TRANSIENT CHARACTERISTICS ANALYSIS OF GROUNDING ELECTRODE IN TWO-LAYER SOIL

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Abstract: This paper studies experimentally the transient characteristics of grounding electrode embedded into soil. The soil is analyzed as two-layer soil and the soil layers parameters are obtained. The spherical grounding electrode is tested by injecting a step like current of different rise times into electrode at different depths. The injected currents and voltages are measured and analyzed. The electrode impedance shows a dependent on the injected frequency and depth of the sphere at different soil layers. Numerical model are proposed by the current source simulation method and the method of successive image technique in two-layer soil to investigate the penetration effects on grounding spherical electrode resistance.

1 INTRODUCTION

The grounding electrodes main job is dissipating fault currents effectively into the ground, and to prevent damage of installations. The performance of the power system also, is influenced by proper functioning of grounding systems.

Up to now, there are no derived formulas of impedance and admittance even for a simple vertical or horizontal naked conductor buried in soil during transient case. Experimental techniques are still the best method to investigate the transient characteristics of the grounding systems.

Transient characteristics of grounding systems can be investigated by numerical electromagnetic analysis [1-4]. Or, it is using experimental technique to investigate transient characteristics of grounding systems. There are two directions for investigating transient characteristics of grounding systems, one concerns of a frequency-dependent effect [5-11] and the other relates wave propagation [12-15].

This paper studies the transient characteristics of grounding spherical electrode buried at different depths and different injected current rise times to study the impedance transient characteristics. A two-layer soil model is assumed to explain the transient characteristics in the soil with aid of analytical model.

2 EXPERIMENT SETUP

Fig. 1 shows an experimental setup to study the transient characteristics of grounding spherical electrode. A step-like current of 7 or 308 nsec rise time is applied from a pulse generator (PG) of 500V to grounding spherical electrode of radius 0.025m via a lead wire that is supported at 4 m height above the ground surface. The grounding spherical electrode is apart from the PG by 11 m. The current is measured by a CT (Peason model 2877, bandwidth from 300Hz to 200MHz), and recorded by a digital oscilloscope (Tektronix TDS 3054m, bandwidth 500MHz). Transient voltages were measured by a voltage probe (TEKTRONIX P6139A, bandwidth 500MHz).

The experimental site was at yard area of Doshisha University, Kyotanabe Campus, Kyoto, Japan. The soil resistivity of experimental site is measured by means of Wenner method using a specific soil resistance tester (Yokgawa Electric Work type 3244) as a function of depth [1-2]. The measured resistivity shows a decreasing of grounding resistivity with soil depth as shown in Fig. 2.

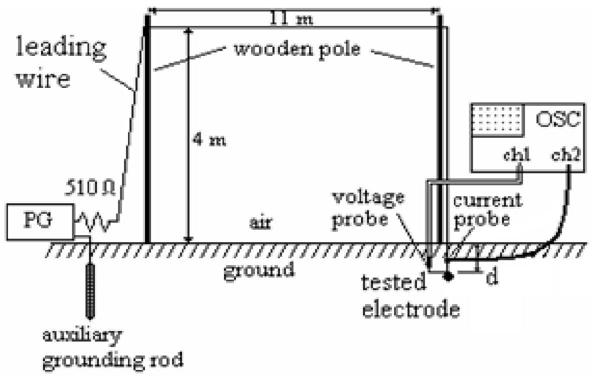


Figure 1: Experimental setup

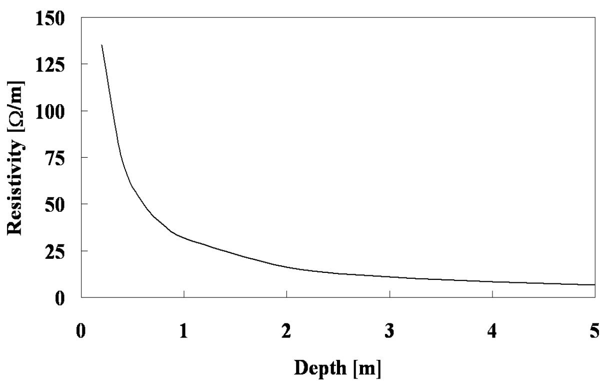


Figure 2: Soil resistivity vs. soil depth

A two-layer soil model is proposed to simplify soil resistivity variation with depth. The surface layer soil resistivity ρ_1 is assumed ρ_1=205 Ω.m with depth h = 0.4 m and the bottom layer soil resistivity ρ_2 is assumed ρ_2 = 45 Ω.m.

The grounding spherical electrode had been buried in the soil to study the effects of grounding spherical electrode depth and injected current rise time (domain frequency). The studied injected current rise times are 7 and 308 nsec. The studied depths of the hemispherical grounding electrodes are 0, 10, 20 and 30 cm.

2.1 Measured Results

Figure 3 shows the measured injected currents and the grounding spherical electrode voltage waveforms for different studied cases.

The capacitive/resistive characteristics are observed in the grounding spherical electrode voltages due to injected currents waveforms.

Table 1 show the steady state calculated resistance and the time delay between the voltage and current waveforms. The grounding spherical resistance decreases as the depth increases and as the injected current rise time increases.

The time delay between the voltage and the current waveforms shows that for 7 ns rise time case, the time delay increases with the grounding spherical electrode depth increases, This is coming from that the 7 ns rise time case has a high domain frequency which penetrate near the soil surface, so as the grounding spherical electrode go deeply in the soil as the current diffusion in soil take a time and increases the voltage waveform time delay.

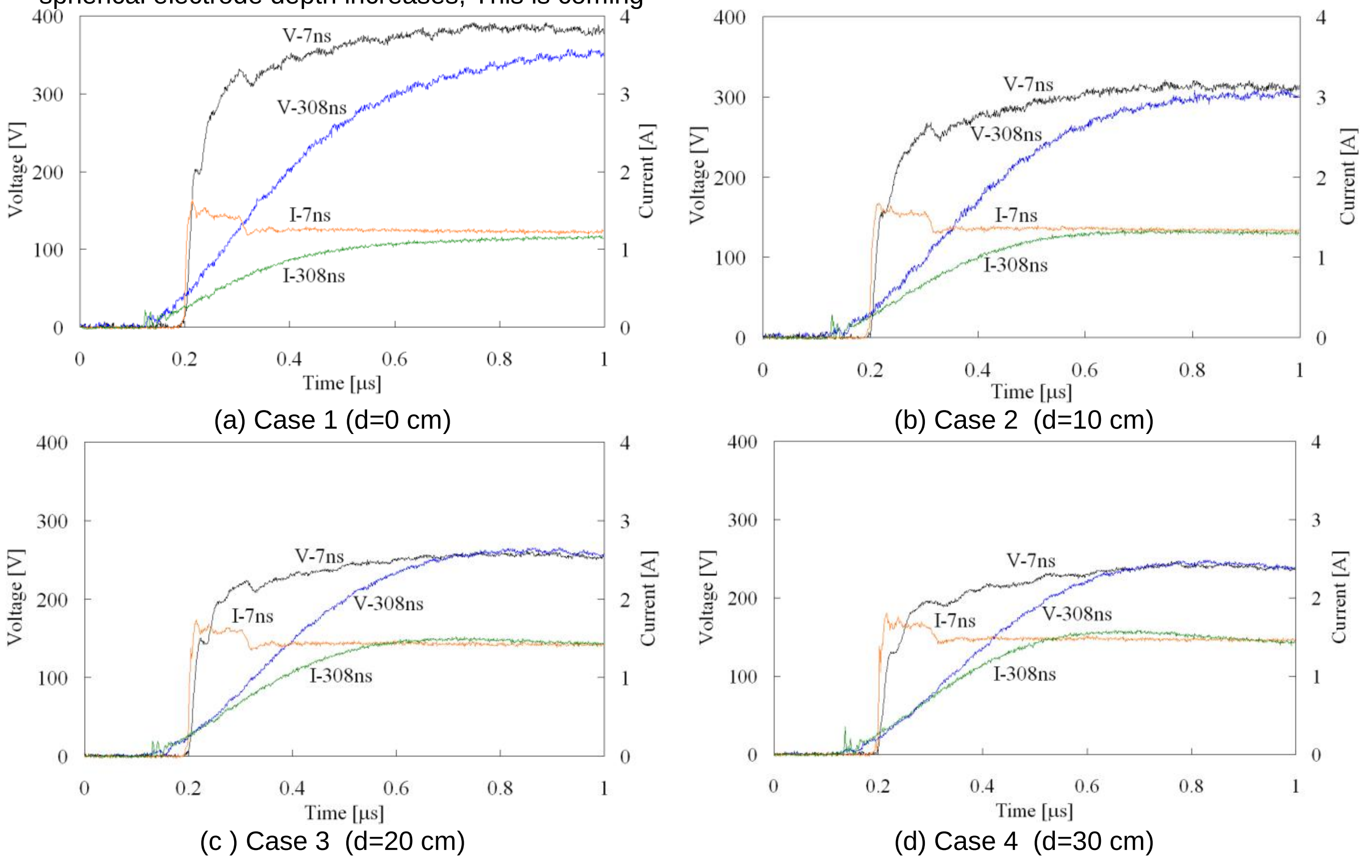
The time delay between the voltage and the current waveforms shows that for 308 ns rise time case, the time delay increases with the depth decreases. This is coming from that the 308 ns case injected current has a low frequency which goes deeply in the soil where the soil resistivity decrease and grounding spherical electrode capacitance decrease vise verse near the soil surface where the grounding spherical electrode capacitance increased.

The percentage differences (R%) between 7 ns and 308 ns resistances show that this difference decreases with the grounding spherical electrode depth increases. This can be explained by the

Table 1: Calculated resistance and time delay

d [cm]	7 ns		308 ns		R_m %
	R_m[Ω]	T_d [ns]	R_m[Ω]	T_d [ns]	
0	311.0	5	299.5	84	3.839
10	233.1	6	228. 2	15.1	2.147
20	179.4	8	178.1	11.4	0.786
30	164.1	35	163.2	11.5	0.551

T_d Time delay between voltage and current wave forms
R% percentage difference between measured V/I at 308 and 7 ns



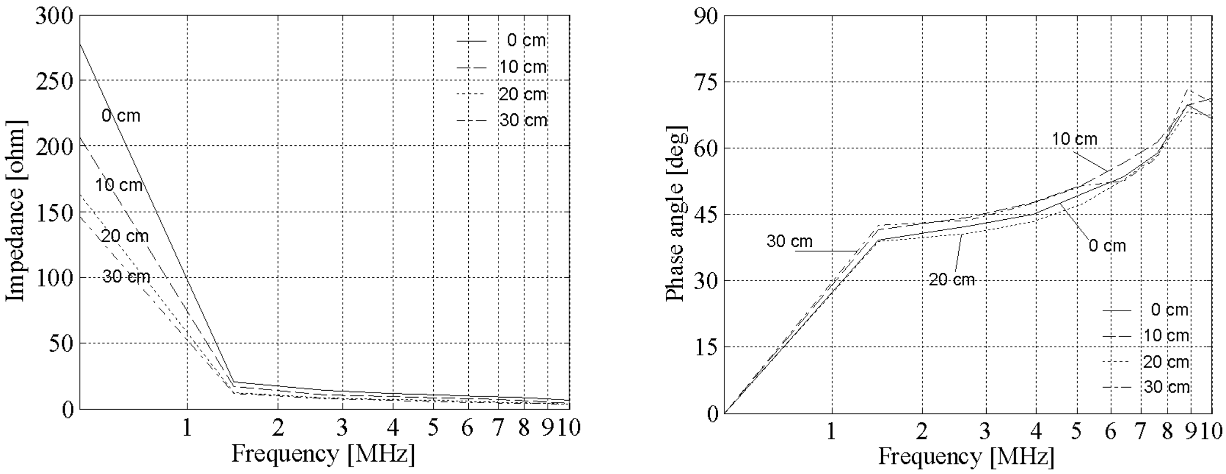
(a) Case 1 (d=0 cm)

(b) Case 2 (d=10 cm)

(c) Case 3 (d=20 cm)

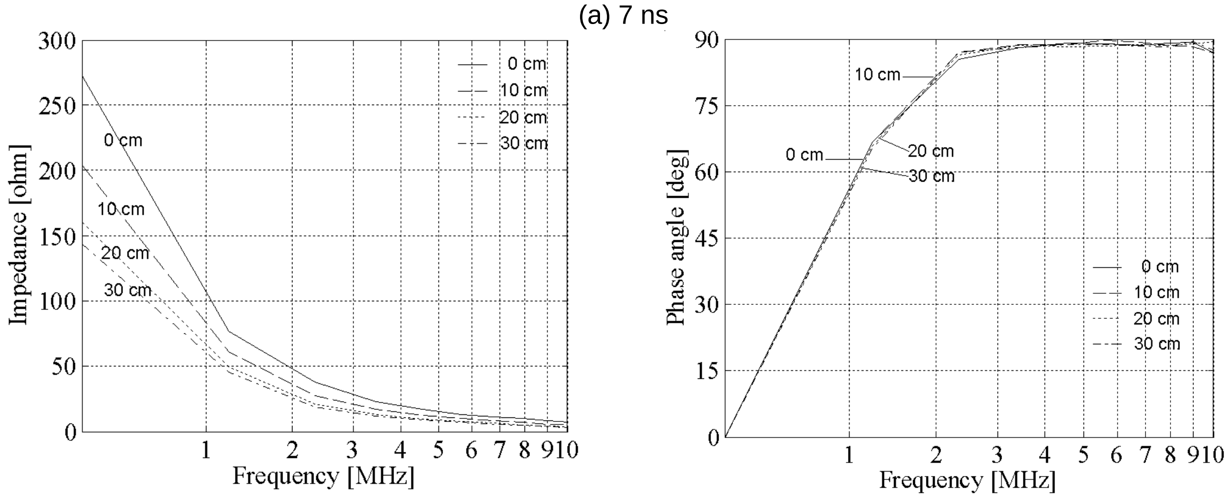
(d) Case 4 (d=30 cm)

Figure 3: Measured voltages and injected currents of rise times 7 and 308 nsec



(I) impedance (II) phase angle

(a) 7 ns



(I) impedance (II) phase angle

(b) 308 ns

Figure 4: Frequency response of spherical electrode for different cases

effect of penetration depth which pass the most of injected currents near the soil surface of high resistivity soil layer and this depth decreases with injected current domain frequency increases.

The impedance of the grounding spherical electrode for different cases is observed in fig. 4 to be composed dominantly of a parallel resistance and a capacitance. The grounding spherical electrode impedance decreases rapidly in the case of 7 ns injected current than that in the case of 308 nsec injected current. The impedance phase angle in case 308 nsec change from 0^o to -90^o rapidly than that in the case of 7 ns injected current. As the grounding spherical electrode go deeply in the soil as the frequency response impedance decreases due to the decreases of soil resistivity with depth as shown in Fig. 2.

3 PENETRATION DEPTH EFFECTS STUDY

It is well known that the electric field or current density decease to 1/e (36.8%) of its initial value, while the wave penetrates to a distance called depth of penetration [16].

$$\delta = \frac{1}{\sqrt{f\pi\mu\sigma}} \quad (1)$$

Where: δ = penetration depth m, f = frequency Hz, μ = soil permeability, σ = soil conductivity.

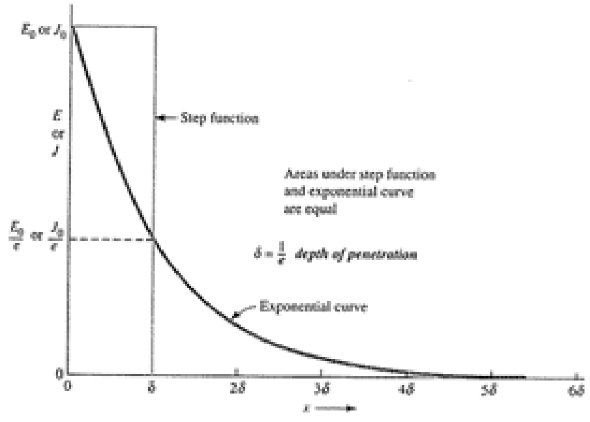


Figure 5: Electric field E or current density J(=σE) as a function of depth of penetration[16]

As Shown in Fig. 5, areas under step functional and exponential curve are equal, based on this, it is assumed that the all of injected current pass in the area of 1/e depth to make sure that will be done the soil resistivity below the penetration depth proposed to be infinity. So, it is proposed the successive image method shown in Fig. 6(a) to consider the penetration depth in homogenous soil. Then the effect of penetration depth on the grounding spherical electrode resistance buried in homogenous soil is assumed to be as follows,

$$R_c = \frac{\rho}{4\pi}\left(\frac{1}{r}+\frac{1}{h-r}+\sum_{n=1}^{\infty}\left[\frac{1}{2n\delta+2(1+n)h-r}+\frac{1}{2n\delta+2(2+n)h-r}+\frac{1}{2n\delta-2nh}+\frac{1}{2n\delta+2(1-n)h+r}\right]\right) \quad (2)$$

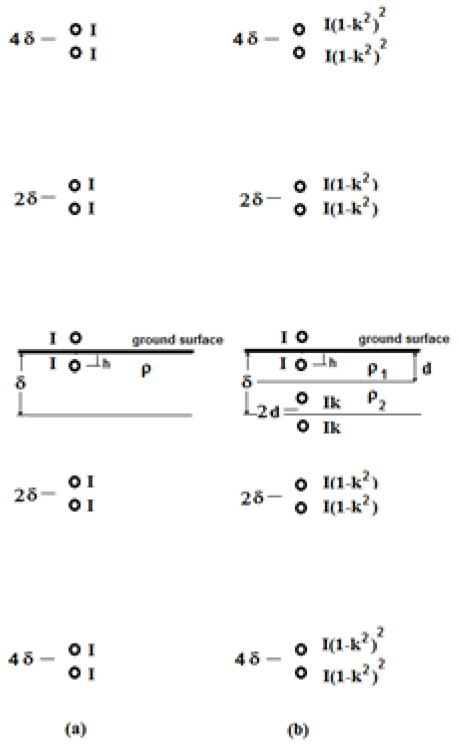


Figure 6: Image maps for a) homogenous soil and b) two-layer soil

The effect of penetration depth on the grounding spherical electrode resistance buried in two-layer soil and the penetration depth of the top layer soil is less than top layer depth, it is assumed to be as follows,

$$\delta_1 = \frac{1}{\sqrt{f\pi\mu_1\sigma_1}} \quad (3)$$

And, the spherical grounding resistance is same like that in homogenous soil.

If the penetration depth of the top layer soil is greater than top layer depth, the penetration of injected current in bottom layer will be considered and it is assumed to be as follows,

$$\delta = \frac{(1+c)\delta_1\delta_2 + d(\delta_1-\delta_2)}{\delta_1} \quad (4)$$

where : d=top layer depth, c=e $^{(\sigma1/\sigma2)}$, $\delta_2 = \frac{1}{\sqrt{f\pi\mu_2\sigma_2}}$

The spherical grounding electrode resistance when the penetration depth is greater than the top layer depth will be as follows:

$$R_c = \frac{\rho_1}{4\pi}\left(\frac{1}{r}+\frac{1}{2h-r}+\frac{k}{2d-2h+r}+\frac{k}{2d-h+r}+\sum_{n=1}^{\infty}\left[\frac{1}{2n\delta-2h+r}+\frac{1}{2n\delta+r}+\frac{1}{2n\delta-r}+\frac{1}{2n\delta+2h-r}\right]\right) \quad (5)$$

where : k=(σ1-σ2)/ (σ1+σ2)

Table 2: Calculated resistance

d [cm]	7 ns		308 ns	
	R_m [Ω]	R_c [Ω]	R_m [Ω]	R_c [Ω]
0	311.0	316.16	299.5	312.5
10	233.1	172.96	228. 2	169.3
20	179.4	161.46	178.1	157.7
30	164.1	149.18	163.2	145.4

Table 2 shows the calculated resistance R_c based on equation (5) to study the effect of the penetration depth in two-layer soil. The frequency dependent of soil resistivity is considered same for 7 nces and 308 nsec cases. The calculation results shows agreement with the spherical electrode measured resistance R_m, Table 1, results and physical explanation. But the frequency dependence of soil resistivity is needed for more deeply investigation.

4 CONCLUSION

From the experimental results and analytical analysis one can obtain the following conclusions

As the grounding spherical electrode go deeply in the soil of reduced resistance with depth, as the grounding spherical electrode impedance decreases.

The grounding spherical electrode impedance decreases rabidly with frequency increases.

The grounding spherical electrode resistance at low rise time is higher than that at high rise time due to penetration depth and both decreases when the grounding spherical electrode goes deeply in the soil for the studied cases.

The time delay between the current and voltage waveforms increases with the grounding spherical electrode depth decreases.

The proposed analytical analysis shows an agreement with the measured results and physical explanation of wave propagation in two-layer soil.

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