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Corrosion Mechanism and Corrosion State Detection Method of the Grounding Grid

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Abstract. Corrosion of grounding grids can affect the safe and reliable operation of power systems. In view of the corrosion problem of the grounding grid, this paper introduces the corrosion mechanism, which is chemical corrosion and electrochemical corrosion respectively. Then, three common grounding grid corrosion detection methods, such as electric network analysis method, electromagnetic field detection method and electrochemical method, are introduced. On this basis, the advantages and disadvantages of three methods are compared. Further prospects for the corrosion detection technology of the grounding grid are pointed out.

1. Introduction

The grounding grid is a concealed project. It integrates functions such as working grounding, protective grounding and lightning protection grounding. It plays a vital role in the reliable operation of the power system and the personal safety of the staff. However, since the grounding grid is in the underground environment for a long time, the chemical and electrochemical corrosion of the soil is unavoidable, and the corrosion of the stray current causes the cross section of the grounding body to be reduced, the thermal stability is insufficient, and the electrical performance is deteriorated. When a short-circuit fault occurs in the system or is struck by lightning, it may cause accidents such as burnout of the grounding grid, increase of ground potential, and high-voltage intrusion into the secondary circuit, which may bring huge economic losses and adverse social impacts to power companies and even the country.

Grounding grid status detection is a necessary means to discover its safety hazards and ensure its safe operation. For a long time, grounding grid detection has received great attention in the field of electrical engineering. With the development of metal corrosion detection technology and the further study of the corrosion mechanism of metals in soil, the researchers found that it is not enough to simply evaluate the grounding grid state by measuring the electrical performance parameters such as grounding resistance. Therefore, corrosion detection is gradually incorporated into grounding grid detection. At present, some phased achievements have been made in the corrosion detection of grounding grids at home and abroad. However, for many reasons, most of these results remain in the theoretical research and experimental stage, and there is still a certain distance from the actual requirements of the project, which still needs to be improved.



With the development of the power grid to high voltage and large capacity, especially the implementation of extreme high voltage projects, the requirements for safe operation of the grounding grid will become more and more strict, and the importance of corrosion detection of the grounding grid will become more prominent.

In this paper, the corrosion mechanism of the grounding grid is introduced, and three detection methods of corrosion state of the grounding grids are described. Finally, according to the status quo, suggestions and prospects for the corrosion detection technology of grounding grid are put forward.

2. Corrosion mechanism

The grounding grid will be affected by substances such as air, moisture and salt in the soil, causing chemical or electrochemical corrosion reactions.

2.1. Chemical corrosion

Chemical corrosion refers to the damage caused by the chemical interaction between the metal surface and the non-electrolyte. The reaction process is characterized by the direct oxidation-reduction reaction between the atoms on the metal surface and the oxidant in the non-electrolyte to form a corrosion product[1]. The transfer of electrons during the etching process is carried out directly between the metal and the oxidant, so that no current is generated. For grounding grids, this corrosion effect is small.

2.2. Electrochemical corrosion

Electrochemical corrosion refers to the damage caused by the electrochemical reaction between the metal surface and the electrolyte. Any corrosion reaction by an electrochemical mechanism includes at least one anode reaction and one cathode reaction, and a circuit is formed by the electron current and the ion current[2]. The anodic reaction is an oxidation process in which metal ions are transferred from the metal to the medium and emit electrons; the cathode reaction is a reduction process in which the oxidant component in the medium absorbs the electron process from the anode.

Unlike chemical corrosion, electrochemical corrosion is characterized by two relatively independent processes that can be performed simultaneously. Since there are spatially or temporally separated anode and cathode regions on the surface of the corroded metal, electrons can flow from the anode region to the cathode region through the metal during the corrosion reaction, with the result that current is generated.

The corrosion of the grounding grid in the soil is generally electrochemical corrosion, including micro-cell corrosion, macro-cell corrosion, corrosion caused by stray currents, and corrosion caused by microorganisms.

3. Corrosion state detection method of grounding grid

Corrosion state detection refers to the detection of the corrosion rate of the grounding grid. It is used to judge the corrosion degree of the grounding grid and provide effective guidance for the corrosion protection.

Up to now, there are three main methods for the corrosion detection of grounding grids, such as electric network analysis[3], electromagnetic field detection[4] and electrochemical methods[5].

3.1. Electrical Network Analysis

The research on electrical network analysis began at the end of the last century. This type of method mainly applies the analog circuit fault diagnosis theory and its algorithm to the corrosion of the grounding grid and its breakpoint diagnosis. The grounding grid is equivalent to a purely resistive network, as shown in Figure 1. When detecting, the grounding grid is injected with current, and the resistance value of the relevant measurable points is calculated[6]. The corrosion degree and breakpoint of the grounding grid are judged by simulation model and corresponding analog circuit fault diagnosis algorithm.

This method needs to know the topology of the grounding grid and need to detect the resistance of multiple terminals. Although there have been a lot of improvements in numerical simulation algorithms and the number of grounding resistance detection ports, Liu Yugen proposed a method for selecting pairs of measurement nodes in corrosion diagnosis[7], based on the diagnosis method of Trelle's theorem and the sensitivity analysis method, which reduced the workload of the method in engineering applications. However, the fault diagnosis equation based on the analog circuit fault diagnosis theory is an underdetermined equation. How to effectively solve the underdetermined equation is a problem to be discussed. Based on the fault diagnosis theory and the Telegen's theorem, the paper established the underdetermined fault diagnosis equation of the grounding grid, and solved the underdetermined problem of the equations to some extent by using the optimization method[8]. However, there have not been any practical analog circuit diagnostic methods and test software in the world.

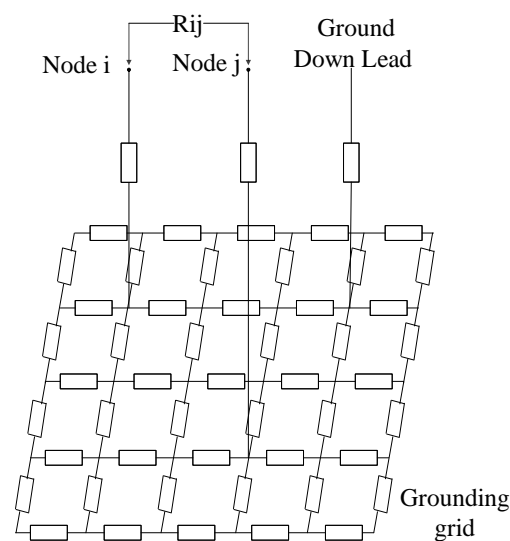


Figure 1. equivalent electrical network diagram of grounding grid.

Especially for the grounding grid with complex geometrical properties and large scale, the practicality of the corrosion detection method for grounding grids based on electrical network analysis needs to be discussed.

3.2. Electromagnetic field detection method

In 1986, Canadian scholar F. Dawalibi calculated and analyzed the electric field and magnetic field of the grounding grid, and firstly explored a defect diagnosis method of the grounding grid based on electromagnetic field theory[9].

The electromagnetic field detection method is to diagnose the severe corrosion section or fracture point by measuring the ground electric field and magnetic field distribution of the grounding grid and combining simulation. The specific process is shown in Figure 2. It injects a large inter-frequency excitation current into the grounding grid to form a magnetic field on the surface. If the grounding body is severely corroded or broken, the surface magnetic field will produce obvious anomalies. The detection coil is used to detect the electromagnetic induction intensity at this time, and the corrosion calculation or the fracture condition of the grounding grid is judged according to the simulation calculation result under normal conditions.

In [10], the paper analyzed the influence of soil structure on the surface magnetic induction intensity based on the finite element method, then directly applied the excitation current to the substation grounding grid, and diagnosed the grounding grid conductor breakpoint fault according to the distribution characteristics and variation law of the magnetic induction intensity. Research institutes such as North China Electric Power University have also made unremitting explorations and

developed a corrosion diagnosis magnetic field detection system for grounding grids[11]. This method can perform corrosion detection of the grounding grid without knowing the topology, and has also been used in practice.

However, due to the influence of natural grounding bodies such as underground metal frames, even if the grounding grid does not corrode, its surface magnetic field may deviate or be significantly different from its simulation results, which may cause difficulties in diagnosis. At the same time, there are many interference factors at the grounding grid site, which are uncertain and will directly affect the accuracy of the measurement results.

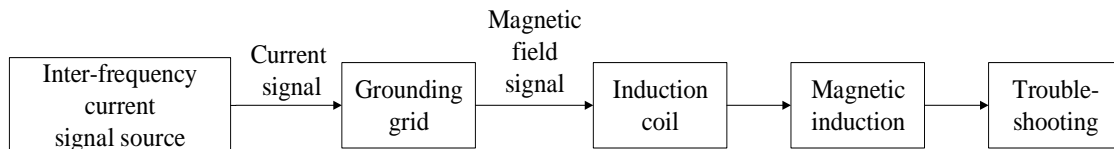


Figure 2.Flow chart of electromagnetic field detection method.

3.3. Electrochemical method

With the development of metal corrosion detection technology and the further study on the corrosion mechanism of metals in soil, electrochemical corrosion detection is gradually applied to the detection of grounding grids.

Electrochemical method is the most effective means to detect the corrosion state of grounding grid. According to the electrochemical corrosion mechanism of grounding grid material in soil, such method uses corrosion electrochemical detection technology and related algorithms to obtain various electrochemical parameters, calculate corrosion state parameters such as corrosion rate and corrosion depth of the grounding grid.

Electrochemical methods generally require a disc or column probe with a reference electrode and an auxiliary electrode. The electrochemical probe is fixed on the surface of the grounding net, and the grounding net is used as the research electrode, and the upper line is taken as the electrical connection point, and the linear change potential signal is applied to the grounding net material of the detected position. The polarization resistance is calculated by linearly changing the polarization current with the polarization overpotential, thereby calculating the corrosion rate and the corrosion depth.

However, if the grounding grid conductor is used as the research electrode, a certain amount of grounding conductor of the detection quantity is not a separate electrode, but is connected to the entire grounding grid conductor, so the polarization current applied to the grounding conductor through the auxiliary electrode is not limited to the conductor to be measured, which causes the polarization current to be unevenly distributed on the surface of the ground grid, and the area of the polarized conductor is difficult to measure. A large error is introduced in the calculation of the corrosion current density, which greatly reduces the measurement accuracy of the corrosion rate.

In order to avoid this problem and improve the measurement accuracy of the grounding grid corrosion rate, it is necessary to use a current confinement method to limit the distribution range of the polarization current, or a sensor can be used to simulate the corrosion of the grounding grid conductor.

By using a small-pore current limiting electrochemical sensor, the polarization current of the metal electrochemical test of the grounding grid can be limited. This method has achieved good application results in the detection of some substations[12]. In the corrosion detection project of a substation in Shanxi, Wang Tianyuan et al. used the guard ring electrode current confinement technology and the electrochemical impedance on-line monitoring system to control the polarization area of the ground grid under the auxiliary electrode projection surface[13].

Hunan University has studied the corrosion detection method of grounding grid based on corrosion electrochemical detection technology, and designed a sensor based on three-electrode measurement system, which consists of research electrode, auxiliary electrode and reference electrode, as shown in Figure 3. The research electrode material is the same as the grounding grid conductor material. The fuzzy optimization method is used to determine the number of sensors and the installation position.

The electrochemical parameters of various types are obtained through steady-state measurement analysis, the corrosion rate and corrosion depth of the ground network are calculated, and the corresponding measuring equipment is developed[14].

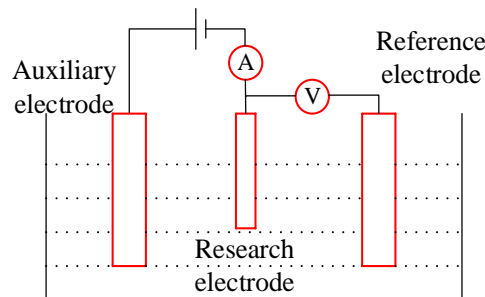


Figure 3. Schematic diagram of the three-electrode sensor.

In general, some phased results have been achieved in the corrosion detection of grounding grids. Comparing three detection methods, as shown in Table 1, the electrochemical method is more suitable for studying the corrosion mechanism of the grounding grid than the electric network analysis method and the electromagnetic field analysis method. However, the corrosion detection of the grounding grid based on electrochemical technology needs further research on the design of sensors, anti-interference technology in the field, and the development of corrosion detection systems.

Table 1. Comparison of three detection methods.

Method	Applicable conditions	Limitations
Electrical Network Analysis	Need to know the topology of the grounding grid	Practicality of analog circuit diagnostic theory
Electromagnetic field detection method	No need to know the topology of the grounding grid	Test field magnetic field detection accuracy
Electrochemical method	Metal corrosion detection	Sensor design

4. Conclusion

With the development of modern power grids to ultra-high voltage, large capacity and long-distance, the requirements for safe and stable operation of power systems are also increasing, and the detection of corrosion status of grounding grids will become more and more important.

The three detection methods mentioned in this paper can quantitatively evaluate the corrosion degree of the grounding grid to a certain extent, but the corrosion point cannot be accurately located. If the conductor is corroded and thinned, it is impossible to know when the conductor no longer satisfies the scattering requirement. With the in-depth development of the state-of-the-art maintenance work of the power grid equipment, it is necessary to have an effective technical means for locating the grounding device continuity defects, and further predict the corrosion of the grounding grid.

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