

# Research on the influence of ac current overflowing on grounding electrode corrosion

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**Abstract.** In the power system, earth electrode is laid in the soil for current overflowing, to ensure secure and stable operation of power grid and electric accessory. Compared with general pipeline laid in the soil, earth electrode is under the circumstance of unbalanced grounding current of neutral point and electric field induced by high-voltage transmission line, so there is current straightly overflowing from electrode surface to the earth. Grounding current density carried by earth electrode is large, with an important effect on electrochemical corrosion of earth electrode in the soil. Based on the established corrosion model, this paper makes research on the influence of AC current overflowing on corrosion potential, current and deformation, without considering the effect of species diffusion. What is more, the relationship between the amount of corrosion deformation and the frequency of ground current is also studied.

## 1 Introduction

Corrosion is a common phenomenon in underground conductors. In the power system, the grounding electrode is buried in the soil, which is used for the overflowing of the ground current, to ensure secure and stable operation of power grid and electric accessory. The buried depth of the grounding electrode is generally 0.3~0.8 m. Due to the long time in the dark and humid environment, the corrosion of grounding electrode is inevitable <sup>[1]</sup>. In the power system, the amplitude of the ground current is relatively large, and the current overflow is directly carried out through the grounding electrode. When an electric current passes through the grounding pole to the earth, the current density of the different parts of the grounding electrode is uneven <sup>[2, 3]</sup>. At present, the research on the corrosion of metal by current is mainly aimed at the corrosion behavior of the buried pipeline under the stray current, and the stray current value is relatively small. However, in the power system, the amplitude of the ground current is relatively large, and the current overflow is directly carried out through the grounding electrode. Therefore, it is necessary to study the influence of the huge ground current overflowing on corrosion <sup>[4]</sup>. Based on corrosion model irrespective of species diffusion, through injecting AC current in simulation, this paper studies the influence of AC current overflowing on corrosion potential, current and deformation, without considering the effect of species diffusion. What is more, the relationship between the amount of corrosion deformation and the frequency of ground current is also studied. The study will be of great significance to corrosion degree prediction and evaluation of earth electrode with AC grounding current in power system.



## 2 Corrosion mechanism and corrosion model of grounding electrode

According to whether the soil's conductive mechanism considers the diffusion effect of species, the corrosion model can be divided into simplified corrosion model irrespective of species diffusion and precise corrosion model respective of species diffusion respectively. Due to the diffusion of oxygen (cathodic reaction) is the main controlling process of electrode corrosion in soil environment, in the sparse soil environment, oxygen can diffuse freely to the surface of the earth electrode, and the effect of the soil on the diffusion is relatively small, so the diffusion effect of oxygen can be ignored. Therefore, it is considered that the corrosion model irrespective of species diffusion corresponds to the sparse soil environment in practical engineering applications.

### 2.1 Influence mechanism of current dissipation on corrosion without considering species diffusion

When the diffusion of any substance is not considered, the conductivity of soil can be expressed by conductivity. In the metal phase of the grounding electrode, the Equation (1) is satisfied.

$$i_s = -\sigma_s \nabla \phi_s, \nabla i_s = Q_s \quad (1)$$

In Equation (1),  $i_s$  is electrode current density,  $\sigma_s$  is the conductivity of metal materials in grounding electrode,  $\phi_s$  is electrode potential, and  $Q_s$  is Current source on grounding electrode.  $Q_s$  is nonzero only at the inflow point or outflow point of external current, and in the rest of the points,  $Q_s=0$ .

Similarly, the Equation (2) is satisfied in soil.

$$i_l = -\sigma_l \nabla \phi_l, \nabla i_l = Q_l \quad (2)$$

In Equation (2),  $i_l$  is soil current density,  $\sigma_l$  is electrical conductivity of soil,  $\phi_l$  is potential for soil,  $Q_l$  is current source on grounding electrode,  $Q_l$  is nonzero only at the surface current of the ground electrode into the soil point or out of the soil point, and in the rest of the points,  $Q_l=0$ .

At the interface between the metal phase of earth electrode and the liquid phase of soil, the cathode considers only the oxygen reduction reaction, and the anode only considers the oxidation reaction of iron. The currents generated in the reaction use Tafel formula as follows:

$$i_{Fe} = i_0 \cdot 10^{\frac{\eta}{A_a}} = 7.1 \times 10^{-5} \times 10^{\frac{\eta}{0.41}} \text{ (A/m}^2\text{)}^{[5]} \quad (3)$$

$$i_{O_2} = -i_0 \cdot 10^{\frac{\eta}{A_c}} = -7.7 \times 10^{-7} \times 10^{\frac{\eta}{-0.25}} \text{ (A/m}^2\text{)}^{[5]} \quad (4)$$

In Equation (3) and Equation (4),  $\eta = \phi_s - \phi_l - E_{eq}$ . Because the grounding electrode has the current flowing along the direction of the earth electrode and the conductivity of the iron is higher, the potential of the surface of the ground electrode has a small voltage drop. That is, the surface potential of the grounding electrode  $\phi_s$  is slightly changed.

$$i_{in} = i_{Fe} + i_{O_2} \quad (5)$$

Equation (5) is the relationship between the total external current and the total current generated by the reaction of anode and cathode. At a specific point on the surface of the ground electrode, the current flowing into or out of the point and the current generated by the reaction of the cathode and anode are also satisfied the relationship of the above Equation (5).

For Equation (5), the variable is the overpotential, and the equilibrium potential in the overpotential is invariable. The variable is only the surface potential of the ground electrode  $\phi_s$  and the adjacent soil potential  $\phi_l$ . Therefore, the change of the current overflowing of the grounding electrode is realized by the change of the surface potential of the ground electrode  $\phi_s$  and the adjacent soil potential  $\phi_l$ .

### 2.2 The establishment of corrosion model irrespective of species diffusion

Considering that the ground zero potential is not the only one when the AC current is injected into the

ground electrode, an AC circuit is needed. In an electric power system, the AC current of a grounding electrode flows back to the grounding electrode through the nearby substation grounding device or other power equipment. Considering the symmetry, the same redox reaction occurs on the grounding electrode, but the current is equal in magnitude and opposite in direction. In practical engineering applications, considering that the grounding electrode needs to be connected with the power system equipment through the down lead, down lead will have a certain impact on the current overflowing of earth electrode. To set up the model shown in Figure 2.1, the midpoint coordinate of the left horizontal grounding electrode is  $(-10,0)$ , and the distance between the two down leads of grounding electrode is 20 dm. The length of horizontal grounding electrode  $L$  is 5 dm with a radius  $a$  of 0.02 dm and a depth  $h$  of about 0.6 dm. The electrical conductivity of the grounding electrode  $\sigma_s$  is  $8.41 \times 10^6$  S/m, and the soil conductivity  $\sigma_l$  is  $1.0 \times 10^{-3}$  S/m. The radius of soil is 25 dm, and the length of the down lead of grounding electrode is 1 dm with a radius of 0.02 dm.

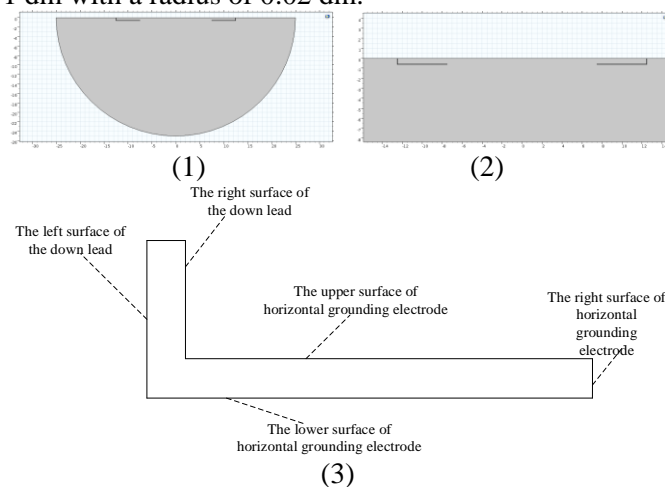


Figure 2.1: Corrosion Model with AC inputted

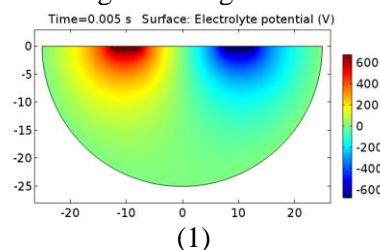
(1) Overall model (2) Partial enlarged diagram of earth electrode (3) Overflowing current model of horizontal earth electrode with down lead

### 3 Simulation analysis of AC current of grounding electrode

On the left grounding electrode, the injection current is  $i_1 = 1 \sin(2\pi \times 50 \times t)$  [A]. On the right grounding electrode, the injection current is  $i_2 = -1 \sin(2\pi \times 50 \times t)$  [A]. The anodic reaction of the two electrodes is the iron dissolution reaction, and the cathodic reaction is oxygen reduction reaction. The corrosion potential, current and deformation are simulated and analyzed, and the relationship between the corrosion deformation and the frequency of the ground current is studied.

#### 3.1 The analysis of electrode potential distribution

The potential distribution of grounding electrode obtained by simulation is shown in Figure 3.1. There are two scale bars in Figure 3.1, the first (from left) is the scale of the grounding electrode, and the second is the scale of the soil. The following are the agreement.



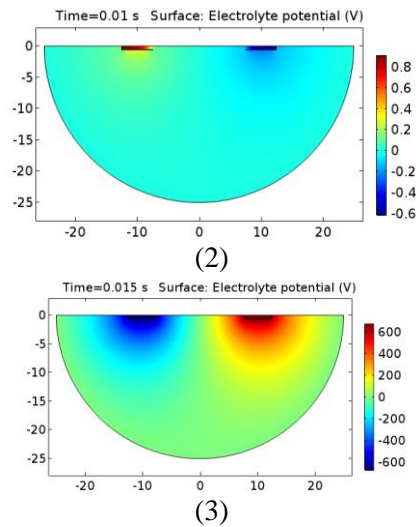


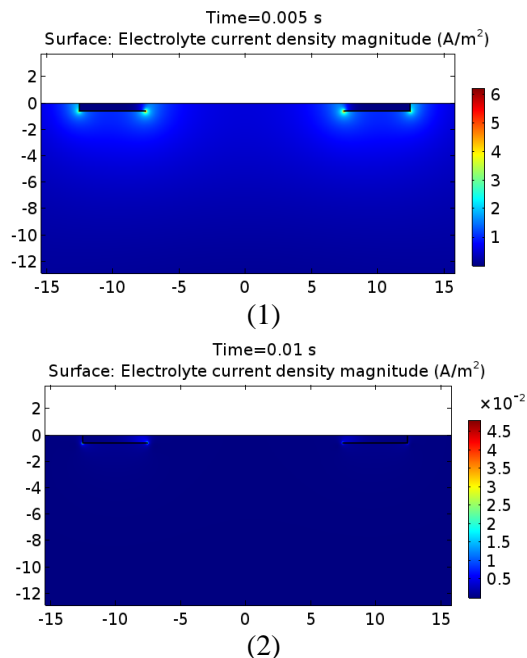
Figure 3.1: Potential distribution with various inputted current of left earth electrode

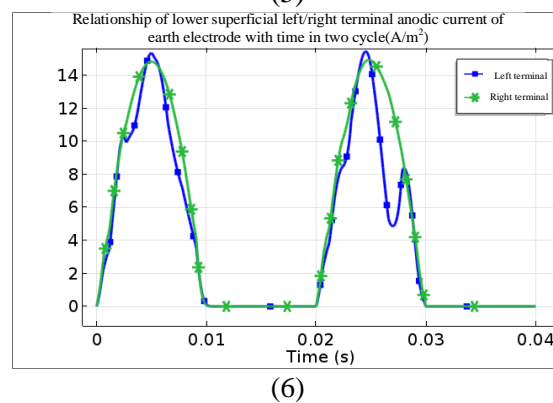
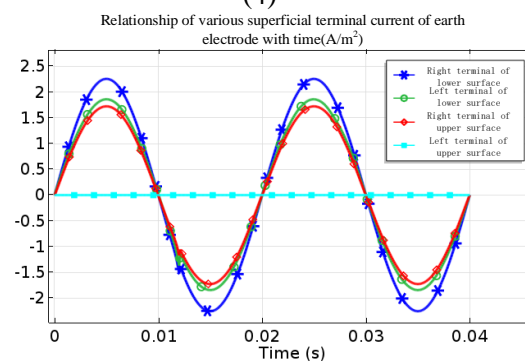
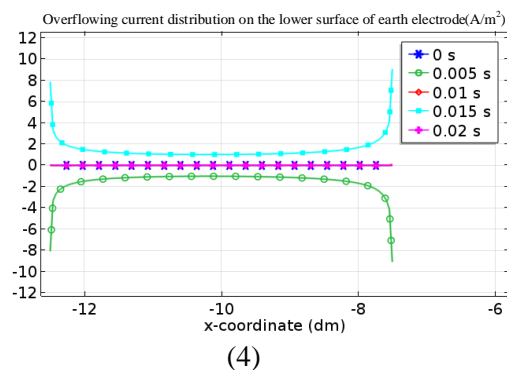
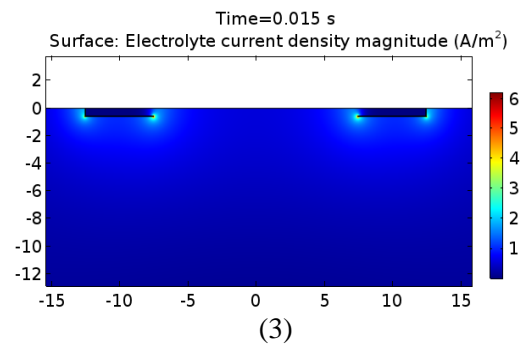
(1) Max 1 A (2) Zero 0 A (3) Min -1 A

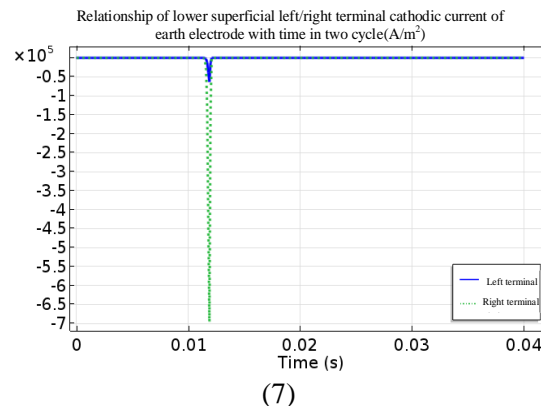
When considering only the potential distribution of the left earth electrode in Figure 3.1, it is the same to replace the single earth electrode with the double electrode of the same redox reaction to inject the AC current.

### 3.2 Relationship of current distribution of earth electrode, the current density and anodic/cathodic current with time

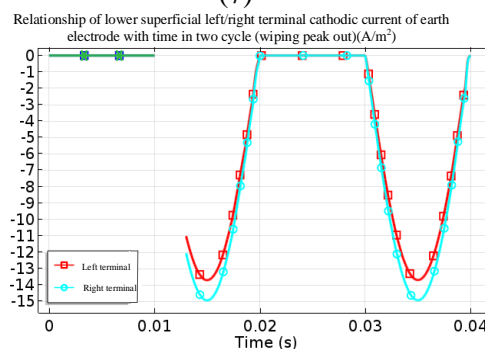
The relationship of current distribution of earth electrode, the current density and anodic/cathodic current with time is shown in Figure 3.2.







(7)



(8)

Figure 3.2: Relationship of current distribution of earth electrode and anodic/cathodic current with time

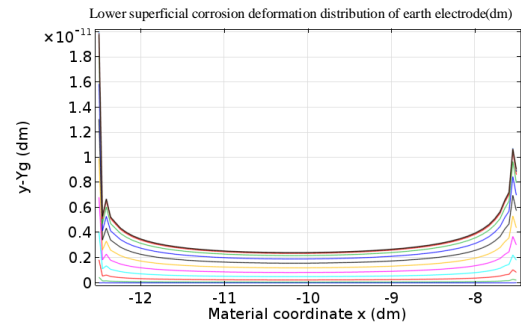
(1) Max 1 A (2) Zero 0 A (3) Min -1 A (4) Overflowing current distribution on the lower surface of earth electrode (5) Relationship of various superficial terminal current of earth electrode with time (6) Relationship of lower superficial left/right terminal anodic current of earth electrode with time in two cycle (7) Relationship of lower superficial left/right terminal cathodic current of earth electrode with time in two cycle (8) Relationship of lower superficial left/right terminal cathodic current of earth electrode with time in two cycle (wiping peak out)

Figure 3.2(4) shows that the electrode current overflowing has the end effect, Figure 3.2(5) shows that the rules about the magnitude of the overflowing current is basically the same at different points on the surface of the ground electrode. There is a small difference in the current value. And the minimum current point is at the internal inflection point in the connection between the down lead and the grounding electrode. It can be seen from Figure 3.2(6) that the anode reaction current only acts on the positive half of the injected current, and almost does not react in the negative half cycle. Compared with the anode reaction current at the end (right) side of the grounding electrode, the anode reaction current of the connection between the down lead and the grounding electrode (The left end of lower surface of grounding electrode) in the positive half cycle has obvious current distortion. This is the reason of serious deformation of corrosion of down lead and grounding electrode. It can be seen from Figure 3.2(7) and Figure 3.2(8) that the cathode reaction current only acts on the negative half of the injected current, which still reflects the law of sine wave, in most of the negative half of the time. However, when the first positive half of the injected current is in the transition to the first negative half cycle, there is a large impulse current.

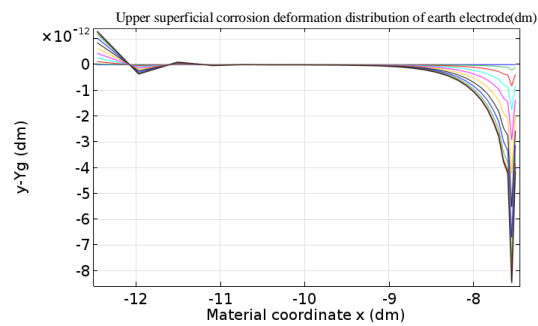
The possible causes of generating the large impulse current when the first positive half of the injected current is in the transition to the first negative half cycle are as follows. In the positive half cycle, for the Nernst double electric layer on the surface of the ground electrode, one end close to the grounding electrode is positive, and the far end is negative. When the positive half cycle is in the transition to the negative half, the inversion of the electric double layer generates a large current transition at this time, so the impulse current is generated.

### 3.3 Analysis of corrosion deformation distribution of grounding electrode and down lead

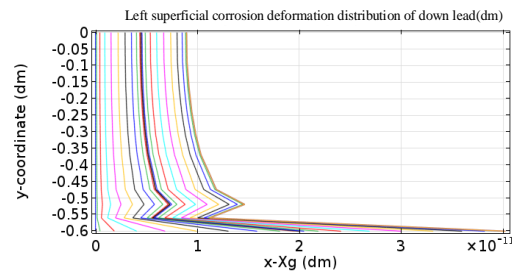
The distribution of corrosion deformation of grounding electrode and down lead is shown in Figure 3.3.



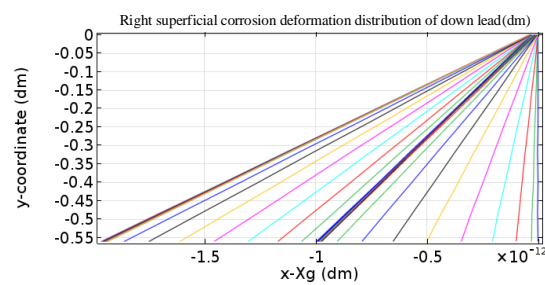
(1)



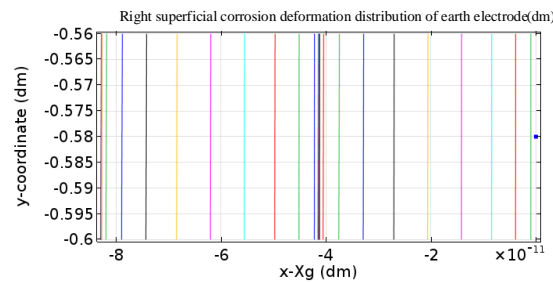
(2)



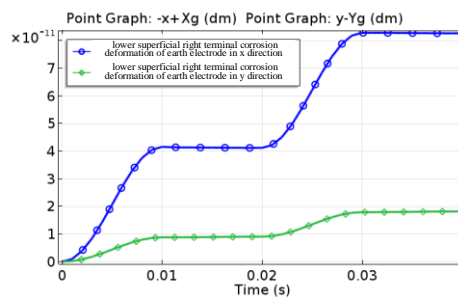
(3)



(4)



(5)



(6)

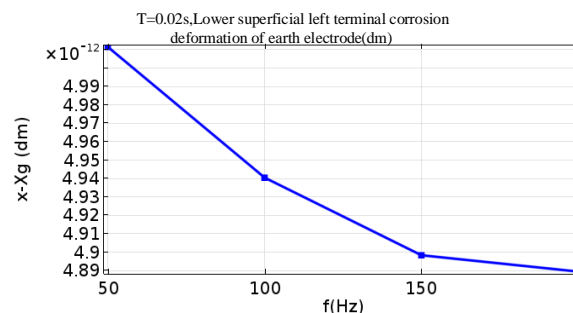
Figure 3.3: Corrosion deformation distribution of earth electrode and down lead

(1) Lower superficial corrosion deformation distribution of earth electrode (2) Upper superficial corrosion deformation distribution of earth electrode (3) Left superficial corrosion deformation distribution of down lead (4) Right superficial corrosion deformation distribution of down lead (5) Right terminal superficial corrosion deformation distribution of earth electrode (6) Relationship of lower superficial right terminal corrosion deformation of earth electrode with time in x/y direction

When the AC is injected, the most influential is the appearance of the right surface of the down lead, and the corrosion of the lower part of the right surface of the down lead is more serious than that of the upper part. The end effect of the corrosion deformation on the upper surface of the grounding electrode is obvious in the case of AC. The corrosion deformation of the connection between the left surface of the down lead and the grounding electrode leads to the internal corrosion depression of down lead in the case of AC.

### 3.4 The relationship between the amount of corrosion deformation and the frequency of injected AC

When the amplitude of the injected AC is 1A, different frequencies are set, and the relationship between the corrosion deformation and the injected AC frequency is obtained in the same time, as shown in Figure 3.4.



(1)



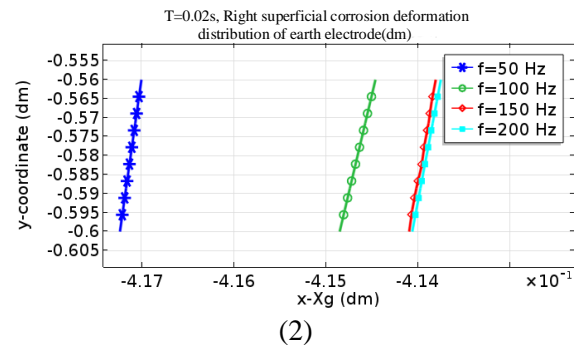


Figure 3.4: Relationship of corrosion deformation distribution with frequency of inputted AC within same time

(1) Relationship of lower superficial left terminal corrosion deformation with frequency of inputted AC within same time (2) Relationship of right terminal superficial corrosion deformation distribution with frequency of inputted AC within same time

It can be seen from Figure 3.4 that in the same time, the corrosion deformation of the grounding electrode decreases with the increase of the frequency of injected AC, which is a negative correlation between corrosion deformation and AC frequency. Therefore, in the power system, when the harmonic wave above 50 Hz is injected into the grounding electrode, the influence of harmonic wave on the corrosion decreases with the increase of the frequency.

#### 4 Conclusions

Based on the established corrosion model, this paper makes study on the influence of AC current overflowing on the corrosion of the grounding electrode, without considering the effect of species diffusion. The following conclusions can be drawn:

(1) When the AC is injected, the most influential is the appearance of the right surface of the down lead. The influence is between the positive DC and negative DC, but it is not a simple superposition of positive DC and negative DC.

(2) When the first positive (or negative) half of the injected current is in the transition to the first negative (or positive) half cycle, there is a large impulse current.

(3) The frequency of the injected AC current is negatively correlated with the effect on corrosion, that is, the corrosion deformation decreases with the increase of the frequency.

#### References

- [1] Yueqiang Li, Cuiwei Du, Hao Feng, Yue Zhao. "Soil Corrosion of Grounding Electrode", *Environmental Technology*, **28**(1), pp. 15-18, (2010).
- [2] Guangrun Xie. "Grounding technology in power system", *Water Resources and Electric Power Press*, (1991).
- [3] Tao Yuan, Wenxia Sima, Xiaoli Li. "Current Distribution of Two Kinds Grounding Electrode", *High Voltage Engineering*, **34**(2), pp. 239-242, (2008).
- [4] Xiaobin Cao. "Study on Current Distribution Rule and Parameter Calculated Method of Grounding System in Large Current and Complex Geological Conditions", (2010).
- [5] E.B. Muehlenkamp, M.D. Koretsky, J.C. Westall. "Effect of Moisture on the Spatial Uniformity of Cathodic Protection of Steel in Reinforced Concrete", *Corrosion*, **61**(6), pp. 519-533, (2012).