Research on Characteristics of Grounding Electrode of HVDC Transmission

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Abstract The grounding electrode is an important part of HVDC transmission system, especially in monopole operation. Based on the actual operation of the grounding electrode of Guanyin Pavilion in the ±500kV Goose-commutation station in Huizhou, Guangdong, this paper analyses in detail the specific influencing factors of the grounding electrode on the surrounding environment, underground metal pipelines and AC grid. Daily maintenance work considering current distribution, temperature, humidity and step voltage is also proposed to strengthen the understanding and attention of operation and maintenance personnel to the grounding electrode.

1. Introduction

HVDC transmission has the characteristics of long-distance, large-capacity, etc. It is suitable for long-distance, point-to-point and high-power transmission and has become an important part of China's power transmission [1]-[3]. Most of the currently widely used HVDC transmission projects use bipolar DC transmission systems, which are characterized by automatic conversion to monopole operation when one of the poles fails or disconnects due to maintenance. When the bipolar DC transmission line is running, the currents in two ground loops are opposite, and there is almost no current in the ground. The role of the grounding electrode is mainly to introduce the unbalance current into the ground while restraining the neutral point potential of the converter valve; In the monopole operation, the ground is used as a transmission line, called the “earth loop”. At this time, a strong direct current will flow into the ground through the grounding electrode to form a constant DC current field in the electrode soil.

At present, there are many problems in the monopole operation mode of HVDC transmission, such as causing step voltage, excessive local temperature and electrochemical corrosion [4]-[5]. The literature [6] summarizes the influence law on the corrosion degree of metal pipelines from three aspects: the grounding electrode types, buried depth of pipelines and soil resistivity. The literature [7] describes the principle of the influence of monopole operation of direct current transmission on 500kV AC transformer. The literature [8] studied the impact of 800kV single-stage direct current transmission on the surrounding AC grid and environment. The literature [9]-[10] discusses the possible impact of high-voltage DC grounding electrodes on new substations in the surrounding area, and puts forward some constructive opinions.

In view of the above problems, this paper combines the actual operating conditions of the grounding electrode of Guanyin Pavilion in the ±500kV Goose City Converter Station in Huizhou, Guangdong Province, and analyses the influencing factors and daily maintenance points of the grounding pole in detail to provide reference for actual work on site.
2. Introduction to the grounding pole of the Goose City Converter Station

At present, the San-Guang HVDC transmission project is the only channel for Three Gorges Power to be sent to the Southern Power Grid in China's West-East Electricity Transmission Project. The San-Guang HVDC transmission project is a ±500kV bipolar DC transmission one from the Three Gorges Jiangling Converter Station to the Huizhou Goose Converter Station in Huizhou, Guangdong. Guangdong Huizhou Guanyin Pavilion grounding electrode is the auxiliary grounding facility of the Goose City Converter Station. It is 40 kilometres away from the Goose City Converter Station, with a construction area of one mu and a design life of 40 years. The plane layout of the grounding electrodes is shown in Figure 1. The grounding electrode has a rated load current of 3000A, a maximum continuous overload current of 3390A, a bipolar unbalanced earth current of 30A, and a maximum step voltage of 14.6V/m. The grounding electrode is shallow buried and the material constituting it is carbon steel rod Q235/φ70. The shape of the electrode is concentric three-circle ring (as shown in Figure 2) with the inner ring diameter of 520m, the middle ring diameter of 640m, and the outer ring diameter of 740m. The copper core cable is used to connect the current from the bus bar to the drainage well. The number of cables to the outer ring, the middle ring and the inner ring are 8, 8, and 4, respectively, and there are 4 drainage wells on each ring. The electrode is buried at depth of 3.5 m and is filled with active filler material, petroleum coke powder.

![Figure 1. Plane layout of the grounding electrode](image1)

![Figure 2. Plane layout of the grounding cables](image2)

Currently, most of DC transmission projects have been built in China use ring-type grounding electrodes, including structure of single-ring, double-ring and three-ring. The annular grounding current overflow density and potential distribution are relatively uniform overall, and there is no serious local current accumulation. The overflow density on the outer ring of three-ring electrode is the largest, the inner ring is the second, and the middle ring is the smallest. The ground potential is highest in 10the area directly above the outer ring.

3. Influencing factors of the grounding electrode

3.1. Thermal effect

When the DC system is operating in a single pole, a large current continues to enter the ground through the grounding electrode, which causes the surrounding soil to be heated [11]. When the temperature rises to a certain extent, the moisture in the soil may be evaporated. The conductivity of the soil will be deteriorated and the electrode will be thermally unstable. In severe cases, the soil will be sintered into glasses which are almost non-conductive and fail to work.
The main soil parameters affecting the temperature rise of the electrode are soil resistivity, thermal conductivity, heat capacity and humidity. Therefore, it is desirable for terrestrial (including coastal) electrodes that the site soil has good electrical and thermal conductivity as well as large heat capacity coefficient and sufficient humidity to ensure good thermal stability of the grounding electrode during operation.

3.2. *Electrochemical corrosion*

A large number of metal pipelines such as oil, gas, and water are buried in the earth, which has much smaller electrical resistivity and stronger conductivity than soil to provide a better diffusing channel for the DC ground [12] current. Therefore, a large amount of ground current flows into one end of the metal pipes near the grounding electrode and is released back to the earth on the other end.

In the part where the current flows into the metal pipe, the potential is lower than the soil due to being in the cathode region, and is protected by the cathode without being dissolved. The other part where the current flows out is called the anode region because of higher potential. The metal material in the anode region loses electrons and becomes positive ions with the oxidation reaction occurring (Fe$^{2+}$ reacts with O$_2$ and H$_2$O to become Fe(OH)$_2$). Therefore, it will be corroded. In severe cases, oil leakage, water leakage, and air leakage will result in waste of resources. It is essentially an anode metal dissolution loss in an electrolytic reaction, and the amount of current flowing through the conductor determines the degree of corrosion of the pipe [6].

Similarly, the redox reaction occurs on the electrode of the grounding electrode. If the grounding electrode is directly buried in the soil by the iron rod anode, the annual iron loss is 1.8 to 12.6t when the iron rod anode passes the current of 1000A. And if the iron rod is not directly in contact with the soil, but is filled with crushed coke having better conductivity, the ionic conduction of the metal body can be converted into electronic conduction, thereby preserving the corrosion. When DC current flows, the data shows that the corrosion rate of steel in coke is only 10%~30% in the soil and less than 10% in the completely dry coke.

3.3. *DC bias*

China's 110kV and above voltage grade grids generally adopt neutral point direct grounding mode. The AC transformer adopts Y0/Y0 wiring mode, and a certain potential difference will be generated between substations in different locations within the grounding electrode current field. Under normal circumstances, the DC current flows from the high-potential neutral point of the transformer closer to the grounding electrode, flows out at a low-potential neutral point farther away, and enters the AC grid. The current flowing through it is shown in Figure 3.

![Figure 3. The schematic diagram of DC current enters the AC grid](image)

The DC current flowing into transformer windings will form an AC/DC superimposed excitation current together with the AC excitation current, which causes the magnetization curve operating point to enter a saturated region on one side, so that the transformer is also in a saturated state, thereby
forming a DC bias [7]-[8]. A large number of harmonics lead to local overheating of the transformer, and insulation damage, which makes transformer vibration and noise increase. What’s worse, the system voltage decrease and relay protection device malfunction created by harmonics result in accidents. According to the requirements of 4.8.4 of DL437-1991, “the DC interference current flowing into transformer windings through the neutral point should be limited to 7‰ of the rms value of the rated current of transformers”.

The key to avoiding the influence of DC grounding current on the transformer is the substation site selection stage, the site should be as far as possible from the grounding electrode [9]. On the basis of relevant regulations, field measured data and simulation calculation results, the optimal site of the substation should be selected 50km away from the grounding electrode. However, with the rapid growth of power demand, it is hard to ensure that substations are not built within 50 km of the grounding electrode for the purpose of improving the regional power supply capacity and strengthening the reliability of power network. Even a substation built outside the 50km grounding pole may be affected by DC current through electrical connections on the grid. Therefore, reasonable control measures must be taken in line with actual situation.

Recently, there are four commonly suppression measures including series small resistance, reverse DC injection device, capacitance blocking device and resistance-capacitance hybrid type straightening device. They both have advantages and disadvantages. Generally, the series small resistance is only suitable for 110kV substation with low soil resistivity; the capacitive blocking device and the RC can be used for substations of 220kV and below; the reverse injection device is mostly employed in 500kV substations.

4. Daily maintenance of the grounding electrode

Daily maintenance of the grounding electrode includes current distribution measurement, temperature measurement, humidity detection, and step voltage measurement. The specific maintenance contents are listed as follows:

4.1. The distribution of current measurement

The grounding electrode is a concealed electrical device whose fault is not easy to observe, but some problems can be found by measuring the current distribution. When there is an open circuit in the feeder cable or sub-electrode group of a branch, the current distribution will be abrupt. Therefore, regular measurements and records are necessary, the flow of the diversion system can be judged through comparing the measurement records. The current of each feeder cable is measured by ammeters, and the current distribution is able to be checked according to the current value.

4.2. Temperature measurement

The temperature and humidity of grounding electrode are important technical indicators for evaluating the running performance of the grounding electrode. It is capable of being judged whether the grounding current density is uniform, whether it can continue to operate in the earth return mode, or whether it is necessary to give the grounding electrode water injection through measuring temperature of the grounding electrode and its changes. A plurality of detection holes are set in the entire electrode, and the temperature of the electrode is easily measured by extending a thermometer or a thermistor to the bottom of the tube (electrode surface).

4.3. Humidity detection

If the electrode is in a water-saturated soil, the groundwater level can be measured directly. If not, a humidity sensitive resistor or probe is demanded to measure soil moisture.

4.4. Step voltage measurement

The maximum step voltage on the ground is an important parameter for normal operation of the grounding electrode. Step voltage measurement reflects the maximum field intensity distribution on
the ground. It can be determined whether the electrode is working normally with changes in field intensity.

4.5. *Grounding resistance measurement*

The current injection method, namely, the ammeter-voltmeter method, the injection current is not alternating current but direct current.

4.6. *Routine inspection*

The grounding electrode is ought to inspect at least quarterly and record to detect damage from external factors such as floods. The contents of the inspection are listed as follows:

1. Whether there is scouring or collapse in the electrode address. If any, it should be restored in time;
2. Checking whether the cable joints, insulators, etc. are damaged. Replacing them in time if any;
3. Checking the seepage wells and inspection wells to prevent the sludge from clogging the pipes and seepage holes, so as not to affect the detection and water injection.

4.7. *Infrared temperature measurement during monopole operation*

When DC system is operated in a single pole, the main conduction loop of the grounding electrode will flow a large current of several thousand amps. If the contact is poor, the joint will heat up. When defect is found, it is necessary to use the power failure maintenance opportunity to deal with it in time.

5. *Conclusion*

In DC transmission projects, the grounding electrode provides a reliable electrical connection to the earth and plays a very important role. However, the presence of grounding poles can also adversely affect the surrounding environment, underground metal pipelines, and nearby AC grids. This paper analyses the negative effects of the grounding pole and the corresponding solutions in combination with actual operating conditions of the grounding electrode of the Guanyin Pavilion at the Goose Converter Station, and puts forward the main points of daily maintenance of the grounding pole. It is significant for operation and maintenance personnel to strengthen the understanding and attention of the grounding electrode, which ensure the grounding electrode effectively accomplish the task of conducting current and improve the reliability and stability of DC transmission system.

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