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Impedance Characteristics of the Grounding Simulation for Grid and Combination of Grid-Rod Configuration which Injected by Variable Current Frequency

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Abstract

Grounding is component in electrical circuit which can return current flow or can make a potential of apparatus body or neutral system to be zero or low potential. To know well the impedance characteristic of grounding system can be measured on field site or in laboratory. This experiment did in laboratory by made down scale sizing simulation of grounding systems. The grounding configurations are grid and grid-rod and then they are injected by variable frequency current from low to high frequency. The grounding grid or grid-rod configuration are 10 x 10 cm2 (4 squares), 15 x 15 cm2 (9 squares), 20 x20 cm2 (16 squares) The result of the experiment is many variation of grounding impedance depends on frequency. The relation between impedance and frequency is not linear. So we can say that the grounding impedance maybe as inductor, resistor or capacitor which depends on phase angle positive, negative or zero.

Keywords: Grounding impedance, grid, grid-rod.

Introduction

The grounding systems is a part of the electrical installation which have a function for protecting personal component or equipment damages caused by malfunction of electrical systems. So the function of grounding systems is very importance and to make this function sure we have to know the characteristics of grounding systems well, Actually the impedance of grounding systems is injected by current which have frequency from zero, low until high for example lightning current, or current from electronics, medical, telecommunication equipment which is connected to body or grounding systems. In practical measuring for impedance of grounding systems use the DC power supply and the result of this measurement is used for design of protection systems.There is wrong approach if the impedance Keywords-component; formatting; style; styling; insert (key words)is measured by the DC current and it have to be measured by AC current. The impedance of grounding systems in not only consist of resistance but also inductance and capacitance so the characteristics of impedance is vary and depend on the current frequency. The resistance is caused by soil resistivity and the inductance and the capacitance are caused by permeability and permittivity of soil. This experiments use a variable current frequency from zero until several MHz and with down scale grounding simulation. The configuration of grounding systems are grid and combination grid–vertical rod and the dimension of the grid are 10 x 10 cm^2 ; 15 x 15 cm^2 ; 20 x 20 cm^2. The result of this experiment show that the quantities of impedance and phase angle depend on injected current frequency.

Theory

Grounding systems can be built by vertical or horizontal conductors or with plate (expensive economically). The configuration types are vertical rods, horizontal rods, grids or combination of grids with vertical rods. The grids and combination of grids with vertical rods are a good of grounding configuration for industry, electrical substation because its can make lowest impedance for many place in the area of grounding systems and the lowest potential difference between two point on the earth surfaces. According to geological data that resistivity of many soil is very from low until high and can be seen at table 1 bellow:

Tabel 1: Soil Resistivity and Grounding Resistance.

Soil Type	**Soil Resis tivity (Ω m)**	**Grounding Resistance (Ω with rod length (m)**		
		3	**6**	**10**
Moist humus soil, moor soil, swamp	30	10	5	3
Farming soil loarny clay	100	33	17	10
Sandy clay	150	50	25	15
Moisty sandy	300	66	33	20
Dry sand soil	1000	330	165	100
Moist gravel	500	160	80	48
Dry gravel	1000	330	165	100
Stoney soil	30000	1000	500	300

Rock	10000000	-	-	-

Many types of configuration of grounding systems and in this experiment we use only grid and combination grid–vertical rods. The resistance, inductance and capacitance of grid configuration as follow:

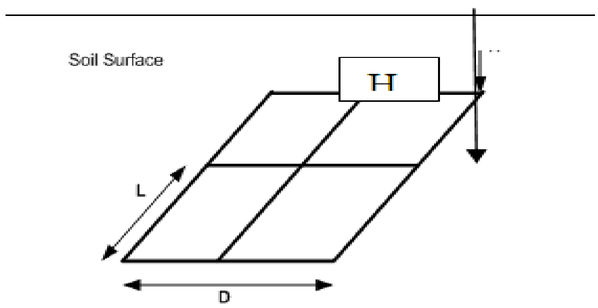
$$R = \frac{\rho}{2\quad D} + \frac{\rho}{L}\ \Omega \tag{1}$$

$$L = \frac{4\pi.10^{-7}}{2\pi}\left[\ln\frac{2.L}{\sqrt{2.h.r}} - 1\right] H\ /\ m \tag{2}$$

$$C = \frac{2\pi.\varepsilon_0}{\left[\ln\frac{2.L}{\sqrt{2.h.r}} - 1\right]} F\ /\ m \tag{3}$$

R=Grounding resistance (Ohm)
ρ =Soil resistivity (Ohm m)
D=Total of grounding conductor (m)
L=Lenght from centre to corner (m)
R=radius of electrode (m)
d=diameter of electroda (m)
ε_0 = permittivity relative ($8{,}85.10^{-12}$) F/m

The grid configuration of grounding systems can be seen at figure 1 bellow:



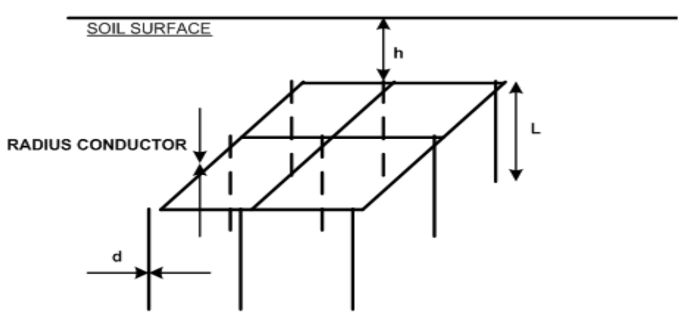


Figure 1: Grid Configuration Figure 2.Combination Grid–Rods Configuration.

$$R_0 \frac{\rho}{2\pi L}(\ln\frac{2L}{r}-1) \quad \Omega \text{ for 1 vertical rod} \tag{5}$$

$$R_N = \frac{\rho}{2\pi . Nl}\left(\ln\frac{8l}{d} - 1 + \frac{2l}{s}\ln\frac{2N}{\pi}\right) \quad \text{for more than 1rod} \tag{6}$$

$$R_A = \frac{R_o}{N}\, x\, R_N \quad \Omega \text{ for many vertical rod} \tag{7}$$

$$R_g = \rho\left[\frac{\sqrt{\pi}}{4\sqrt{A}} + \frac{1}{Lt}\right] \quad \Omega \text{ for grid} \tag{8}$$

$$R_t = \frac{R_g . R_A - R_m{}^2}{R_g + R_A - R_m} \quad \Omega \text{ for grid–rod} \tag{9}$$

$$R_m = \frac{0{,}73.\rho}{Lt}\log 10\frac{2.Lt}{\sqrt{2r_g .h}} \tag{10}$$

Ro > RN > RA > Rg > Rt

R=Grounding resistance (Ohm) ρ=Soil resistivity (Ohm m)

N=Number of vertical rod L=Length of electrode (rod) (m)

d=Diameter of electrode(rod) (m) s=Space of each electrode (m)

h=Depth of electrode (m) A=Total grid area (m2)

r=radius of rod rg=radius of grid

Lt=Total width of grid=width x 2 x (number of mesh)

Experiment

The experiments have done at High Voltage and High Current Laboratory of School of Electrical Engineering and Informatics of ITB by making the grounding simulation. A box of soil with dimension 1,5 m x 1,5 m x 0,75 m as a land for grounding experiment. The conductor grid and grid–rod is buried at 5 cm depth in this soil has diameter 2,5 mm from copper. The measuring systems use 3 rods for measuring voltage and current and the grounding impedance can be calculated with formula:

$$Z(t) = \frac{V(t)}{I(t)} \tag{11}$$

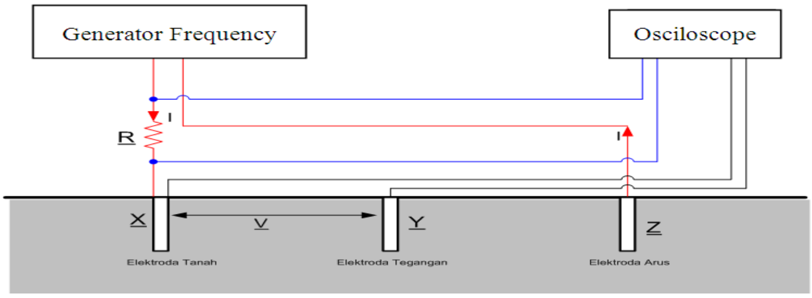


Figure 3: Measuering Circuit.

Voltage and current are measured by oscilloscope and from these data can be calculate impedance and phase angle of the grounding systems. From the phase angle can be seen that the impedance is an inductance or a capacitance. The measuring circuit can be seen at Figure 3 bellows.

Experiment Data

Table 2: Data for grid 10 x 10.

F (Hz)	**Z(ohm)**	**Θ**	**Log f**
0	50.05	0	0
50	71.83	19.80	1.70
1 K	51.07	5.76	3
5 K	46.22	5.04	3.70
10 K	53.16	4.32	4
50 K	51.32	30.60	4.70
100 K	59.67	112.32	5
200 K	59.67	64.80	5.30
500 K	69.03	93.60	5.70
1 M	67.86	176.40	6
2 M	68.32	175.68	6.30
5 M	68.25	-122.4	6.70
6 M	70	-75.60	6.78
7 M	58	26.21	6.85
8 M	62.76	146.88	6.90
9 M	70.91	181.44	6.95
10 M	72.52	205.20	7
13 M	33.67	190.95	7.11

Tabel 3: Data for Combination Grid–Rods 10 x 10.

F (Hz)	**Z (ohm)**	**Θ**	**Log f**
0	38	-	0
50	37.6	12.60	1.70
1K	28	7.20	3
5K	26.4	13	3.70
10K	27.2	4.32	4
50K	26.4	25.92	4.70

100K	28	40.32	5
200K	32	57	5.30
500K	54	104	5.70
1M	60	123.84	6
2M	84	159.84	6.30
5M	96	216.00	6.70
6M	96	220.32	6.78
7M	82	237	6.85
8M	48	228	6.90
9M	64	259.20	6.95
10M	68	266	7
13M	41.6	-140.4	7.11

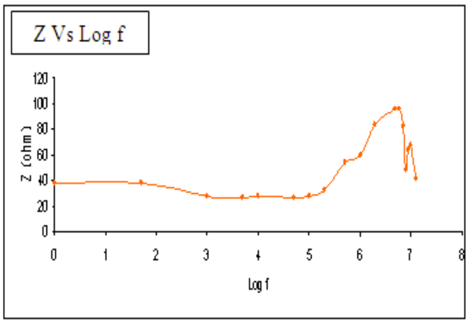


Figure 4: Impedance Vs Log f for Grid–Rods 10 x 10.

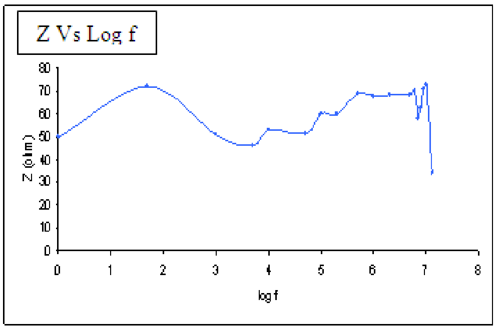


Figure 5: Impedance Vs Log f for Grid 10 x 10.

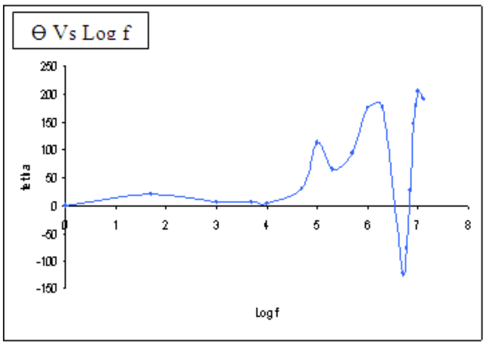


Figure 6: Phase Angle Vs Log f for Grid 10 x10.

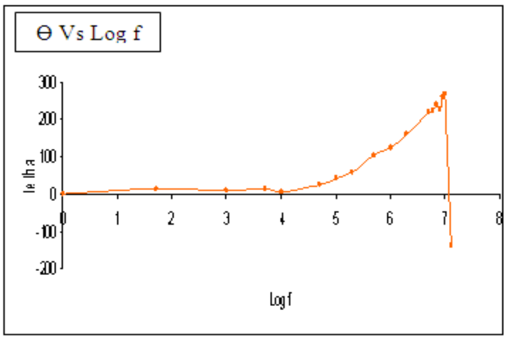


Figure 7: Phase Angle Vs Log f, Combination Grid–Rods.

These data and figures above specially for grid and grid–rod configuration with dimension 10 x 10 and then for dimension 15 x 15 and 20 x 20 only the figures would be presented for grid and grid–rod configurations below.

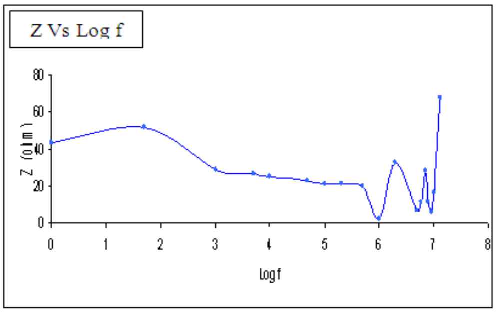


Figure 8: Impedance Vs Log f for Grid 15 x 15.

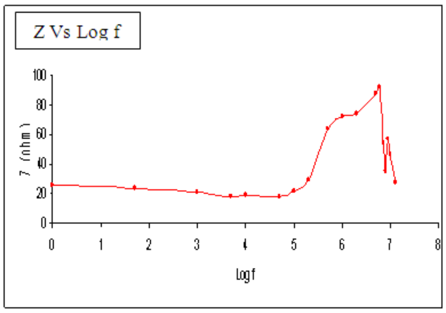


Figure 9: Impedance Vs Log f, Combination Grid–Rods 15 x 15.

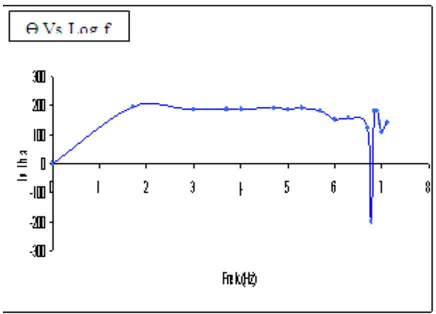


Figure 10: Phase Angle Ө Vs Log f for Gird 15 x 15.

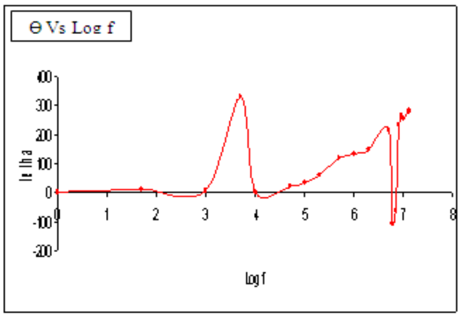


Figure11: Phase Angle Ө Vs Log f, Combination Gird-Rods 15x15.

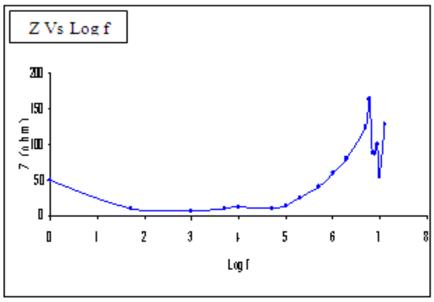


Figure 12: Impedance Vs Log f for Gird 20 x 20.

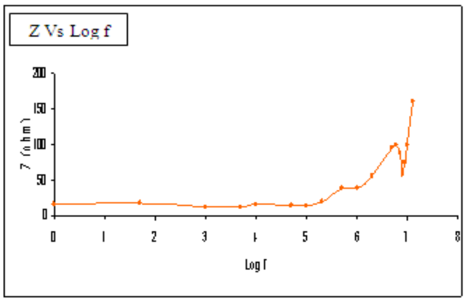


Figure 13: Impedance Vs Log f, Combination Gird- Rods 20 x 20.

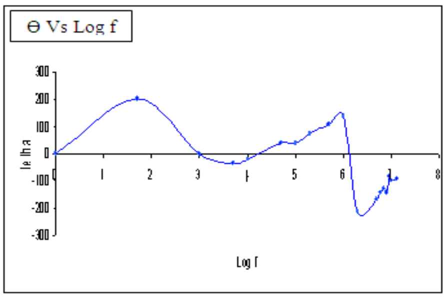


Figure 14: Phase Angle Ө Vs Log f for Gird 20 x 20.

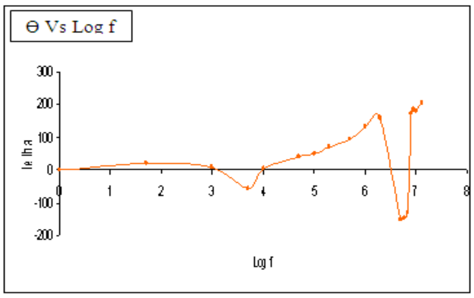


Figure 15: Phase Angle Vs Log f, Combination Gird- Rods 20 x 20.

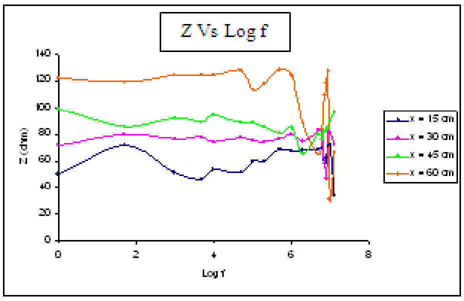


Figure 16: Z Vs Log (f), grid 10 x 10 at 15; 30; 45; 60 cm.

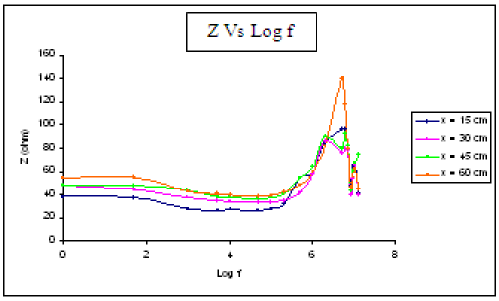
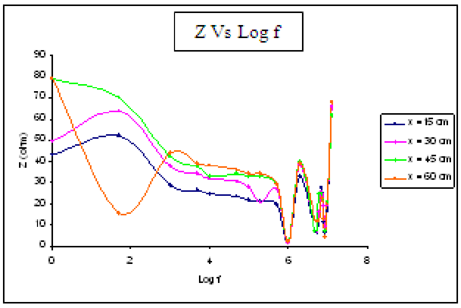


Figure 17: Z Vs Log (f), grid–rod 10 x 10 at 15; 30; 45; 60 cm.



Figu1re 18: Z Vs Log (f), grid 15 x 15 at 15; 30; 45; 60 cm.

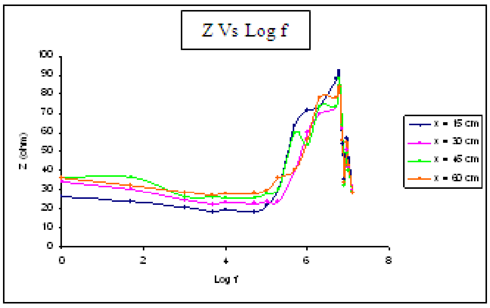


Figure 19: Z Vs Log (f) f, grid- rod 15 x 15 at15; 30; 45; 60 cm.

All of data and figures above have been measured at point 15 cm radial from the corner of grid, in this experiment also measured at point 30 cm, 45 cm and 60 cm. The result of these measurement can be seen at figure bellows:

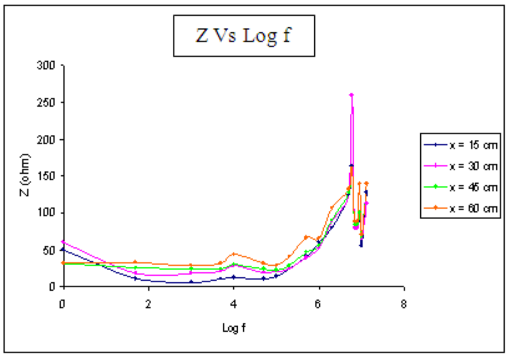


Figure 20: Z Vs Log (f), grid 20 x 20 at 15; 30; 45; 60 cm.

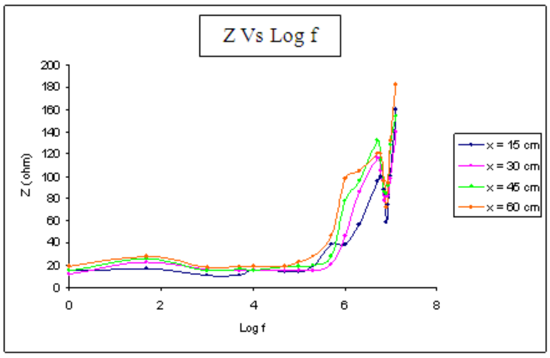


Figure 21: Z Vs Log (f) grid–rod 20 x 20 at 15; 30; 4 ; 60 cm.

Analysis Data

From all data and figures above we analyzed that the impedance of grounding systems fluctuated to injected current frequency and almost of the data experiment said that the impedance of grounding grid is higher than the impedance of grounding grid–rod. At high frequency the impedance trend to higher than at the lower frequency. That means this impedance is more inductive than capacitive. The characteristics of grounding systems have the same formula for all point measurement but difference quantities. Frequency of cut rise which make the impedance of grounding systems start to rise is 1 MHz, because at this frequency the impedance will be greater than the other frequency.

Conclusion

1. The impedance of grounding systems is not only consist of resistance but also inductance and capacitance.
2. The impedance fluctuated with frequency of injected current.
3. The frequency of cut rise is nearly to 1 MHz
4. The impedance of grounding grid is higher than grounding grid–rod
5. The character of grounding systems can be as resistance, inductance or capacitance.

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