Research on the design principle of the contact terminal in large DC current loop of ±800 kV, 10,000 MW UHVDC converter station

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Abstract: The abnormal heating phenomena of contact terminal in large DC current loop of the ultra-high voltage direct current (UHVDC) converter station became one of the most serious problems, which caused serious impact on the operation reliability of the power grid. Based on existing codes and standards of contact terminal temperature rise and the results of large current temperature rise test, the design principle of the contact terminal in large DC current loop of UHVDC converter station, which caused serious impact on the operation reliability of the power grid, brought out great economical damage and adverse social effects. How to effectively prevent temperature rise of the contact terminal in large DC current loop of the UHVDC converter station became an important problem in the design of UHVDC converter station [4].

According to statistics from Xiangjiaba–Shanghai, Jinping–Sunan, Hami–Zhengzhou, and Xiluodu–Zhixi UHVDC transmission projects, there are >100 abnormal heating problems of contact terminal in large DC current loop in those eight ±800 kV UHVDC converter stations. Especially, 10 serious heating problems caused the DC transmission line break down. Among all the abnormal heating parts, >80% heating parts are contact terminals in large DC current loop of the UHVDC converter station. The main reasons that caused contact terminals abnormal heating are insufficient design margin, poor installation process, and substandard quality of the metal fittings. The main methods to effectively prevent temperature rise of the contact terminals in large DC current loop are effective controlling the of construction technology and acceptance of contact terminals in large DC current loop of new converter stations, and using a variety of temperature rise test tools to find out the abnormal heating contact terminals. However, the design principle of the contact terminal in large DC current loop has not been put forward fundamentally.

In order to prevent the abnormal heating problems of the contact terminal in large DC current loop of new UHVDC converter stations and UHVDC converter stations’ operation and maintenance, Shi et al. [7] and Mao et al. [8] analysed the abnormal heating phenomena of contact terminals in large DC current loop, and put forward some suggestions and measures from the construction technology of contact terminals in large DC current loop of new converter stations. Shi and Lei [9] analysed several reasons of the abnormal heating phenomena of contact terminal in large DC current loop, and put forward some suggestions and measures from the construction acceptance of contact terminal in large DC current loop, based on the requirements of the current density of contact terminal.

Reference [10] conducted the large current temperature rise test of the contact terminal, researched the material, type, and rule of temperature rise of the contact terminal. The empirical formula’s parameters of contact resistance for the copper–copper contact terminal are deduced. Then, the temperature rise calculation method of the copper–copper contact terminal was put forward. This large current temperature rise test provided important experimental data for the design principle of the contact terminal in large DC current loop of UHVDC converter station.

In addition, on the condition that the insulation level was not significantly increased in large DC current loop of UHVDC converter station, the rated DC current of ±800 kV, 10,000 MW UHVDC converter station is 6250 A, which can enhance the capacity of long-distance power transmission. There are also abnormal heating problems of the contact terminal in large DC current loop in this kind of converter stations. The material and type requirements of the contact terminal in the rated DC current 6250 A was not defined in the existing codes and standards. Therefore, according to the existing codes and standards of temperature rise of the contact terminal and the large current temperature rise test, this paper puts forward the design principle of the contact terminal in large DC current loop of ±800 kV, 10,000 MW converter station. Taking the design of three typical contact terminals in large DC current loop of Taizhou ±800 kV converter station as an example, the infrared temperature measurement results of contact terminals on the large current operation condition are analysed. The results indicate that the design principle of the
contact terminal in large DC current loop can meet the requirements of existing codes and standards of the temperature (temperature rise) limit of the contact terminal.

2 Design requirements of the contact terminal in large DC current loop

In order to prevent the abnormal heating problems of the contact terminal in large DC current loop of ±800 kV, 10,000 MW converter station, based on existing codes and standards of the temperature (temperature rise) limit of the contact terminal and the results of the large current temperature rise test, this paper puts forward the design requirements of the contact terminal in large DC current loop including temperature (temperature rise) limit, current density, size of contact terminals, and construction technology and acceptance.

2.1 Temperature (temperature rise) limit of the contact terminal in large DC current loop

According to the temperature (temperature rise) limit in [11] and [12], the temperature (temperature rise) limit of the contact terminal in large DC current loop depends on the highest temperature and allowed temperature rise of the contact terminal. The highest temperature of the contact terminal is mainly affected by the threshold temperature of the material properties mutation, e.g. tin creeps point is 105°C. Allowed temperature rise of the contact terminal is mainly affected by the temperature difference between the material with the surrounding environment temperature, which can cause the electrical or mechanical performance deteriorated and reduce the contact terminals’ service life. At the same time, based on the defect diagnosis criterion of the current heating type equipment in [13], the temperature (temperature rise) limit of the contact terminal in large DC current loop is shown in Table 1.

![Table 1](image)

| Types                                      | Maximum temperature (°C) | Peak temperature rise, K |
|--------------------------------------------|--------------------------|--------------------------|
| aluminium–aluminium                        | 40                       | 40                       |
| copper–copper                              | 105                      | 50                       |
| copper–copper–aluminium                    |                          |                          |
| copper plated silver–aluminium             |                          |                          |
| plated tin                                 |                          |                          |
| copper rod plated silver–cast aluminium   |                          |                          |
| holding clip plated tin                    |                          |                          |

2.2 Current density design value of the contact terminal in large DC current loop

According to [14], when the current in large current loop is >2000 A, the current density of the no-cladding copper–copper contact terminal in large current loop should not exceed >0.12 A/mm², the current density of the no-cladding aluminium–aluminium contact terminal in large current loop should not exceed >0.0936 A/mm². According to the ±800 kV, 10,000 MW UHVDC converter station, when the contact terminal is designed, the rated DC current is not only taken into account, but also 2 h maximum overload working current 6700 A is considered. Based on the temperature (temperature rise) limit of the contact terminal in large current loop in Table 1 and the results of the large current temperature rise test, the current density of different types of the contact terminals in large DC current loop is shown in Table 2.

![Table 2](image)

| Maximum overload current, A | Terminal types                                      | Current density design value, A/mm² |
|----------------------------|----------------------------------------------------|-------------------------------------|
| 6700                       | single-sided aluminium–aluminium                   | 0.07488                             |
|                            | double-sided aluminium–aluminium                   | 0.05                                |
|                            | copper–copper                                      | 0.0936                              |
|                            | copper plated silver–aluminium plated tin          | 0.0936                              |
|                            | copper–adapter–aluminium                           | 0.08                                |
|                            | copper rod plated silver–cast aluminium holding clip plated tin | 0.0936 |

2.3 Recommended size of the contact terminal in large DC current loop

Based on current density design value of the contact terminal in large DC current loop in Table 2, and considering the requirements of plate and rod contact terminals’ hole size and hole spacing in [15], the recommended size of different types of the contact terminals in large current loop is shown in Table 3.

![Table 3](image)

| Terminal types                                      | Current density, A/mm² | Required contact area, mm² | Actual contact Terminal size, mm Hole size, mm Hole spacing, mm |
|----------------------------------------------------|------------------------|-----------------------------|------------------------------------------------------------------|
| single-sided aluminium–aluminium                   | 0.07488                | 89,476                      | 89,894 380 × 260 35–Φ18 50                                       |
| double sided aluminium–aluminium                   | 0.05                   | 134,000                     | 137,457 280 × 260 16–Φ18 50                                      |
| copper–copper                                      | 0.0936                 | 71,581                      | 72,675 380 × 210 28–Φ18 50                                      |
| copper plated silver–aluminium plated tin          | 0.0936                 | 71,581                      | 72,675 380 × 210 28–Φ18 50                                      |
| copper–adapter–aluminium                           | 0.08                   | 83,750                      | 84,766 330 × 280 30–Φ18 50                                      |
| copper rod plated silver–cast aluminium holding clip plated tin | 0.0936                 | 71,581                      | 73,697 260 × φ95 5–Φ18 50                                      |
Based on the design requirements of the contact terminal in DC large current loop, contact terminals in large DC current loop of Taizhou ±800 kV converter station are designed. The rated DC current of Taizhou converter station, DC voltage ±800 kV and transmission capacity 10,000 MW, is the first to achieve 6250 A in the word. There are three types of contact terminals in outdoor DC field of Taizhou ±800 kV converter station, including single-sided aluminium–aluminium plate, double-sided aluminium–aluminium plate and copper rod plated silver-cast aluminium holding clip plated tin plate. Taking the pole 1 800 kV isolating switch contact terminal, pole 1 neutral line power line carrier (PLC) reactor contact terminal, and bipolar neutral zero-flux current transformer (CT) contact terminal as examples, the design principle of three types of contact terminals are introduced as follows.

3.1 Design of single sided aluminium–aluminium contact terminal

The single-sided aluminium–aluminium plate is designed in pole 1 800 kV isolating switch contact terminal. The single-sided aluminium–aluminium plate is connected with the pole 1 800 kV isolating switch, and the other side is connected with the cable fastened by six-split cable clamp, then connected to the pole 1 bus. Based on Tables 2 and 3, the required value of current density of single-sided aluminium–aluminium contact terminal is 0.07488 A/mm², and the required value of the contact area is 89,476 mm². Then, considering the mechanical strength of contact terminal and the requirement for pole 1 800 kV isolating switch connection, the size of single-sided aluminium–aluminium contact terminal of pole 1 800 kV isolating switch is designed as shown in Fig. 1. The actual current density of single-sided aluminium–aluminium contact terminal is 0.074479 A/mm², and the actual contact area is 89,958 mm².

3.2 Design of double-sided aluminium–aluminium contact terminal

The double-sided aluminium–aluminium is designed in pole 1 neutral line PLC reactor contact terminal. The double sided aluminium–aluminium is connected with the pole 1 neutral line PLC reactor, and the other side is connected with the cable fastened by six-split cable clamp, then connected to the pole 1 neutral line bushing. Based on Tables 2 and 3, the required value of current density of double-sided aluminium–aluminium contact terminal is 0.05 A/mm², and the required value of the contact area is 134,000 mm². Then, considering the mechanical strength of contact terminal and the requirement for pole 1 neutral line PLC reactor connection, the size of double-sided aluminium–aluminium contact terminal of pole 1 neutral line PLC reactor is designed as shown in Fig. 2. The actual current density of double-sided aluminium–aluminium contact terminal is 0.044121 A/mm², and the actual contact area is 151,854 mm².

3.3 Design of copper rod plated silver-cast aluminium holding clip plated tin contact terminal

The copper rod plated silver-cast aluminium holding clip plated tin is designed in bipolar neutral zero-flux CT contact terminal. The contact terminal's holding clip is connected with the zero-flux CT's copper rod, and the other side is connected with the cable fastened by six-split cable clamp, then connected to the bipolar neutral bus. According to Tables 2 and 3, the required value of current density of copper rod plated silver-cast aluminium holding clip plated tin contact terminal is 0.0936 A/mm², and the required value of the contact area is 71,581 mm². Then, considering the mechanical strength of contact terminal and the requirement for zero-flux CT's copper rod connection, the size of copper rod plated silver-cast aluminium holding clip plated tin contact terminal is designed as shown in Fig. 3. The actual current density of copper rod plated silver-cast aluminium holding clip plated tin contact terminal is 0.073138 A/mm², and the actual contact area is 91,607.4 mm².

3 Design examples of the contact terminal in large DC current loop

ii. Requirements of surface treatment technology: According to the results of the large current temperature rise test, the bright and clean degree of the contact terminals in large current loop should be controlled in 5 μm. When the contact terminals are installed or replaced, 400 mesh fine sandpaper should be used to remove the surface oxide layer.
4 Results and analysis of temperature rise test

Each voltage valve system, including pole 1 high-voltage valve system, pole 1 low-voltage valve system, pole 2 high-voltage valve system, and pole 2 low-voltage valve system, in Taizhou ±800 kV converter station has been in smooth operation, respectively. Each system operated on the rated DC current 6250 A, capacity 2500 MW, and the local environment temperature is 15°C, each system operated for 2 h. The temperature of the contact terminals in large DC current loop in the whole converter station are measured by infrared. The infrared temperature measurement results show that the maximum temperature (temperature rise) of all contact terminals in large DC current loop in outdoor DC field can meet the existing codes and standards of temperature rise of the contact terminal as shown in Table 1. Among them, the maximum temperature (temperature rise) situation of pole 1 800 kV isolating switch contact terminal (single-sided aluminium–aluminium contact terminal), pole 1 neutral line PLC reactor contact terminal (copper rod plated silver-cast aluminium holding clip plated tin contact terminal) and bipolar neutral zero-flux CT contact terminal (copper rod plated silver-cast aluminium holding clip plated tin contact terminal) are, respectively, shown in Figs. 4–6.

On the condition that each voltage valve system operated in rated DC current 6250 A, the infrared temperature measurement results of three types of contact terminals are shown in Table 4. As Table 4 shown, the temperature of pole 1 800 kV isolating switch contact terminal (single-sided aluminium–aluminium contact terminal) is 44.0°C, the local environment temperature is 15.0°C, temperature rise is 29.0 K, which can meet the temperature rise limit 40.0 K of the single-sided aluminium–aluminium contact terminal as shown in Table 1. The temperature of pole 1 neutral line PLC reactor contact terminal (double-sided aluminium–aluminium contact terminal) is 47.9°C, the local environment temperature is 15°C, temperature rise is 31.9 K, which can also meet the temperature rise limit 40.0 K of the double-sided aluminium–aluminium plate contact terminal. The temperature of bipolar neutral zero-flux CT contact terminal (copper rod plated silver-cast aluminium holding clip plated tin contact terminal) is 40.3°C, the local environment temperature is 15°C, temperature rise is 25.3 K, which can meet the temperature rise limit 50.0 K of the copper rod plated silver-cast aluminium holding clip plated tin and the maximum temperature is <105°C as shown in Table 1.

5 Conclusion

In order to prevent the abnormal heating problems of the contact terminals in large current loop of new UHVDC converter stations and UHVDC converter stations’ operation and maintenance, based on the existing codes and standards of temperature rise of the contact terminal and the results of the large current temperature rise test, this paper puts forward the design principle of the contact terminals in large current loop of ±800 kV, 10,000 MW converter station. Taking the design of three typical contact terminals in large current loop of Taizhou ±800 kV converter station as examples,
including single-sided aluminium–aluminium contact terminal, double-sided aluminium–aluminium contact terminal and copper rod plated silver-cast aluminium holding clip plated tin contact terminal. The infrared temperature measurement results of contact terminals on the large current operation condition are analysed. The results indicate that the design principle of the contact terminal in large DC current loop proposed in this paper is able to meet the requirements of existing codes and standards of the temperature (temperature rise) limit of the contact terminal.

The research results in this paper will contribute to improving the operation reliability of the UHVDC converter station, providing the direct technical support for operation and maintenance of the UHVDC converter station, and enhancing design effort of the UHVDC converter station.

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### Table 4

| Terminal name | Terminal types | Current density, A/mm² | Environment temperature, °C | Terminal temperature, °C | Terminal temperature rise, K |
|---------------|----------------|------------------------|-----------------------------|--------------------------|-------------------------------|
| pole 1 800 kV isolating switch contact terminal | single-sided aluminium–aluminium | 0.074479 | 15.0 | 44.0 | 29.0 |
| pole 1 neutral line PLC reactor contact terminal | double-sided aluminium–aluminium | 0.044121 | 15.0 | 47.9 | 31.9 |
| bipolar neutral zero-flux CT contact terminal | copper rod plated silver-cast aluminium holding clip plated tin | 0.073138 | 15.0 | 40.3 | 25.3 |

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