle N-2, continuous Commutation failure happen at the low-terminal of Lugu DC between 188-496 cycles |
| 591.6           | 852.4             | 1127.3 | 862.9  | 3434.2         | After Quancheng-Changle N-2, continuous Commutation failure happen at the low-terminal of Lugu DC between 188-496 cycles. While unit in the near area of Lugu DC landing point has been fully started |

From the calculation results, while the DC power of Lugu and Zhaoyi is fully transmitted, when the N-2 fault occurs in Quancheng-Changle, more than 15 commutation failures happens at the low terminal of Lugu DC, even the power plant in the near area of Lugu DC landing point is fully turned on. In the actual project, Lugu DC will be locked after 4 consecutive commutation failures.

In terms of the effective short circuit ratio of multi-infeed HVDC, when Lugu and Zhaoyi DC system are both fully transmitted, the receiving active power of Shandong AC section is reduced to about 3400MW. While the effective short circuit ratio of Yindong, low-terminal and high-terminal of Lugu DC system is 2.60, 2.18 and 2.61, while the effective short circuit ratio on low-terminal and high-terminal of Zhaoyi DC is only 1.87 and 2.33, which is very weak and hard to support the full power transmission of Zhaoyi DC.

From the perspective of grid structure, after the N-2 failure of Quancheng-Changle, the 1000kV connection between Lugu and Zhaoyi is lost. Due to the weak grid structure, it is not strong enough to support the stable operation of the low-terminal of Lugu and Zhaoyi DC system. Even if the receiving power of Shandong AC section is greatly reduced, the problem can not be solved. Therefore, at the time when Changle-Gaoxiang 1000kV line is put into operation in 2019, Lugu and Zhaoyi DC cannot operate at full power at the same time.

3.3. Characteristics and transmission capacity of light-load situation

3.3.1. Section transmission limit. The transmission limit of the receiving section of Shandong power grid is restricted by the problem of thermal stability limit of main transformer in Quancheng, which is 3500MW limit. After the N-1 fault of the main transformer in Quancheng, the thermal stability limit of the other main transformer is 3500MW. The transmission limit of Shandong's external AC section is about 9270MW ~ 10780MW. Among them, after the three-phase permanent N-1 fault of Quancheng main transformer, the simulation results of the thermal stability limit of another main transformer are shown in the figure below.
3.3.2. **Pre-control when one circuit of Quancheng-Changle is overhauled.** Under the condition of 10000MW in Lugu DC system and 5500MW in Zhaoyi DC system and one circuit of Quancheng-Changle is overhauled. The N-1 fault in the other circuit line would cause low voltage in Shandong power grid, as shown in the figure below.

After the DC power of Zhaoyi is reduced to 5000MW, under this maintenance mode, after the failure of Quancheng-Changle N-1, the power grid voltage can be restored to above 0.9p.u. and the DC system operate stably.

**Figure 8.** Thermal stability limit of another main transformer after N-1 fault of Quanzheng main transformer

**Figure 9.** Simulation curve of N-1 fault in Quancheng-Changle while the other one circuit is overhauled

**Figure 10.** Simulation curve of N-1 fault in Quancheng-Changle while the other one circuit is overhauled
3.4. Characteristics and transmission capacity of heavy-load grid

Under the heavy-load mode in summer 2019, the receiving limit of the power section of Shandong is subject to the 3500MW thermal stability limit of Quancheng main transformer. After the N-1 fault of the main transformer in Quancheng, the thermal stability limit of the other main transformer is 3500MW. The transmission limit of Shandong's external AC section is about 7635MW ~ 8845MW. Among them, after the three-phase permanent N-1 fault of Quancheng main transformer, the simulation results of the thermal stability limit of another main transformer are shown in the figure below.

**Figure 11.** Thermal stability limit of another main transformer after N-1 fault of Quanzheng main transformer

(2) Pre-control when one circuit of Quancheng-Changle is overhauled

Under the condition that one circuit of Quancheng-Changle is overhauled. The N-1 fault in the other circuit line would cause low voltage near the inverter station and sudden DC power reduction operation, as shown in the figure below.

**Figure 12.** Simulation curve of N-1 fault in Quancheng-Changle while the other one circuit is overhauled

After the DC power of Zhaoyi is reduced to 8500MW, under this maintenance mode, after the failure of Quancheng-Changle N-1, the power grid voltage can be restored to above 0.9p.u. and the DC system operate stably.

**Figure 13.** Simulation curve of N-1 fault in Quancheng-Changle while the other circuit is overhauled and 8500MW in Zhaoyi DC.
(3) **Pre-control when one circuit of Changle-Gaoxiang is overhaul**

Under the condition that one circuit of Changle-Gaoxiang is overhaul. The N-1 fault in the other circuit line would cause low voltage near the inverter station and sudden DC power reduction operation, as shown in the figure below.

![Figure 14. Simulation curve of N-1 fault in Changle-Gaoxiang while the other one circuit is overhaul.](image)

After the DC power of Zhaoyi is reduced to 9000MW, under this maintenance mode, after the failure of Changle-Gaoxiang N-1, the power grid voltage can be restored to above 0.9p.u. and the DC system operate stably.

![Figure 15. Simulation curve of N-1 fault in Quancheng-Changle while the other line is overhaul and 9000MW in Zhaoyi DC](image)

### 4. Conclusion

1. The power limit of Shandong AC connection section is about 9270mw~10780mw while 10000MW in Lugu DC system and 5500MW in Zhaoyi DC system.

   During the maintenance of Quancheng-Changle line, Xingtai, Changle and Gaoxiang main transformers, restricted by the continuous low voltage of Shandong power grid after the N-1 failure of another loop line or another main transformer, Zhaoyi DC system needs to be pre-controlled to 5000mw.

   During the maintenance of Guanggu-Changle and Yinan-Gaoxiang lines, due to the continuous low voltage of the power grid after N-1 fault in Changle-Quancheng, Gaoxiang- Changle, main transformer in Changle and Gaoxiang, it is necessary to pre-control Lugu DC system to 8000mw or Zhaoyi DC system to 4500mw respectively.

2. The power limit of Shandong AC connection section is about 9667MW~10712MW while 10000MW in Lugu DC system and 5500MW in Zhaoyi DC system.

   During the maintenance of Xingtai-Quancheng, Quancheng-Changle, Changle- Gaoxiang, Xin'an-Liaocheng and Huanghua-Binzhou lines, due to the continuous low voltage of Shandong power grid after the N-1 failure in the other line, Zhaoyi DC system needs to be pre-controlled to 9000MW.
Under the maintenance mode of Guanggu-Changle and Gaoxiang-Yinan, due to the low voltage or voltage collapse after N-1 or N-2 failure, it is necessary to pre-control the DC power of Lugu under 5000mw or Zhaoyi under 8000mw.

(3) According to the main oscillation modes of the North China Power Grid in 2019, there are oscillation modes from Mengxi to North China in both the abundant and the withered modes, with damping ratios of 6.3% and 4.9% respectively; there are oscillation modes from North China to central China in both the abundant and the withered modes, with damping ratios of 12.1% and 15.8% respectively; there are also oscillation modes from Shanxi and Mengxi units to Shandong and from Mengxi to Shanxi in the withered mode As well as the oscillation modes of Hengshan, Ordos Shanxi, Hebei South grid, Beijing Tianjin Tangshan, the damping ratios are 14.5%, 4.6% and 8.8% respectively, all of which are strong damping.

With the confirmation of power grid characteristics, damping characteristics and transmission limits, the next step is to analyze the impact of safety and stability on the local N-2 fault of the loop network, and put forward corresponding treatment measures and configuration principles.

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