Brief analysis of Jiangsu grid security and stability based on multi-infeed DC index in power system

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Abstract. The impact of Multi-infeed HVDC has gradually increased to security and stability operating in Jiangsu power grid. In this paper, an appraisal method of Multi-infeed HVDC power grid security and stability is raised with Multi-Infeed Effective Short Circuit Ratio, Multi-Infeed Interaction Factor and Commutation Failure Immunity Index. These indices are adopted in security and stability simulating calculation of Jiangsu Multi-infeed HVDC system. The simulation results indicate that Jiangsu power grid is operating with a strong DC system. It has high level of power grid security and stability, and meet the safety running requirements. Jinpin-Suzhou DC system is located in the receiving end with huge capacity, which is easily leading to commutation failure of the transmission line. In order to resolve this problem, dynamic reactive power compensation can be applied in power grid near Jinpin-Suzhou DC system. Simulation result shows this method is feasible to commutation failure.

1. Introduction
At present, Jinping-Suzhou ±800 kV UHVDC and Sanxia-Zhengping ±500 kV HVDC has been accessed to Jiangsu power grid. According to the UHV power grid planning and Jiangsu power grid "12th Five-Year ", "13th Five-Year " planning, a number of UHVDC projects such as Ximeng-Taizhou ±800 UHVDC project has been under construction. By then, the Jiangsu power grid will form a complex AC / DC mixed power grid. The capacity of DC transmission is enlarged, and the transferring of power flow is aggravated after faults. The risk of interaction among multiple HVDC system becomes greater as well [1-2], thus it will affect the security and stability of Jiangsu power grid. Therefore it is necessary to study the multi-infeed DC power grid for optimizing the power grid planning and improving the security and stability of power grid [3-4].

With the development of the power grid and the wide application of and HVDC and UHVDC transmission technology, electrical distance between HVDC receiving points will become increasingly close. Stable operation of HVDC system is becoming more and more dependent on the voltage stability level of AC grid in the infeed area [5-7]. Under normal conditions, the stronger of the AC system in the converter station of the HVDC transmission system is (i.e., the short circuit capacity is greater), the smaller the voltage fluctuation will be. When the DC system is in steady state and transient operation, and the better the stability of the system will be [8-9].

Some achievements have been made in the security stability assessment of multi-infeed UHVDC system. In reference [10] the expressions of multi-infeed short circuit ratio and multi-infeed critical short-circuit ratio are derived. In reference [11] the quantitative relationship between the multiple
feed effective short circuit ratio and the power stability of the multi-infeed UHVDC system is analysed based on the simplified model of two UHVDC infeed systems. In reference [12] the factors that affect the short circuit ratio of multi infeed DC are analysed. In reference [13] the existing interaction factor and multi-feed short circuit ratio are extended to AC / DC parallel multi-drop system. Proposed complex power short circuit ratio. However, the relationship between the relative index of multi-infeed DC system and the safety and stability of DC feeding in power grid has not been analysed in the above literatures. Furthermore it has not been applied to the actual large receiving power grid for analysis and research.

In this paper, three multi-infeed effect indices so called multi-infeed effective short circuit ratio (MIESCR), multi-infeed interaction factor (MIIF) and commutation failure immunity index (CFII) are used to analyse security and stability of large scale power grid. The weakness of multi-infeed HVDC system is pointed out. Finally relevant solutions and recommendations are proposed.

2. Evaluation index of multi-infeed UHVDC

2.1. Multi-infeed effective short circuit ratio (MIESCR)

Short circuit ratio (SCR) and effective short circuit ratio (ESCR) are common indices used to evaluate the interaction between DC system and AC system [13-15], defined by

\[
SCR = \frac{S_C}{P_{dc}}
\]

\[
ESCR = \frac{S_C - Q_f}{P_{dc}}
\]

In which: \(S_C\) is the short circuit capacity of AC system at the convert AC bus; \(P_{dc}\) is the transmission capacity of the HVDC; \(Q_f\) is the filter capacity in the converter.

The strength of the AC system is divided according to the ESCR in the reference [11]. The AC system is strong if ESCR>5; the AC system is moderately strong if 3<ESCR<5; the AC system is weak if ESCR<3. In order to maintain a certain degree of flexibility in the operation of the system, the general effective short-circuit ratio is chosen between 2-2.5.

For multi infeed HVDC systems, the index MIESCR can be represented as

\[
MIESCR = \sum_i SCL_i - Q_{fi} \sum_{j=1}^{n} MIIF_{j,i} \cdot P_{dcj}
\]

In which: \(SCL_i\) is the short circuit capacity of AC system at the convert \(i\); \(Q_{fi}\) is the total capacity of all filters and capacitors connected to the convert \(i\) AC bus.

MIESCR >3 means a strong AC system;
2< MIESCR <3 means a moderate AC system; MIESCR <2 means a weak AC system.

The critical effective short-circuit ratio of the multi infeed DC systems is around 1.5, that is, when MIESCR is less than 1.5, the voltage stability problems may occur.

2.2. Multi-infeed interaction factor (MIIF)

In order to represent the level of voltage interaction between the converter AC buses of multi-infeed HVDC converters, the multi-infeed interaction factor (MIIF) is put forward in [11]. For a multi-infeed HVDC system as shown in figure1, the MIIF can be obtained from Equation (4).

\[
MIIF_{j,i} = \frac{\partial U_j}{\partial U_i}
\]
In Figure 1, $Z_{S1} \angle \phi_1$, $Z_{S2} \angle \phi_2$ is the system impedance, and $Z_{Tie} \angle \theta_{Tie}$ is the link impedance between the DC lines. $E_1 \angle \phi_1$ and $E_2 \angle \phi_2$ are the Thevenin equivalent power. In Equation 4, $i$ and $j$ are the numbers of the converter station. The multi-infeed interaction factor can be expressed as the ratio of the voltage change at bus $i$ with a voltage drop at bus $j$.

### 2.3. Commutation failure index (CFII)

A commutation failure may be caused by an AC fault, which will lead to voltage drop. If the voltage drops to a certain level, commutation failure is most likely to happen. In order to quantitatively describe the possibility of commutation failure in multi-infeed HVDC, the index CFII is defined. Different voltage drop levels are simulated through different short-circuit impedances. In a single infeed DC system, the commutation failure coefficient can be defined as:

$$CFII = \frac{V_{ac}^2}{Z_{\min} \cdot P_{dc}} \cdot 100\%$$  \hspace{0.5cm} (5)

In which $V_{ac}$ is the rated voltage, and $Z_{\min}$ is the critical fault ground impedance that causes commutation failure. The smaller the transmission capacity of the DC system is, the larger the index CFII is, and the smaller the risk of commutation failure will be. CFII can be represented as

$$CFII = \frac{S_{CF}}{P_{dc}} \cdot 100\%$$  \hspace{0.5cm} (6)

In which $S_{CF}$ is the critical short-circuit capacity that causes commutation failure. It can be seen that from the expressions of CFII and ESCR that they have strong relativity. The larger the ESCR is, the larger the CFII will be, which means that the stronger the AC system is, the stronger the ability of the DC system to resist commutation failure will be obtained.

### 3. Case study of Jiangsu planning power grid

#### 3.1. Jiangsu power grid conditions

According to the development planning of UHV power grid and Jiangsu grid "13th Five-Year", Ximeng - Taizhou UHVDC project will be built besides existing Zhengping HVDC system and Jinping HVDC system. The initial scheme is to consider the capacity to deliver 8000MW through the ±800kV HVDC system. The Capacity is converted to two voltage levels of 1000kV and 500kV, respectively. And Ximeng - Taizhou UHVDC system is considered to be built over the same period with the East China 1000kV UHVAC network. The grid structure is shown in figure 2.
3.2. Calculation and analysis of indices

Calculation of SCR, ESCR and MIESCR for Jiangsu power grid Multi-infeed DC system are shown in table 1.

As can be seen from the results of table 1:

(1) There is big difference between the different DC systems, such as the SCR level of Zhengping HVDC may reaching 16.2. Without the influence of each other, the result is not referential. Considering mult-infeed DC factors, the calculation results of MIESCR are reliable and can be used to evaluate the grid strength.

(2) The calculation results show that the short circuit capacity in Jiangsu 500kV and 1000kV power grid is high, in normal operation mode, the MIESCR indices in Jiangsu power grid are higher than 3, and Jiangsu power grid is a strong AC system. Therefore, when the DC systems encounter commutation failure, strong active and reactive power can be offered to the DC systems, which is helpful to ensure the normal operation of the DC systems.

(3) Among the three DC systems, the MIESCR index of Zhengping HVDC system is maximum, which owns the strongest AC system. While the MIESCR index of Jinsu UHVDC system is minimal, which has the relatively weak AC system.

(4) Relevant literatures suggest the MIESCR index should be greater than 2.5, when taking into account the MIESCR index of Jinsu UHVDC system is slightly greater than 3, and without considering the influence of DC systems in East China, such as Shanghai, Zhejiang, the calculation results may be positive.

Table 1. Calculation of SCR for Jiangsu power grid Multi-infeed DC system.

|                | active power transmission (MW) | short circuit level of AC-bus (MVA) | Filter capacitor (MVar) | SCR   | ESCR   | MIESCR |
|----------------|-------------------------------|-------------------------------------|-------------------------|-------|--------|--------|
| Zhengping HVDC system | 3000                          | 48467                               | 1800                    | 16.2  | 15.6   | 5.04   |
| Jinsu UHVDC system    | 7200                          | 38135                               | 4320                    | 5.3   | 4.7    | 3.14   |
| Ximeng UHVDC system (1000kV Side) | 4000                          | 40176                               | 2400                    | 10.0  | 9.4    | 4.24   |
| Ximeng UHVDC system (500kV Side)  | 4000                          | 34123                                | 2400                    | 8.5   | 7.9    | 4.23   |

Figure 2. Jiangsu Ultrahigh-voltage power grid diagram.
The interaction analysis results of Multi-infeed DC voltage drops in Jiangsu power grid are shown in Table 2. (1) The effect of voltage drops between converter stations can be analysed with the MIIF index. Considering the voltage threshold of minimum voltage drops, the possibility of simultaneous or successive commutation failures in multiple converter stations can be obtained. (2) As can be seen from the results, the voltage drops of Taizhou UHVDC system (500kV) have the least influence on Zhengping bus, which is 0.18. The main reason is that two DC systems are located in North Jiangsu and South Jiangsu, and the electrical connection between them is weak. In addition, the DC capacity of Zhengping HVDC system is minimal so that it is not easily affected. The voltage drop of Zhengping HVDC system has the largest influence on Jinsu UHVDC system, which is 0.53. Otherwise the two DC systems are all located in South of Jiangsu power grid, and the electrical distance is close, besides the capacity of Jinsu UHVDC system is larger. (3) The last column in Table 2 is sum of the MIIF indices, which is the accumulation of the impacts on a DC bus caused by other DC voltage drops. It can be seen that the MIIF of Zhengping HVDC system is minimum, which means it has the strongest ability to resist fault; the MIIF of Jinsu UHVDC system is maximum, which means it has the weakest ability to resist fault. Therefore, it is necessary for the power grid planning to make the corresponding measures on Jinsu UHVDC system, which is beneficial to prevent the DC blocking caused by the voltage drops after the fault.

Table 2. Calculation of MIIF for Jiangsu power grid Multi-infeed DC system.

| DC system code | MIIF_{1,1} | MIIF_{1,2} | MIIF_{1,3} | MIIF_{1,4} | MIIF_{∑} |
|----------------|------------|------------|------------|------------|-----------|
| Zhengping HVDC system | 1 | 1.00 | 0.39 | 0.25 | 0.18 | 1.82 |
| Jinsu UHVDC system | 2 | 0.53 | 1.00 | 0.34 | 0.25 | 2.12 |
| Taizhou UHVDC system 1(1000kVside) | 3 | 0.34 | 0.32 | 1.00 | 0.29 | 1.95 |
| Taizhou UHVDC system 1(500kVside) | 4 | 0.27 | 0.28 | 0.43 | 1.00 | 1.98 |

Preliminary assessment of commutation failures of Multi-infeed DC systems in Jiangsu power grid is shown in Table 3. (1) As can be seen from Table 3, considering the interaction of Multi-infeed DC system, the commutation failure coefficient CFII of each DC system could be calculated. Among them, the High-Voltage Side and Low-Voltage Side CFII indices of Zhengping HVDC system and Taizhou UHVDC system are fairly higher, so the probability of commutation failure after the fault is lower. The CFII indices of Jinsu UHVDC system is only 0.32, therefore the probability of commutation failure after the fault is greater, which is easy to cause safety and stability problems. (2) For the reason of the electric distance, basically, the interaction of two DC systems in South Jiangsu (Jinsu and Zhengping) is great. But the DC system from Taizhou UHVDC system to the1000kV bus has a greater impact on the grid in South of Jiangsu.(3) As a result that Taizhou UHVDC substations are switched to different voltage level of AC buses, the mutual influence of the results is not significant due to the electrical distance.

Table 3. The minimum short circuit MVA of commutation failure for Jiangsu power grid Multi-infeed DC system.

| short circuit level of AC bus (MVA) | Transmission power Pdc (MW) | the capacity of fault short-circuit SCL (MVA) | commutation failure immunity index CFII=SCL/Pdc |
|-----------------------------------|-----------------------------|---------------------------------|--------------------------|
| Zhengping HVDC                  | 48467 | 3000 | 2908 | 6934 | 12687 | 17062 | 0.97 | 0.96 | 3.17 | 4.27 |
| Jinsu UHVDC                     | 38135 | 7200 | 5816 | 2288 | 8609 | 10776 | 1.94 | 0.32 | 2.15 | 2.69 |
| Taizhou UHVDC 1(1000kVside)     | 40176 | 4000 | 11185 | 8800 | 2411 | 8902 | 3.73 | 1.22 | 0.60 | 2.23 |
| Taizhou UHVDC 1(500kVside)      | 34123 | 4000 | 13218 | 10400 | 6515 | 2047 | 4.41 | 1.44 | 1.63 | 0.51 |
3.3. Measures and suggestions
According to section 2.2, the overall planning of Jiangsu power grid is adequate, which could meet the access requirements of Multi-infeed DC systems. Thus the DC systems in the planning period could operate in safe and stable. Among them, three indicators of Jinsu UHVDC system are relatively weak. The main reason is the capacity of Jinsu UHVDC system is quite large and in the centre of the receiving end. When serious fault occurs, it is easy to lead to a great voltage drop, which causes the commutation failure in DC system. Therefore, enhancing the restoration level of voltage in the nearby of Jinsu UHVDC system is the key factor to improve the security of Jinsu UHVDC system. It is suggested to install dynamic reactive compensation devices STATCOM near the placement of the risky DC system.

As a simulate example, the STATCOM is installed in the 500kV electricity substation that is located in the nearby of Jinsu UHVDC system. The curves of current in Jinsu UHVDC converter station before and after installation are shown in figure 3.

![Figure 3. Valve current curve at serious failure.](image)

As shown in figure 3, without the installation of dynamic reactive power compensation device, in serious fault cases, two commutation failure in Jinsu UHVDC system were occurred in 0.2 second. After the 300Mvar STATCOM was installed in the nearby bus of DC system, no commutation failure occurred. The STATCOM has corresponding speed, better dynamic reactive power output characteristics, which could provide reactive power support at the same time to reduce voltage fluctuations. The DC commutation failure after the voltage recovery rate is improved.

4. Conclusions
In this paper, three multi-infeed indices are applied on security and stability simulation of Jiangsu Multi-infeed HVDC system, which is helpful to identify the weakness of Jiangsu Multi-infeed HVDC system, and put forward relevant measures and suggestions.

1. Calculation results show that using MIESCR, MIIF and CFII in analysing the safety and stability of Jiangsu Multi-infeed DC system is feasible. The assessment result shows that Jiangsu planning grid is strong as a whole. The indicators can meet the requirements of safe operation and satisfy the access of Multi-infeed DC system.

2. Through the analysis of Jiangsu Multi-infeed DC system, the three indices of Jinsu UHVDC system are relatively weak, which is the weakness of Jiangsu Multi-infeed HVDC system.

3. The main reasons are the capacity of Jinsu UHVDC system is large, and the system is in the centre of the receiving end. In serious fault, it is easy to lead to a great voltage drop, which causes the commutation failure. It is necessary to install dynamic reactive compensation devices near the placement of DC system to improve dynamic stability. Results of simulation analysis show that installation of dynamic reactive power compensation device is feasible on the 500kV bus near Jinsu UHVDC system. The frequency of commutation failures is reduced in Jinsu UHVDC system under severe faults. Accordingly, the safety and stability of power grid is improved.
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