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Study on the Influence of the Grounding AC Current on the Protection of Sacrificial Anode in Galvanized Steel Grounding Grid

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Abstract:

In this study, the test device is designed and developed for simulating the effect of sacrificial anodic protection on the grounding electrode material that is subjected to the interference of high-frequency AC current in the power transmission and transformation system. The results show that Mg alloy sacrificial anode showed limited protection at the high current density of the grounding AC current in the grounding grid.

Keywords: *Ground connection, Corrosion, Cathodic protection.*

I. INTRODUCTION

Grounding facilities are an important technical approach in the high-voltage power transmission and transformation system for ensuring stable and reliable operation of electrical equipment and life safety [1]. It can be monitored during power utilization for maintaining personnel and equipment safety in order to facilitate a cathodic protection system. So far, extensive development has been carrying out in the supply of high-voltage power transmission to the various regions i.e. all over China. In 1972, 330 kV power transmission line was installed in China [2], and 500 kV electric transmission lines had established in 1981. Nowadays, the ultra-high-voltage power system of 500 kV electric transmission lines serves as the backbone in China. The total stretched power transmission lines in China have been increased from 1,150,000 km to 1,590,000 km since 2010.

The grounding electrode in the power transmission and transformation domain has been a critical concern for safe and stable power operation. Since the grounding metals are buried in soil for a long time so that corrosion is an inevitable phenomenon [3], which can lead to sectional loss of grounding conductors [4]. The too-small conductor section cannot bear high-amplitude lightning current and fault current, which can result in the breakage of grounded metal electrode and failure of the cathodic protection system. Meanwhile, the corrosion of the grounding materials increases the grounding resistance and reduces the grounding performance. When the lightning current or the fault current strikes at the grounding facilities, the electric transmission lines either get tripped or fluctuates during operation. On the other hand, the earth's potential gradient possesses a serious threat to the life safety of personnel around the electric lines. According to investigation statistics, many vicious incidents can be induced by grounding fault because of corroded metal, thereby causing huge economic and social losses. Despite small proportion of the total investment of the power transmission and transformation system is spared on grounding facilities, the induced accidents can be a tremendous loss. Apparently, grounding electrode has become a necessity to facilitate the safety of power transmission and transformation grid and plays an important role in maintaining the safe and stable operation of the power grid [5].

II. SACRIFICIAL ANODIC PROTECTION FOR GROUNDING GRID IN POWER TRANSMISSION AND TRANSFORMATION DOMAIN

In order to prevent the corrosion of grounding materials and reduce the corrosion rate, some applicable measures such as increasing the sectional area of the grounding connector, conductive coating, and cathodic protection system have been used. Among all, the sacrificial anode can be regarded as an effective method for the protection of the grounding grid [6]. However, the recent research results showed that the sacrificial anodic protection cannot perform as well as expected or even achieve limited effect in the existence of a grounding power circuit. Fig 1, 2, and 3 demonstrate the corrosion of grounding electrodes in a 66 kV transformer substation in Dalian, Liaoning, China. Fig 4 shows the corroded morphology of a grounding electrode in this substation. Despite the application of sacrificial anodic protection, the grounding electrode in the transformer substation can be seriously corroded. Moreover, the grounding electrodes in the same grounding grid exhibited a significantly different corrosion rate.

Fig 1: The corrosion of the grounding electrode beneath the main transformer

Fig 2: The sacrificial anode in the grounding grid.

Fig 3: The corroded grounding electrode outside the grounding grid.

Fig 4: Corroded surface morphology of the grounding electrode underneath the main transformer.

The current density of the grounding electrode below the main transformer into the earth's crust has high density than the current at other places. Despite sacrificial anodic protection, the corrosion rate of the grounding electrode beneath the main transformer far exceeds the counterpart of other places. Therefore, this study performed simulations for analyzing the effects of alternating current (AC) on the sacrificial anodic protection.

III. EXPERIMENTAL METHOD INVESTIGATION OF THE EFFECT OF AC ON SACRIFICIAL ANODE VIA LABORATORY SIMULATION

3.1 Setup for Environmental Parameters in Laboratory

In this study, a rectangular plastic box with a length of 600 mm, a width of 500 mm, and a height of 500 mm was selected to simulate the soil environmental within a container. The uncovered box was filled with the simulated soil electrolyte. The simulated soil water solution was used in the device for simulating soil, which can provide a stable and uniform electrolyte environment for the simulation device. The simulated soil water solution was similar to real soil in terms of electrolyte properties but devoid of the complex physical structure and multi-phase system of the real soil. Owing to simple properties, the simulated soil water solution shows a slight effect on electrochemical and electrical testing results. Table I lists the components of the simulated soil water solution.

Table I. Components in the simulation soil water solution

Component	Concentration (%)
$NaHCO_3$	0.02
NaCl	0.03
Na_2SO_4	0.04

The specimens in this study were made up of carbon steel with an identical size of 20×20×2 mm. The specimen has opened on one end and connected with the conductive wires via screw and nut. The connecting part and the corner and back section of the specimen were all sealed by high-density paraffin so as to be conveniently disassembled for further analysis. The exposure area of each specimen was 1 mm^2. The magnesium (Mg) alloy sacrificial anode was used in the soil during the procedure. The specimen was connected with the sacrificial anode of identical size. Fig 5 shows the circuit in the present simulation. The two symmetrical/opposite graphite electrodes were set on both sides of the soil test tank. The AC voltage regulator, being connected to the graphite electrode, was used for generating high-frequency AC current in the media in the test tank with the input high-frequency AC current. The test circuit device consisted of the carbon steel specimen, and the sacrificial anode was placed in the middle of the test tank. The carbon steel specimen was connected with the sacrificial anode by cables, and a standard resistor with a resistance of 0.1 Ω was connected to the circuit in series. The cathodic protection DC circuit composed of the test medium and the standard resistor was driven by the potential difference (PD) between the sacrificial anode and the carbon steel specimen. The AC circuit consisted of the specimen, conductive wires, standard resistor, and sacrificial anode. Both DC and AC currents passed through the wires can be calculated by the AC and DC potential differences through the standard test resistor. Since both conductive wire and standard resistor were possessed quite low resistance, the current in the metal circuit (circuit composed by sacrificial anode, conductive wire, resistor, and specimen) was the AC circuit current, which is corresponding to AC current passing through the specimen and surface of the sacrificial anode.

The AC/DC potentials on the specimen and the sacrificial anode can be obtained by the surrounding … Different AC current intensities in the AC circuit can be obtained by adjusting the AC voltage output on the AC regulator or the distance between the specimen and sacrificial anode.

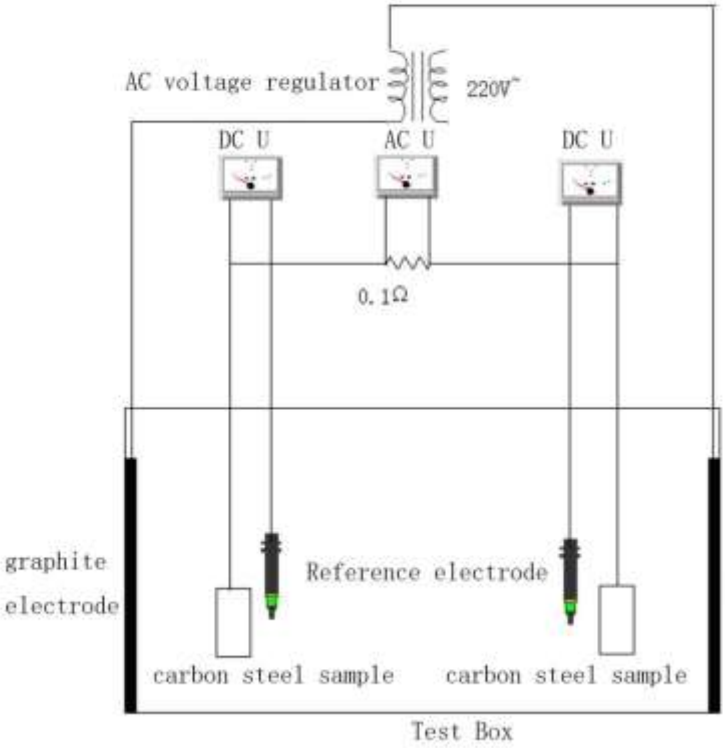

Fig 5: Illustration of the simulation circuit consists of AC regulator

3.2 Variation in the Potential Difference between the Specimen and Sacrificial Anode under the Interference of High Current Density

Fig 6 and 7 are the variation curves of the DC potentials on the specimen and sacrificial anode under different current densities. Under the interference of AC current, Mg alloy sacrificial anode showed different responses to AC current i.e. positive deviation was observed at the AC potential of the sacrificial anode. At 20A/m^2 current density, the positive deviation rate of the anode was low, though at an AC current density of 20~80 A/m^2, the slope of the positive deviation of the DC potential increased drastically. Notably, at the current density of over 80 A/m^2, the positive deviation rate changed slowly and showed three different response phases to AC current. It is generally acknowledged by the rectification characteristics between the Mg alloy sacrificial anode matrix and the corrosive product (membrane). Due to the high electrochemical activity of Mg, some corrosive products always appear on the surface under natural conditions. Corrosion electrochemical properties of Mg heavily depend on the properties of this layer of surface membrane. Within the test range, the DC potential of Mg alloy sacrificial anode dropped by 200 mV. The DC potential of the carbon steel specimen under the protection showed a positive deviation of over 500 mV. As the AC current density increased, the potential of the carbon steel specimen showed a positive deviation, meanwhile, the driving potential of Mg alloy sacrificial anode to the specimen is dropped gradually. Therefore, the specimen underwent a positive deviation from the protected state to the protective potential, and the protective potential showed a positive deviation from -1.25 V to -0.68 V. The sacrificial anode showed complete failure in cathodic protection.

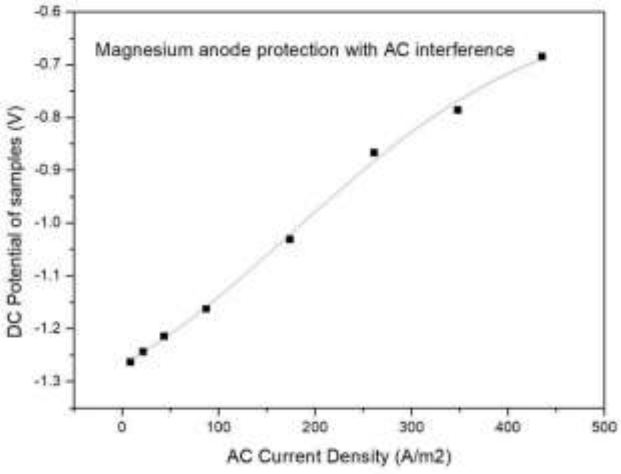

Fig 6: Variation of the DC potential on the specimen with respect to AC current density.

DC potential on the specimen and Mg anodic protection under AC interference

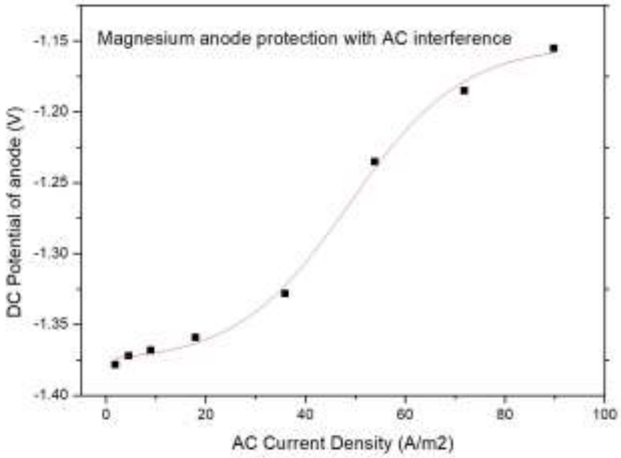

Fig 7: Variation of the DC potential on the sacrificial anode with respect to AC current density.

IV. CONCLUSIONS

In summary, under the action of a high-frequency AC current, the driving potential of the sacrificial anode at the grounding electrode is dropped, thereby leading to inadequate protection of the sacrificial anode. At the high current density in the grounding grid of the power transmission and transformation system, the Mg alloy sacrificial anode of the grounding grid cannot be sufficient to prevent the ground electrode.

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