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Causes, Forms and Remedies of Substation Grounding Grid Corrosion

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Abstract- **The information in this paper includes the basic corrosion theory and forms of substation grounding grid corrosion. In order to investigate the corrosion in substation grounding grid and acquire corrosion data to give a guide for steel grounding grid's design, 21 grounding grids of substations distributed in different areas of Foshan were excavated to test corrosion rates of grounding conductors. Corrosion data show that corrosion in grounding down leads and grounding conductors in cable trenches are more serious than in the main grounding grid. Corrosive factors in the substation soil samples were measured on the spots and in the lab, and the data were analyzed using the principal component analysis method for statistics. The result demonstrated that soil resistivity, pH value, water content and soluble salts content were the key factors in substation grounding grid corrosion. Different methods available for the protection of steel grounding grids are discussed in this paper. Allowance for corrosion should be provided for both uniform and pitting corrosion while selecting the area of the grounding conductors based upon the soil corrosion data.**

I. Introduction

Substation grounding grids are important to keep stable operation of the power system. The two primary functions of a safe grounding system are to ensure that a person who is in the vicinity of earthed facilities during a fault is not exposed to the possibility of a fatal electric shock and to provide a low impedance path to earth for currents occurring under normal and fault conditions.

Although IEEE Standard No.80-2000: "IEEE Guide for Safety in AC Substation Grounding"[1], discusses the grounding grid design procedure for AC substation with copper as the primary grid material, steel-grounding system is widely used in China and readily accepted in many other countries worldwide, where copper is very expensive. However, it is still common in this kind of grounding system for grounding faults problems to occur due to corrosion, which might result in plenty of economical loss and become a hidden danger to the safety of power system [2]. And the effect of corrosion on the reliability of electronic equipment is of growing importance as growing of the power capacity and increasing of the voltage level.

The steel grounding grid buried in earth will be eroded by the soil inevitably. Though zinc-coated (galvanized) steel has been used to control corrosion rate, the corrosion of steel grounding grids are very serious in some corrosive soil, even sometimes the conductor of grounding grid is broken due to corrosion.

Unfortunately, there is no practical design guide available for the use of steel as ground grid material. This paper presents a basic review of corrosion theory and then focuses on the factors determining corrosion rate, forms and remedies of substation ground grid corrosion.

II. Basic Electrochemistry in Corrosion Reactions

Corrosion is the exothermic chemical transformation of a metal or metal alloy to a non-reactive covalent compound such as an oxide or silicate that is often similar or even identical to the mineral from which the metals were extracted [3]. Most of the corrosion in soil is the result of an electrochemical reaction. Each galvanic corrosion cell comprises (i) anode and cathode areas on metal surface, (ii) soil electrolyte to enable occurrence of cathodic and anodic processes and current flow between anode and cathode and (iii) conducting path for the flow of current from cathode to anode as shown in Fig. 1. In the absence of any of these components, the corrosion cell would cease to operate.

III. Forms of Substation Grounding Grid Corrosion

There are a number of corrosion forms. However, for this application, four major corrosion forms (discussed below) are of importance.

A. *Uniform Corrosion*

Uniform corrosion refers to corrosion damage occurring evenly over the metal/alloy surface, and the rate of corrosion is nearly the same over the entire surface. Although uniform corrosion is the most important form of corrosion, it is relatively easily measured and predicted, making disastrous failures relatively rare [4].

B. *Pitting Corrosion*

Pitting corrosion is a form of localized corrosion that produces pits (holes) in the metal/alloy. It occurs when discrete areas of a material undergo rapid attack while the vast majority of the surface remains virtually unaffected. This is in sharp contrast to uniform corrosion in which all parts of the exposed surface recede at approximately the same rate. Pitting of a given material depends strongly upon the presence of an aggressive species in the environment.

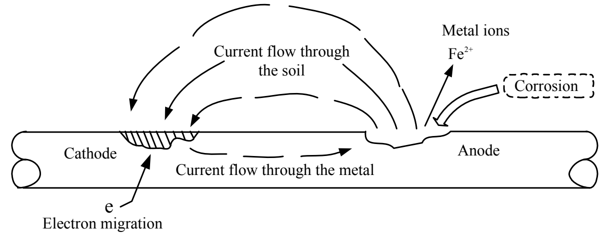


Figure 1. A basic galvanic corrosion cell

C. Galvanic Corrosion

When a difference in electric potential exists between two dissimilar metals, as an example, copper and iron, connected externally and buried in soil (Fig. 2), the electrolyte (soil) allows some current to flow and causes corrosion in steel [5]. Galvanic corrosion tends to be particularly severe if the anodic material's surface area is small compared to that of the cathode. In this case the galvanic current is concentrated on a small anodic area, resulting in rapid corrosive penetration of the anode material.

D. Microbial Influenced Corrosion

In contaminated soils, another form of corrosion called microbial influenced corrosion (MIC) can occur. The most common form is where a range of bacteria called sulphate reducing bacteria (SRB) in anaerobic environments, can react to produce hydrogen sulphide (H_2S). The acidic conditions generated can lead to rapid, localised corrosion.

Pictures of different corrosion forms in substation grounding grid are presented in Fig. 3.

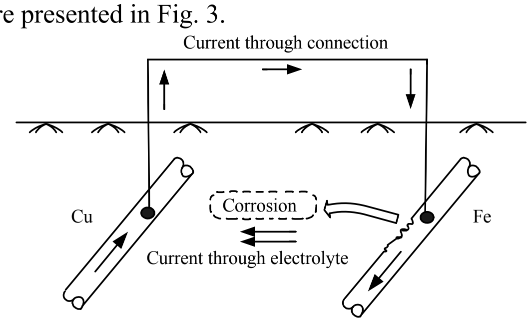


Figure 2. Galvanic corrosion

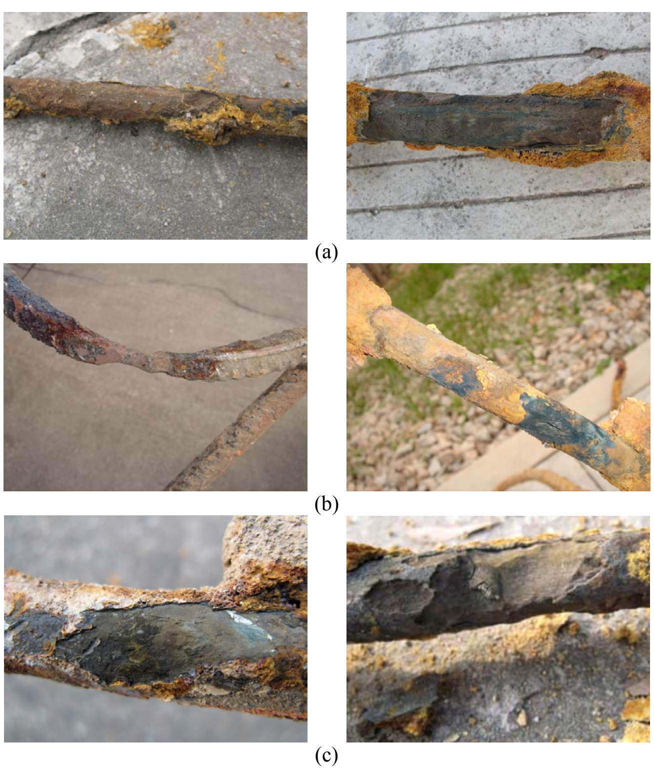


Figure 3. Corrosion forms of (a) uniform corrosion, (b) pitting corrosion and (c) microbial influenced corrosion in substation grounding grid

IV. SURVEY ON CORROSION RATE OF SUBSTATION GROUNDING GRID

In order to acquire the practical corrosion rate of substation grounding grid, 21 spot-checks by excavation were made on substations of different voltage levels distributed over Foshan area, whose operation time vary from 1 to 30 years. Corrosion data computation was done on 70 samples from main grounding conductors (buried in soil), grounding conductors in cable trench and grounding down lead. The distribution map of sampled substations is shown in Fig. 4.

The corrosion of substation grounding grid are mainly characterized by two parameters, the average corrosion rate and the maximum corrosion rate. The average corrosion rate, expressed as mm/y (millimeter per year) and calculated assuming uniform corrosion over the entire surface of the metal, accounts for the weight loss after exposure to a corrosive environment as given by (1).

$$\text{Average corrosion rate (mm/y)} = 10\cdot\Delta W/(d\cdot A\cdot t) \qquad (1)$$

Where

ΔW = weight loss in grams

d = metal density (g/cm^3)

A = area of metal (cm^2)

t = time of exposure in corrosive environment (years)

The maximum corrosion rate, expressed as mm/y too, is the corrosion rate of pitting corrosion. The maximum corrosion rate is computed by (2) and the average of the ten deepest observed pits.

$$\text{Maximum corrosion rate (mm/y)} = h/t \qquad (2)$$

Where

h = depth of the deepest hole in mm

t = time of exposure in corrosive environment (years)

Using (1) and (2), the relationship between operation time of the substations and both the average corrosion rate and maximum corrosion rate of main grounding conductors, grounding conductors in cable trench and grounding down lead in substations are presented in Fig. 5.

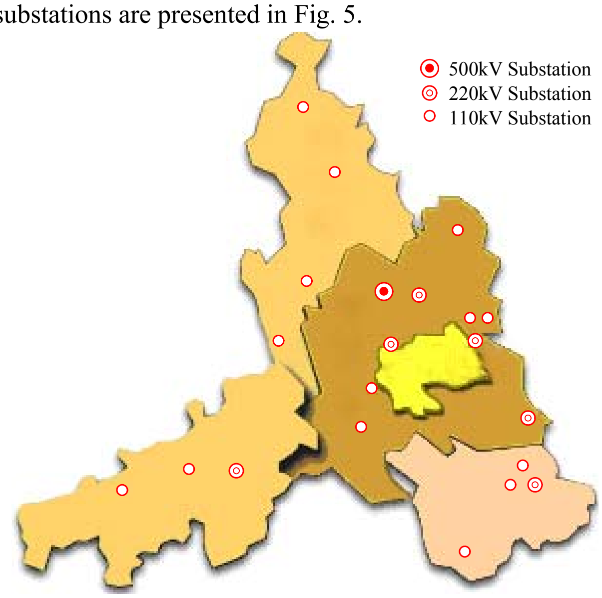
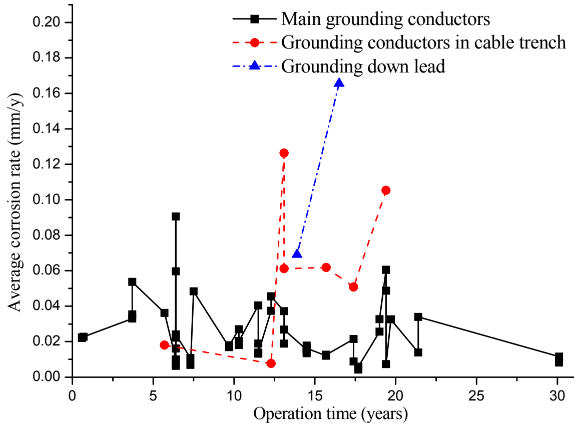
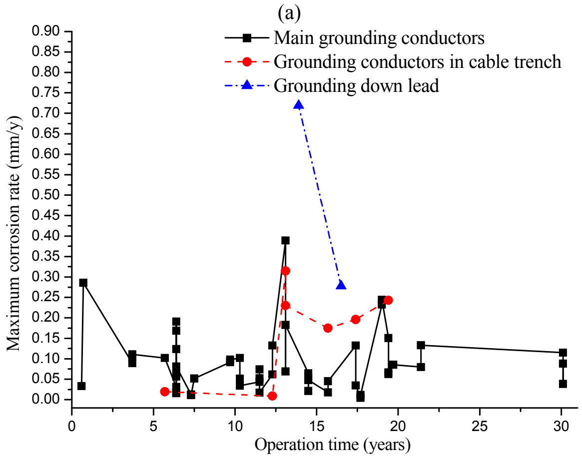


Figure 4. Distribution map of sampled substations in Foshan area



(a)



(b)

Figure 5. The relationship between the substation grounding grid corrosion and operation time for (a) average corrosion rate and (b) maximum corrosion rate

According to statistic results, the average corrosion rate of the grounding grid varies from 0.0043 mm/y to 0.0906 mm/y in main grounding conductors and from 0.0077 mm/y to 0.1263 mm/y in grounding conductors in cable trench. Usually additional anti-corrosion measures should be done to the grounding down lead in substations at the design and construction stage. But two places were found to be omitted, of which the average corrosion rate is respectively 0.0691mm/y and 0.1656 mm/y. As can be seen from Fig. 3, the uniform corrosion of grounding conductors in cable trench is generally more serious than the main grounding conductors. And the corrosion of grounding down lead without any anti-corrosion measures is the most serious of all.

The maximum corrosion rate is several times as large as the average corrosion rate. In main grounding grid, the maximum corrosion rate of the steel grounding conductors varies from 0.0045 mm/y to 0.3893 mm/y. And in cable trench it varies from 0.0089 mm/y to 0.3145. The maximum corrosion rate of the two grounding down lead is respectively 0.71942 mm/y and 0.27758 mm/y. It can be found that there in no too much difference in pitting corrosion between main grounding conductors and grounding conductors in cable trench.

The relationship between corrosion rate and the operation time of the substations hasn't been found.

V. Factors Affecting the Corrosion Rate

Corrosive factors in the soil samples including soil resistivity, water content, aeration, bulk density, pH value, electric conductivity, soluble salts content, redox potential, grid-to-earth potential, Cl^-, SO_4^{2-} and so on were measured on the spots and in the lab. The data were analysed using the principal component analysis method for statistics. Results demonstrated that soil resistivity, pH value, water content, soluble salts content were the key factors in substation grounding grid corrosion.

A. Soil Resistivity

Soil resistivity has historically been used as an indicator of soil corrosion [6-7]. Because soil resistivity governs the effectiveness of the ionic current pathway, it has a strong influence on the rate of corrosion, particularly where macro-corrosion cells are developed on larger steel grounding grids. Corrosion increases as resistivity decreases. However, if resistivity is high, localized ratherthan general corrosion may occur. Soil resistivity is by no means the only parameter affecting substation grounding grid corrosion. The relationship between soil resistivity and corrosion rate of substation grounding grid is illustrated in Fig. 6. It can be seen that a high soil resistivity alone will not guarantee absence of serious corrosion.

B. pH value

Soils usually have a pH range of 5-8. More acidic soils obviously represent a serious corrosion risk to steel. Alkaline soils tend to have high sodium, potassium, magnesium and calcium contents. The latter two elements tend to form calcareous deposits on buried structures with protective properties against corrosion. Fig. 7 shows the relationship between pH value and corrosion rate of substation grounding grid. When the pH value is between 5.8 and 7.3, both the average corrosion rate and maximum corrosion rate are relatively shorter than other pH values.

C. Water Content

Water, in liquid form, represents the essential electrolyte required for electrochemical corrosion reactions. The relationship between water content and corrosion rate of substation grounding grid is shown in Fig. 8. When water content of a soil is between 15 and 25 percent, the rate of general corrosion is reaching highest. Below this value the corrosion rate will decrease as water content decreases and above this value the corrosion rate will decrease as water content increases.

D. Soluble Salts Content

The amount of dissolved inorganic solutes (anions and cations) in water or soil is directly proportional to the solution electrolytic conductivity. Most salts are active participants on the corrosion process, with the exception of carbonate, which forms an adherent scale on most metals and reduces corrosion. Chlorides, sulphates and sulfides have been identified in the literature as being the chief agents in promoting corrosion [7].

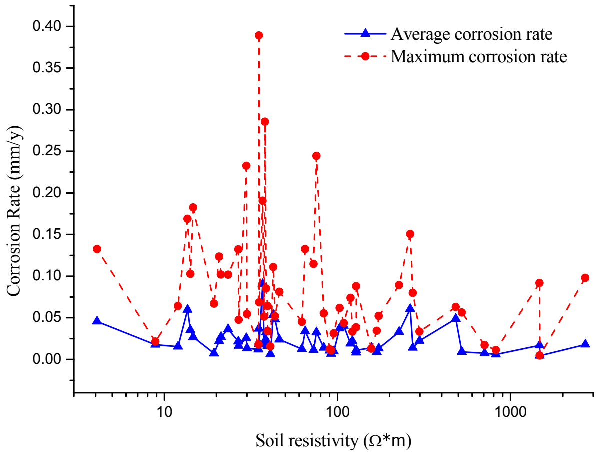


Figure 6. The relationship between soil resistivity and substation grounding grid corrosion

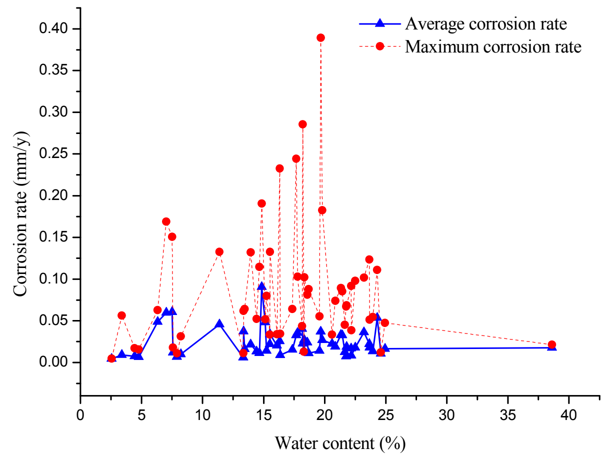


Figure 8. The relationship between water content and substation grounding grid corrosion

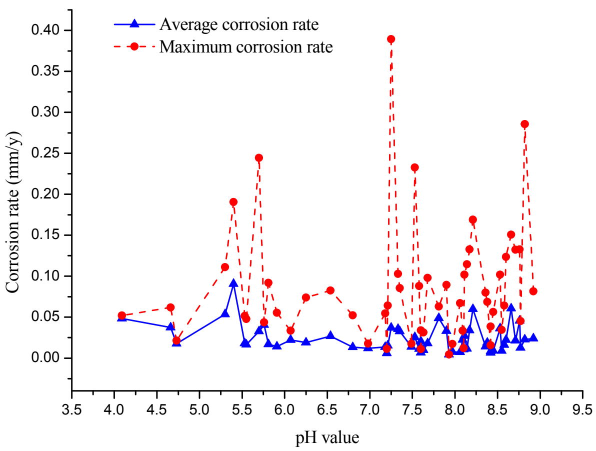


Figure 7. The relationship between pH value and substation grounding grid corrosion

VI. Remedies of Substation Grounding Grid

The most common methods available for the protection of steel grounding grids are metallic coating, cathodic protection and corrosion allowance in conductor cross-section area.

Coating has been used to control corrosion rate. Zinc-coated (galvanized) steel is the most used type of coating. Zinc coating protects steel from corrosion by two important aspects, passivity and galvanization. Passivity is the formation of a thin, non-conductive, oxide surface film that hinders the flow of electrical current and reduces the rate of corrosion. Galvanization is that zinc has a high electric potential and will sacrifice itself to protect steel [3]. However, the protection provided by the zinc coating depends upon its thickness and corrosion of the soil. It is also observed that the when the continuity of the coating is destroyed, the corrosion rate of the base metal is normal or above normal [8]. Hence galvanizing is not recommended as a basic means of protection of steel grounding conductors.

Cathodic protection operates by stopping the current flow from the metal to the electrolyte by neutralizing it with a stronger current of opposite polarity from an external source [5, 9]. Sacrificial anodes and impressed current are the two basic methods of cathodic protection. It has been found to be quite difficult to provide an economic and reliable system for effective protection of steel conductors. This is due to the presence of a number of cables, reinforcement steel, steel columns etc which are generally connected with grounding grid. Also, impressed current system may lead to serious corrosion of other metals unless proper care is taken at the time of installation.

Reliable performance of steel grounding systems can be insured by selecting a conductor cross-section area so that its fusing characteristic is acceptable over years of operation [9]. In order to satisfy this requirement Allowance for corrosion should be provided for both uniform and pitting corrosion while selecting the area of the grounding conductors based upon the soil corrosion data.

References

[1] IEEE Standard No.80-2000: "IEEE Guide for Safety in AC Substation Grounding".

[2] Rong Zheng, Jinliang He, Jun Hu, Guojun Lu and Bin Luo, "The theory and implementation of corrosion diagnosis for grounding system," in *Industry Applications Conference*, vol. 2, pp.1120 -1126, Oct 2002.

[3] A. P. Howard, "Introduction to Corrosion and Galvanizing of Helix Foundations", Presented at "Helical Foundations and Tiebacks" (November 2004) Specialty Seminar, Helical Foundations and Tiebacks Committee, Deep Foundation Institute, Tampa, FL. Nov 2004.

[4] M. Tullmin and P. R. Roberge, "Tutorial corrosion of metallic," *IEEE Trans. Materials Reliability*, Vol. 44, pp.271- 278, June 1995.

[5] P. K. Sen, K. Malmedal and J. P. Nelson, "Steel grounding design guide and application notes," in *IEEE Rural Electric Power Conference*, pp.C2 - C2, May 2002.

[6] J. H. Prayer, et al. Material Performance, May- Nov. 1980.

[7] M. Romanoff, "Underground Corrosion," NBS Circular 579, U.S. Dept. of Commerce, 1957.

[8] V. N. Manohar, "Design of steel earthing grids in India," *IEEE Trans. Power Apparatus and Systems*, Vol. PAS-98, Nov/Dec 1979

[9] V. R. Lawson, "Problems and detection of line anchor and substation ground grid corrosion", *IEEE Trans.* Industry Applications, Vol. 24, pp. 25 - 32, Jan.-Feb 1988.