Study on electrochemical corrosion mechanism of steel foot of insulators for HVDC lines

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Abstract. The main content of this paper is the mechanism of electrochemical corrosion of insulator steel foot in HVDC transmission line, and summarizes five commonly used artificial electrochemical corrosion accelerated test methods in the world. Various methods are analyzed and compared, and the simulation test of electrochemical corrosion of insulator steel feet is carried out by water jet method. The experimental results show that the experimental environment simulated by water jet method is close to the real environment. And the three suspension modes of insulators in the actual operation, the most serious corrosion of the V type suspension hardware, followed by the tension string suspension, and the linear string corrosion rate is the slowest.

1. Introduction
Our land is vast. The reserves of natural resources and energy consumption in the eastern and western regions are uneven. With the advantages of long distance transmission, large transmission capacity, low transmission environment and low comprehensive cost, UHVDC has effectively solved this contradiction in our country. However, part of the DC transmission line in the running section of the natural environment is relatively humid, large rainfall. In recent years China's haze increasing, insulator fittings along with easy water, dirt form electrolyte, in the action of an external DC voltage, forming a conductive loop, local corrosion phenomenon.

The corrosion of insulators has occurred in most of the transmission lines, and their harm can cause the mechanical and electrical performance of insulators to decline in different degrees. The decline of mechanical and electrical performance is likely to cause serious transmission accidents such as flashover or broken string, thus threatening the safe and stable operation of power system.

Therefore, the electrochemical corrosion mechanism of the steel foot of insulator is studied, and the main factors affecting the electrochemical corrosion of insulator are obtained based on the experimental data. It is very important to study the restraining measures of insulator corrosion and prolong the service life of insulators. In view of the electrochemical corrosion of insulators, a sacrificial anode cathodic protection method is adopted to slow down the corrosion of steel materials. The sacrificial electrode is made of pure zinc sheath. The scheme can inhibit the corrosion caused by the electrochemical principle, but the volume expansion of the corrosion product will cause the porcelain parts of insulators to crack.

American scholars put forward a kind of anticorrosive cover improvement measures. This method can effectively reduce the expansion of the corrosion product caused by the expansion of the corrosion products, but the project is difficult to implement and is not conducive to promotion. Soviet scholars proposed a method for improving the structure of steel feet. The steel foot at the joint of the cement and air is

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improved into the shape of the boss. The relevant tests conducted by the domestic researchers show that the convex platform of the Soviet scholars is replaced by pure zinc sheath, and this combination structure has a good inhibitory effect on the electrochemical corrosion of insulators in the current running insulators in China. At present, the technical requirements for insulator protection, zinc ring and zinc sleeve are also different at home and abroad. In this paper, based on the electrochemical corrosion of the steel foot of insulator, the simulation experiment scheme is summarized and the main factors affecting the electrochemical corrosion of steel foot are put forward.

2. Electrochemical corrosion mechanism of steel foot
The mechanism of DC electrochemical corrosion is shown in figure 1.1. The applied DC power supply, the positive and negative metal electrode and the electrolytic solution together form the conductive circuit of the three. The anode connected to the applied power source is an anode. Under the action of the DC electromotive force, the anode is oxidized and loses electrons, and the cation is formed from the surface of the metal material, which is anodic corrosion.

![Figure 1. Schematic Diagram of Direct Current Electrolysis](image1)

An analogy to the process of electrochemical corrosion of insulators is shown in figure 1.2. When the porcelain surface is moist and the contaminants dissolve in the water and form the flow path of the leakage current, the metal at the anode will undergo an oxidation reaction, losing electrons and forming a positive valence cation.

\[
Fe \rightarrow Fe^{2+} + 2e^- \quad (1)
\]

While the cathode metal will get electrons, the reduction reaction, the formation of anions.

\[
O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad (2)
\]

Anions and cations combine in electrolyte solutions to produce hydrogen and oxygen compounds that are not soluble in water.

\[
Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2 \downarrow \quad (3)
\]

And the hydrogen and oxygen compounds will be further oxidized under the action of water and oxygen.
4Fe(OH)$_2$ + O$_2$ + 2H$_2$O → 4Fe(OH)$_3$    (4)

If at different temperatures, different humidity, different PH conditions, as well as different oxygen content and other conditions, you can get different elements of the proportion of hydrogen oxidation and substance, so you can rust composition as follows:

\[ m\text{FeO} + n\text{Fe}_2\text{O}_3 + pH_2\text{O} \]  

The m, n, and p here represent the proportions of the elements in the compound, and their values vary with the conditions[1].

In the DC transmission line, the insulator on the positive side is prone to corrosion of the steel foot. The utility model is mainly provided with an insulator positioned on the positive side, and a transmission line is connected on one side of the steel foot. Therefore, the steel foot side belongs to the high potential side relative to the cap. When the rain or moisture insulator, insulator surface contamination in water soluble form electrolyte environment, and steel feet and were served as iron anode and cathode, together constitute the conditions of electrolytic cell. As an anode, the steel foot oxidizes, loses electrons, forms two valent iron ions, dissolves in the electrolyte, and combines with anions to form hydrogen and oxygen compounds. At the same time, the electrolyte on the metal surface flows through the leakage current, the corrosion rate and the leakage current density in the anode region (i.e., the current on the metal unit area I). The current flowing through the insulator surface can cause electrochemical corrosion of the metal parts. The main influence is as follows: the steel foot loses the electron, forms the ion, causes the steel foot to dissolve unceasingly, and the mechanical strength of the insulator reduces. In the vicinity of the steel feet inside the porcelain, if the accumulation of hydrogen and oxygen compounds, it will lead to volume expansion, and will cause the insulator porcelain to crack when it is serious[2].

3. Simulation test method for electrolytic corrosion of insulators

The simulation test methods of electrolytic corrosion of insulators are mainly divided into two major categories. One is the long time field simulation method. The other is to build the accelerated simulation method of test platform, including salt spray method, electrolytic tank method, solid soil layer method, spray method, etc.:

3.1 Field Simulation Method

Field simulation is a new insulator placed in the outdoor environment, exposed to outdoor insulators, long-term exposure to heavy industrial waste gases and coal, gas and other corrosive gases erosion. The voltage applied to the insulator string is 44kv, and the corrosion data of the fittings are recorded regularly by the experimental personnel. The field test proves the effect of the polarity of the voltage on the corrosion of the steel foot.

3.2 Salt Fog Method

Salt mist method is a certain concentration of NaCl solution through high-pressure electric spray gun form fog particles, sprayed on the clean surface of the insulator. As a result of high pressure, the fog particles will form a conductive film directly on the surface of the insulator to produce a certain leakage current. The test will clean insulators hanging in the fog chamber, gossan ground, steel pin is connected with a power supply cathode. The researchers used high-pressure electric spray guns, pre spraying salt fog of about 5 to 6min. When the visibility of fog chamber is less than 0.3m, 7 ~ 10kV DC voltage is applied to the insulator. The leakage current through the insulator surface is about 60 ~ 80mA. The conductivity of the salt fog solution is 17.6mS/cm, and the current fluctuates greatly. Salt spray test can be carried out continuously, and no other follow-up operation is needed during the test. When salt spray test is carried out abroad, the insulator is placed in the airtight box with relative humidity of more than 95%, and the sulfide gas is used to corrode, so as to simulate the corrosion of fossil fuel burning area.

3.3 Electrolytic Bath Method
The electrolytic bath is the process of filling the electrolyte into the electrolyte, which is a common solution, such as Nacl. Then, the metal parts which need to be tested are placed in the electrobath, and the test DC power supply is tested. In order to ensure that electrolytic corrosion occurs only at the corrosion site of the hardware, the corrosion free parts of the fittings shall be sealed with waterproof materials such as sealant. For example, in the simulation test of steel foot corrosion, the wire and the steel foot should be sealed to ensure that the corrosion shape is similar to the corrosion situation at the site, and only the annular area at the junction of the steel foot and the cement can be exposed. In order to achieve the purpose of quantitative corrosion simulation experiment, the electrolysis current should be monitored in real time, and the accumulated amount of corrosion charge in the electrolytic circuit is calculated. The sample preparation method of electrolysis process is complicated, especially the gossan corrosion, sealing area is large, the sample is ready.

3.4 Solid waste layer method
Solid waste layer method is one of the most popular test methods for electrolytic corrosion of steel feet. Similar to the pollution flashover test, a layer of salt and insoluble material is coated on the surface of the cleaned insulator. When it is dry, it is damp in the fog chamber. And test the DC voltage to do the electrolytic corrosion test. The fog chamber and power supply condition are the same as the salt fog method. The suspension composition is as follows: 250g diatomite, 1000g tap water, a certain amount of Nacl. Surface average contaminant density 3mg/cm^2. The test is carried out in a 220mm×220mm×260mm container. The filter paper is placed in the container, the bottom is water, the filter paper is kept moist, and the humidity inside the container is close to 100%. Dalian electric porcelain factory and Chinese EPRI experts in the test by solid pollution method, the leakage current is maintained at 80mA, and to mark steel foot protection zinc sleeve exposed part is etched off half the zinc sleeve end of life. Some researchers on the adhesion of different components of pollution layer were studied, pointed out that the first grade product with hot tap water plus bone paste lovastatin is heated to 90℃ with a glass rod to stir, then add the right amount of formaldehyde additives (40% formaldehyde solution) attachment delay solution prepared has strong adhesion and long the (in insulators attached to the surface of 8 ~ 10 hours). The thickness of the sewage layer is 40~60 microns. If the porcelain surface is short with aluminum foil near the steel foot, it can solve the problem that the corrosion rate decreases due to the frequent discharge of dry zone in the area. At the same time, the adhesion time can be extended to 20~24 hours. During the test, the applied DC voltage is 10kV, and the current remains at 60±2mA.

3.5 Water Spraying Method
The method of spraying water is to hang the insulator according to the method of hanging in the field, and spray a certain concentration of Nacl solution on the corrosion of the steel foot, and form a conductive channel with the additional DC voltage. Anode corrosion occurs when the steel pin is connected to the positive electrode of the power supply. The simulation formed by the method of accelerated corrosion tests in which the electrical conductivity of solution flow rate and conductivity of the solution has a great influence on the corrosion rate, flow rate can be adjusted by the water speed, the conductivity can be calculated by the concentration of Nacl solution.

4. Comparison of accelerated simulation experiments for electrochemical corrosion of insulators
According to the existing research results, compare the advantages and disadvantages of the above five experimental methods:
1) The scene simulation method is a method of simulation experiment results in all the most close to the actual situation, but the duration is too long, unable to obtain experimental data in a short period of time, so it is not suitable to be used as artificial accelerated corrosion test methods.
2) Salt fog has the advantages of large corrosion current, long experimental duration and small amount of labor. It is a practical and convenient simulation experiment method. It is also suitable for the artificial accelerated corrosion of the steel foot of insulators, especially for the simulation experiment of the DC suspension steel foot corrosion. However, in the experiment, we should pay
attention to limit the flashover of insulators, and prevent the salt fog corrosion of the test equipment and flashover of the wall through the fog chamber. In addition, salt spray test should pay attention to salt mist particles for high pressure nozzle corrosion and blockage.

3) The electrolytic cell method is a simple and easy to operate accelerated corrosion simulation method, which is suitable for studying the corrosion of steel feet separately. But for other complex suspension insulator, its preparation process is complicated, especially the gossan corrosion, sealing area is large, the sample is ready. For the steel foot corrosion test, the corrosion area is mainly at the exposed part of the steel foot and cement, and the corrosion shape is close to a circle shape. There is a certain difference between the simulation result and the actual corrosion condition of the insulators, so it is not suitable for use.

4) The method of solid waste layer can be applied to the electrochemical corrosion test of steel foot of insulator. However, if a stable leakage current is to be obtained, the coating material and coating process must be highly technically required. Coated and dirt layer workload, must enter into the spray chamber repeatedly remove repeated smear samples. Not only the work is tedious, but also the repeated operation is also easy to have the error influence to the experiment, therefore also does not apply to the insulator steel foot corrosion simulation experiment.

5) Compared with the previous four simulation methods, the water jet test has lower requirements for the test equipment, and the test platform is easy to build. The test is easy, simple and easy to prepare. Moreover, the simulated test results are in good agreement with the field operation, so the water jet method is suitable for studying the accelerated corrosion test of the electrochemical corrosion of the steel foot of insulator.

5. The accelerated simulation experiment of electrochemical corrosion of insulators is carried out by water jet method

Set up the following experimental platform for simulation experiments:

![Experimental Platform of Spray Irrigation](image)

Figure 3. Experimental Platform of Spray Irrigation

In order to compare the effect of three kinds of suspension methods on the electrochemical corrosion of steel foot in practical operation, 3 new ceramic insulators were selected in the experimental group. Wherein, the plane and the horizontal plane of the 3 insulators form parallel, 45 and 90 angles respectively, and simulate the running conditions of the linear string, the V string and the strain string, and the numbers are 1#, 2# and 3# respectively. The leakage charge of each of the three insulators was recorded at intervals of one hour. The three insulators were removed at 20 hours, and the data were plotted as follows:
As a result, the corrosion rate of the steel foot is the fastest in the V shape suspension mode, followed by the stress absorption string suspension mode, and the linear string corrosion rate is the slowest in the actual operation.

Select one of the V insulators suspended from the actual running line 4#. The service life of the insulator is 5.5 years, and the running time of the insulator 2# is equivalent to that of the leakage charge amount in this simulation test, and the corrosion situation of the two is contrasted.

Through preliminary observation, we can get the corrosion test sample under the accelerated simulation of water jet method. The corrosion state is more serious than that in the field. This and we select the worst case average leakage charge as the benchmark consistent, corrosion area and similar shape, showed that spraying under laboratory conditions accelerated corrosion test and field operation of corrosion equivalent better.

6. Conclusion
From the experimental results and analysis, we can draw the following conclusions: the main reason for the electrochemical corrosion of the steel foot is that the insulator surface is polluted, and the electrolyte environment is formed in the humid environment. And steel foot and gossan exists between the potential difference between the steel pin connected to the positive potential of oxidation reaction. Compared with several simulation experiments, the simulation experiment with water jet method is most feasible, and the simulated experimental environment is in line with the actual environment. In the actual operation process, the three kinds of suspension modes of insulators, V type suspension of the most serious corrosion of metal fittings, tensile string suspension mode followed, linear string corrosion rate is the slowest.

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