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Full Length Research Paper

The impedance characteristics and equipotential pattern in ground surface of horizontal and grid configuration of grounding systems which are injected by frequency variable alternating currents

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Electrical energy is a importance thing for all of human life, but at the same time the electrical energy is dangerous for that life if it's not installed in a good conditions. For making a good condition of electrical installation so all of the life part of this installation that must be zero potential have to be grounded. In case of fault of installation or insulation that make the body or casing of electrical equipments so the touch potential / voltage occur, the touch voltage must not be more than 50 volt. This condition can be made by grounding systems that connected to this body and this grounding resistance must be small. We have known well that at the time fault the condition of current is high and the frequency is also high. The resistance or impedance of grounding systems that is injected by high frequency current in not the same value that it is injected by DC currents or low frequency currents. This fenomena is caused by the grounding impedance is not only resistance but also the inductance and capacitance at high frequency. In this paper is reported the result of laboratory experiments with the simulation of grounding systems in scaling down. The measurements in this experiments use the fall of potential method. Special grounding systems for body or casing of equipments, the impedance is small and this value can be obtained by buried the grounding electrode so deeply.

Keywords: Grounding systems; impedance and resistance of grounding; fall of potential method, alternating currents injection.

INTRODUCTION

Background

The first functions of the grounding systems is for personal safety if some one touch the body of electrical equipments that the touch voltage is not more than 50 volt. The good electrical installation can be done by installing the small impedance of grounding systems. How to make small impedance of grounding systems ? a. To choose the soil of land that have the small resistance or to treate that soil so tobe the good resistance b. To make the good configuration (gird, paralel etc) so the grounding impedance is small c. To burry the elctrodes more deeply so to make the contact volume in the ground is large.

In this paper we made experiments by grounding simulation of horizontal and grid configurations with several depth of electrodes burried. In the same cofigurations for electrode is burried in more deep will make the grounding impedace smaller than the electrode is burried shorter. Personal accidence is caused by touch voltage or step voltage occur if the grounding impedance is too high , so if we want to avoid the high touch voltage so the grounding electrode must be burried in long depth under the ground surface. .

The laboratory exsperiments use the black soil from Bandung – Indonesia near thr thrasmission line and lay in the box with the dimension 1.5 x 1.5 x 1 and the grounding ele3ctrode with horizontal and grid

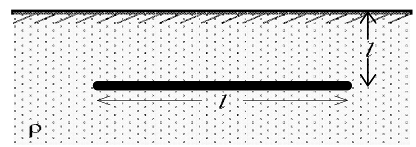


Figure 1. One (1) Electrode Horizontal Configuration

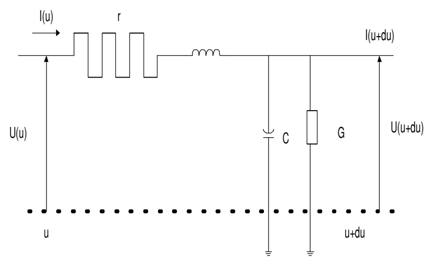


Figure 2. Equivalent Circuitr of *Counterpoise*

configuration were burried in several depth. The method of measurement is used *fall of potensial* by injection the current to the current rod and measure the voltage dropp at the potential rod.

Condition of experiments

1. Range of frequency for measuring voltage dropp is 50 Hz – 200 KHz.
2. The diameter electrode rod is 2,5 mm.
3. There are 4 types of configuration electrode are used at these experiments 2 horizontal electrodes, 4 horizontal electrodes, grid , dan combination of grid + vertical electrode
4. The condition of soil is assumed homogenuous so the conductivity ; resistivity and permeuabilitry are assumed all same .
5. The result of this experiments only measure the impedance and phase agle of the impedance for indicating the state of impedance .

The characteristics of grounding systems

Configuration

In general the type of configurations are :

a. Vertical single rod or paralel
b. Horizontal single rod or paralel
c. Grid
d. Combination of grid and vertical
e. Plate vertical or horizontal

Although there many configuration of grounding systems, but in this experiment we chose only 2 types, horizontal and grid

Horizontal configuration of 1 rod

The grounding systems with horizontal configuration can be made by burry the electrode under the ground surface with the depth variable. The electrode also may be laied paralel with the effective distance. If the electrode are laied paralel must have the distance so make the effect of paralellism is effective. Several transmission tower use the grounding horizontal and it's called *counterpise*. Usually c*ounterpoise* is used at the mountain or the land wit high resistivity (Figure 1 and 2)

The value of R, G, L and C are:

$$R = \frac{\rho}{2\pi l}\ln\frac{l^2}{1{,}85hd}$$

$$G = \frac{2\pi}{\rho\left(\ln\frac{2l}{\sqrt{2hr}} - 1\right)}$$

$$L = \frac{\mu_0}{2\pi}\left(\ln\frac{2l}{\sqrt{2hr}} - 1\right)$$

$$C = \frac{2\pi\varepsilon_0\varepsilon_r}{\left(\ln\frac{2l}{\sqrt{2hr}} - 1\right)}$$

where :

R = Grounding Resistance (Ohm/m)
G= Grounding conductance $(\text{Ohm.m})^{-1}$
L = Grounding Inductance (H/m)
C = Grounding Capacitance (F/m)
ρ = Resistivity of soil (Ohm-m)
r = Grounding Conductor Radius (m)
l = Conductor lengh (m)

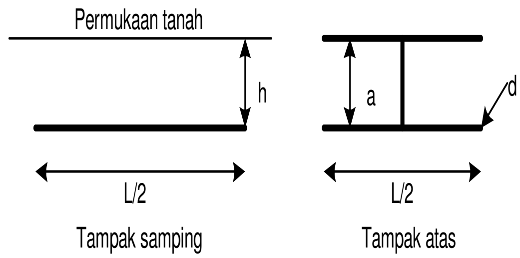


Figure 3. The 2 Electrodes Horizontal Configuration

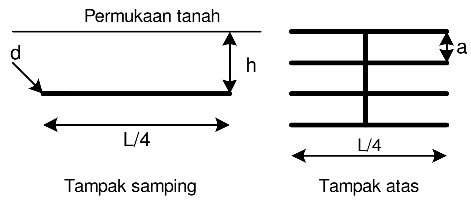


Figure 4. The 4 rods parallelism horizontal cofiguration

h = Depth of conductor burried (m)
d = Diameter of electrode (m)

Horizontal configuration of 2 rods

2 Electrodes are layed parallelism under the ground surface, with about 1 – 1.5 meter depth. (Figure 3)

$$R = \frac{\rho}{2\pi L}\left(\ln \frac{L^4}{163{,}42 h.d.a.A}\right) \qquad Ohm$$

Where :
h = Depth of layed electrode (s) (m)
L = Electrode Leght (m)
a = Electrodes Distance of each other (m)
d = Diameter of electrode (m)

$$A = \sqrt{a^2 + 4h^2}$$

Horizontal configuration of 4 rods

The 4 Rods of electrodes is layed parallelism under the ground surface about 1 – 1.5 m. (Figure 4)
The grounding resistance can be calculated by the S.J. Schwerz formulation :

$$R = \frac{\rho}{2\pi L}\left(\ln \frac{L^8}{2567{,}4.h.d.a.A}\right) \qquad Ohn$$

Where :
h = Depth of layed electrode (s) (m)
L = Electrode Leght (m)
a = Electrodes Distance of each other (m)
d = Diameter of electrode (m)

$$A = \sqrt{a^2 + 4h^2}$$

Grid configuration

The Grid / Mesh configuration of electrical grounding systems is several electrodes are layed horizontal and crossing each other to make the mash. The distance between two conductors must be enough so there's no intefference each other. The depth of the electrodes layer is about 1 – 1.5 meters under the ground surface. (Figure 5)

The Resistance of grid configuration can be done by this formulation:

$$R = \frac{\rho}{2D} + \frac{\rho}{L}$$

Where :
R =Grounding Resistance (Ohm)
ρ = Soil Resistivity (Ohm meter)
D = Total leght of coductors. (meter)
L = Distance between the centre of electrode to the end of conductors (meter)
h = Depth of layed electrode (s) (m)
h<<D

The chaaracteristics of the grounding impedance (resistance) is small enough but rather not stable, for making the stability of grounding impedance the grid

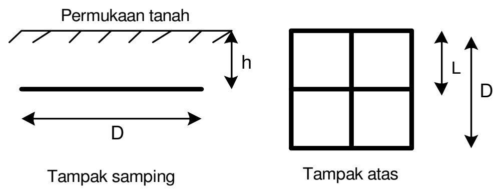


Figure 5. The grid configuration

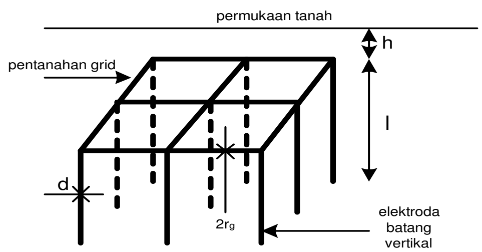


Figure 6. Grid and Vertical Configuration of Grounding Systems(*Rod*)

configuration is added by several vertical rods at several junctions.(Figure 6)

The grounding resistance for one vertical electrode can be calculated by this equation

$$R_0 = \frac{\rho}{2\pi . l}\left(\ln \frac{3.l}{d}\right) \quad Ohm$$

For multi vertical electrodes of grounding systems , the resistance can be calculated by this formulaion

$$R_N = \frac{\rho}{2\pi . N.l}\left(\ln\frac{8.l}{d} - 1 + \frac{2.l}{s}\ln\frac{2.N}{\pi}\right) \quad Ohm$$

Special for vertical paralelism and rectangular shape of grid, the resistance can be calkculated by equation below:

$$R_A = \frac{R_o}{N} \, x \, R_N \quad Ohm$$

For the grid electrodes and layed horizontal under the ground surface, the resistance can be calculated by this equation.

$$R_g = \rho\left[\frac{\sqrt{\pi}}{4\sqrt{A}} + \frac{1}{Lt}\right] \quad Ohm$$

The com bination of grid and verical configuration of grounding systems so the resistance can be calculated by the combination these two systems with formulation :

$$R_t = \frac{R_g . R_A - R_m{}^2}{R_g + R_A - R_m} \quad Ohm$$

Where

R_m = Combination grid and vertical resistance.

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

The result of the above calculation is

$R_o > R_N > R_A > R_g > R_t$

Note :

R = Grounding Resistance (Ohm)

ρ = Soil Resistivity (Ohm meter)

N = Numbre of Vertical Rods

l = Vertical Electrode Lenght (*rod*) (meter)

d = Diamater of electrode (*rod*) (meter)

s = Space between 2 electrodes (meter)

h = Depth of layed electrode (s) (m)

A = Total Grid Area (m^2)

r_g = Electrode radius of *grid*

Lt = Total wide of grid

Potential calculation on and under ground surface area

In this experiment we need special potential prob that can measure voltage / potential in all of the ground area . By knowing the potential of position or coordinate in and on the ground surface so can make the potential pattern and electric field. For identifing the grond potential at each position we can use the La Place Equation for 3 demensions

$$\nabla^2 \phi(x, y, z) = 0$$

$$\nabla^2 \phi(x, y, z) = \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} = 0$$

With the differential equation and the La Place equation for 3 dimensions, so can calculate the potential of all the position in and on groung surface. (Figure 7)

$$\frac{\partial^2 \phi}{\partial x^2} = \frac{\phi_1 + \phi_2 - 2\phi_0}{h^2} \quad \frac{\partial^2 \phi}{\partial y^2} = \frac{\phi_3 + \phi_4 - 2\phi_0}{h^2}$$

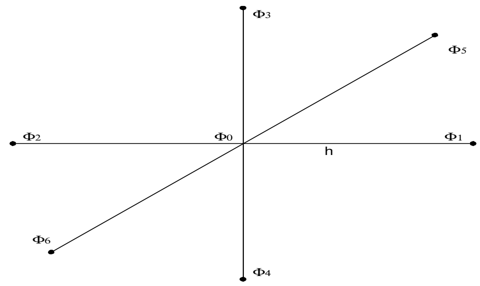


Figure 7. 3 Dimensions for La Place qauations.

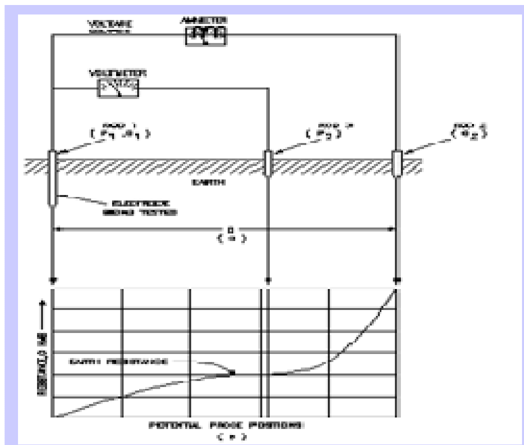


Figure 8. Measurement

$$\frac{\partial^2\phi}{\partial z^2} = \frac{\phi_5 + \phi_6 - 2\phi_0}{h^2}$$

$$\nabla^2\phi(x,y,z) = \frac{\phi1+\phi2+\phi3+\phi4+\phi5+\phi6-6\phi0}{h^2} = 0$$ to manipulate from this equation above , so:

$$\phi0 = \frac{\phi1+\phi2+\phi3+\phi4+\phi5+\phi6}{6}$$

Where :

ϕ1, ϕ2 are potentials at X ordinate

ϕ3, ϕ4 are potentials at Y ordinate

ϕ5, ϕ are potentials at Z ordinate

ϕ0 Calcutaed potential

The calculation be done itterative untill the potential error at each coordinate is less than the tolerance value.

MEASUREMENT

MEASUREMENT METHOD

In this experiments we use the *fall of potential Methode* which it is common grounding measurement. The measuring systems can be seen at Figure 8 above. This measuring systems consist of current source as power supplai, osciloscope, current rod and potential rod.

In this measuring method need 2 electrodes (rods) beside of grounding electrode , they are for injecting current in to the ground and for measuring the potential. The resistance or impedance of grounding systems can be calculated by dividing the potential with the current . Actually an resistance is not linear to the distance of cuurent rods and the real value if the comparassion between the distance of current rod to the distance of potential rod about 62 % (Figure 9 and 10)

Experimental equipment

In this experiment use several equipments that they are for indicating the quantity of measurement. :

1. Grounding Electrodes

The simulated electrodes tha's used in this experiment are the copper electrodes with diameter 2,5 mm. The configurations of grounding systems are 2 (two) rods paralel, 4 (four) rods paralel , rectangular and combination of rectangular and rods. All of these configuration of grounding systems are burried under the

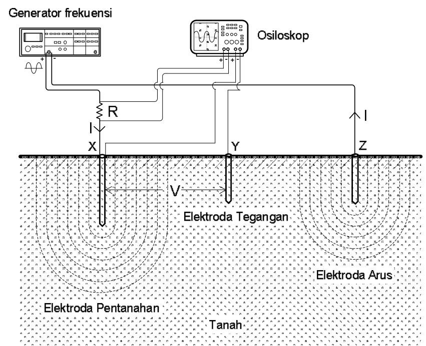


Figure 9. Experiment Circuit of *Fall of Potential Method*

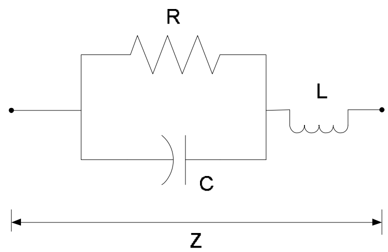


Figure 10. Equivalent Circuit of Grounding Impedance for alterting cureent

Figure 11. Block Diagram of Measuring Circuit

ground surface about 5 mm depth.

2. Box

The box dimension is 1,5 m x 1,5 m x 0,75 m which is filled by the soil that will be analized it's characteristcs.

3. Frequency Generator

Frequency Generator as the power supplai which generate sinusoidal current about 0.01 A and frequency range are 50 Hz-200 KHz. The cuurent will be injected to grounding systems

4. Digital Oscilloscope

Digital oscilloscope for measuring the voltage drop and the injected current included the phase angle between them

Block diagram of measuring circuits

The constant current from frquency generator is injected to the grounding systems so the potential / voltage drop is measured by osciloscope at the several point on the ground surface and in the ground surface . These experiments were done to all of the several combinations of grounding systmes horizontal and grid. The result of measurement about current, voltage drop and phase angle at many frequency can be seen at the below tables (Figure 11)

EXPERIMENT RESULTS

The influence of frequency to Grounding Impedance

The grounding impedance can be calculated from several experiment data and use the formula of equation:

$$Z = \frac{V}{I}$$

Where:

Z = Grounding Impedance (Ohm)

V = The Voltage at the measuring pont (Volt)

I = Injected current (Ampere)

Tabel 1. Grounding Impedance for 2 Rods Paralel

f(Hz)	Impedansi(Ohm)			
	z = 5cm	z = 15cm	z = 30cm	z = 70cm
50	17.289	15.624	11.927	1.328
1000	16.697	15.058	11.488	1.279
5000	15.886	14.338	10.936	1.216
10000	15.692	14.162	10.805	1.202
50000	14.933	12.853	9.870	0.910
100000	14.768	12.288	9.118	0.901
200000	14.390	11.941	8.883	0.875

Tabel 2. Grounding Impedance for 4 Rods Paralel

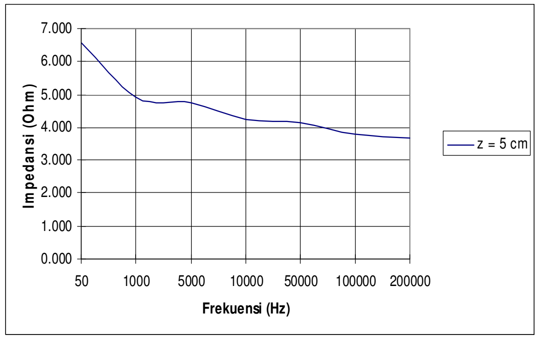
f(Hz)	Impedansi(Ohm)			
	z = 5cm	z = 15cm	z = 30cm	z = 70cm
50	16.337	14.889	11.401	1.271
1000	15.801	14.373	10.994	1.225
5000	15.096	13.747	10.519	1.172
10000	15.083	13.561	10.292	0.937
50000	13.072	12.691	9.509	0.903
100000	13.036	12.194	8.891	0.874
200000	12.966	11.906	8.087	0.845

Tabel 3. Grounding Impedance for Rectangular Grid

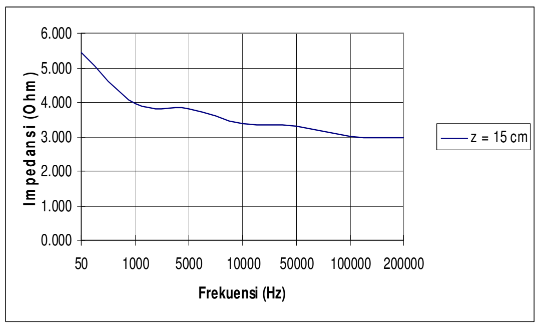
f(Hz)	Impedansi(Ohm)			
	z = 5cm	z = 15cm	z = 30cm	z = 70cm
50	10.279	9.631	7.843	0.882
1000	8.654	7.485	5.858	0.655
5000	7.509	6.489	5.073	0.566
10000	7.178	6.201	4.843	0.540
50000	6.161	5.310	4.144	0.460
100000	6.114	5.237	4.051	0.448
200000	5.794	4.948	3.820	0.422

Tabel 4. Grounding Impedance for Combination of Rectangular Grid and Rods

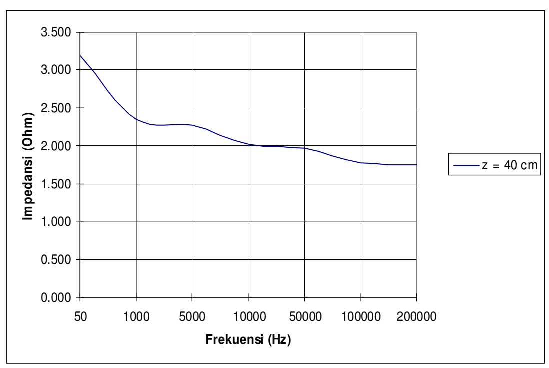
f(Hz)	Impedansi(Ohm)			
	z = 5cm	z = 15cm	z = 30cm	z = 70cm
50	9.367	8.116	6.370	0.714
1000	6.599	5.685	4.428	0.492
5000	5.438	4.674	3.630	0.401
10000	5.144	4.419	3.427	0.378
50000	4.128	3.513	2.714	0.298
100000	3.993	3.366	2.563	0.279
200000	3.849	3.237	2.461	0.267



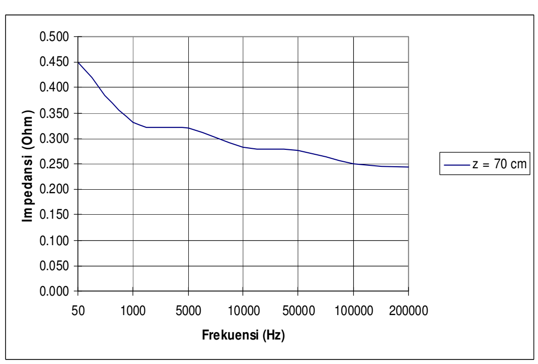
Z = 5 cm



Z = 15 cm



Z = 30 cm



Z = 70 cm

Figure 12. Grounding Impedance Vs Frequency

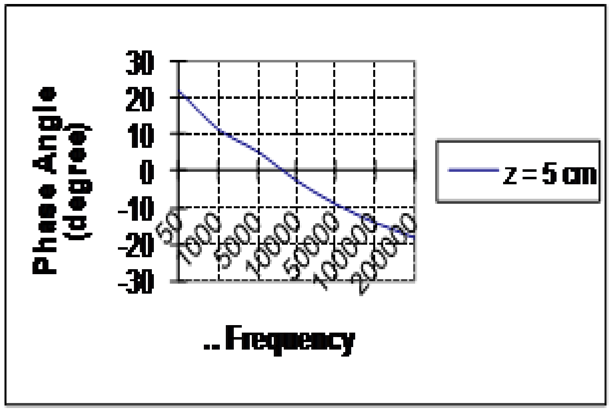


Figure 13. Phase Angle Vs Frequency for 2 Horizontal Paralel Rods

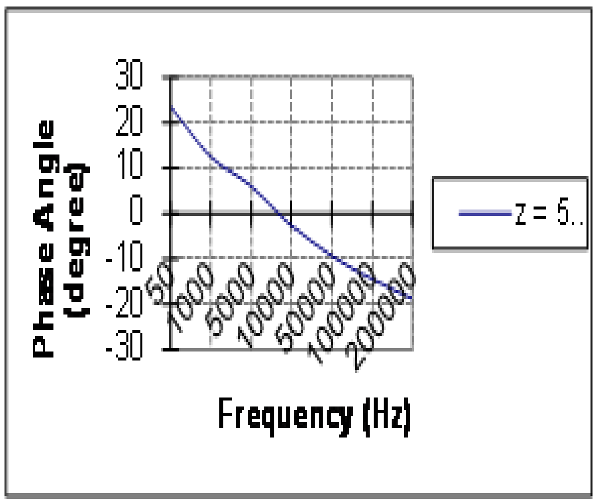


Figure 14. Phase Angle Vs Frequency for 4 Horizontal Paralel Rods

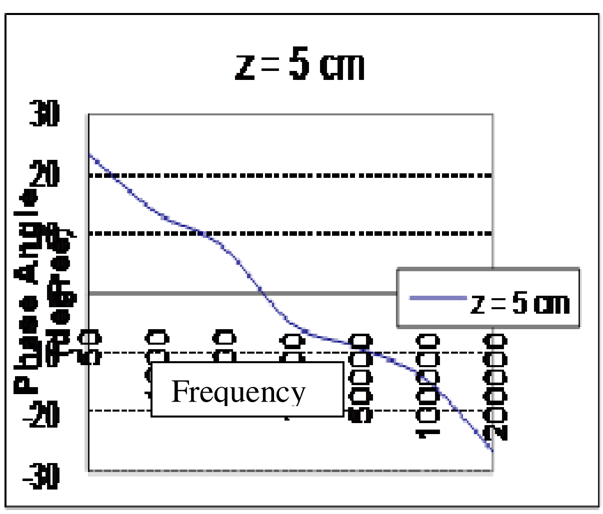


Figure 15. Phase Angle Vs Frequency for Rectangular Grid.

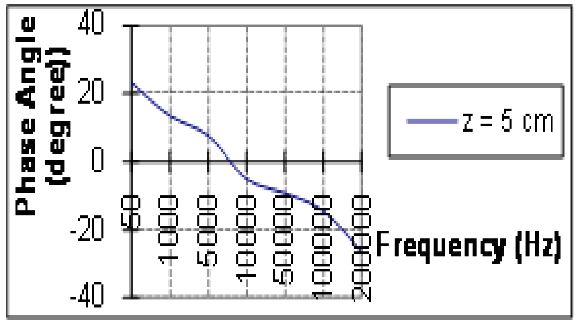


Figure 16. Phase Angle Vs Frequency for Combination of Rectangular Grid and Rods

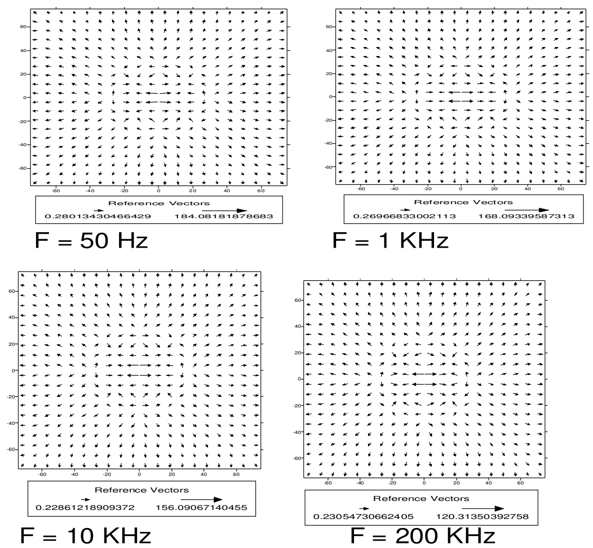


Figure17. Electric Field Pattern for 2 Horizontal Paralel Rods at 5 cm depth

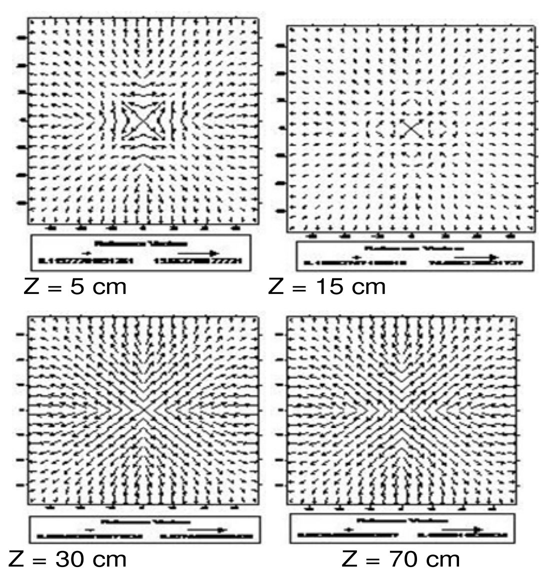


Figure 18. Electric Field Pattern for Grid Configuration for many depth (z) at frequency f = 1 KHz

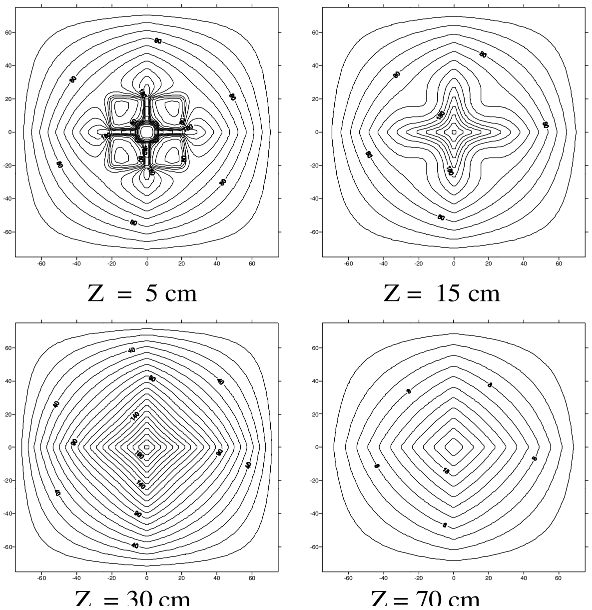


Figure 19. Equipotential Pattern for Grid Configuration for many depth (z) at frequency f = 1 KHz

From Table 1 and Table 2 above can be mentioned that the value of grounding impedance will decrease if used 4 parale rods than 2 paralel rods, that it means that more electrodes will make more effective grounding systems. Actually we must also consider the distance between the 2 rods . For high frequency the grounding impedance will decrease too, and the measurement data like this maybe the inductance of grounding systems not yet inluencies of impedance. The depth Z also make the experiment data of grounding impedance will decrease , from this phenomena can be indicated that the electrode prob for measuring the voltage not allowed too long , because can make the confuse indication . This measurement with the long prob for the measuring voltage is for calculating the distribution of under ground voltage and to calculate the electric field in the ground. By knowing the distribution of under gournd voltage and electric field can be perdicted the condition of grounding systems , and at the later can make the pro9cedure how to reduce the impedance of grounding systems.

From Table 3 and Table 4 special for Grid and combination of Grid and Rods configuration can be seen that the grounding impedance are vary to the frequency and to the depth of measuring prob. For high frequency, the grounding impedance will decrease and impedance of the grid configuration is higher than the combination of grid and rods, at the same frequency and the same depth of measuring prob. The detail pattern of these data can be seen at Figure 12

Phase angle of grounding systems

According to the basic of experiments that the injected current is sinussoidal frequency variable, and the range of this frequency is from 50 Hz untill 200 KHz so the result of this experiment indicate that at the low frequency the grounding impedance is capacitive and at the high frequency trend to inductive . The curve of this data for all tipe of configuration can be seen at Figure 13; 14; 15 and 16 below. The frequency changes of the impedance about 5 KHz - 10 KHz

Electric field and equipotential pattern in the ground surface

The pattern of elctric field and equipotential in the ground surface specially for the 2 horizontal paralel rods and grid cofiguration of grounding systems for many frequency at 5 cm depth and for many depth at 1 KHz can be seen at Figure 17-19 below.

CONCLUSIONS

According to experiment data so can be concluded that the characteristics of grounding impedance for horizontal and grid configuration are :

1. The measurement of grounding impedance with the sinusoidal injected current to indicate that the frequency of current is very influence to the grounding impedance
2. The grounding impedance for 2 horizontal paralel rods is higher tahn the 4 horizontal paralel rods . This phenomena also occur for the grounding impedance for grid is higher tahn the grounding impedance for cobination of grid – rods.

3. The volume and surface area of grounding conductors is very importance for grounding impedance , for the configuration that have the higher volume or surface area will make the grounding impedance will be amller than the configuration that have the small / little volume or surface area.
4. The grounding impedance for grid configuration is higher than the grounding impedance of combination gird – rod configuration, and the grid configuration is smaller than the horizontal configuration, so the grounding impedance also depends on the configuration.
5. The characteristcs of grounding impedance at low frequency trend to higher than if the grounding impedance is injected by the high frequency.
6. According bto experiment data that the grounding impedance at frequency f = 50Hz-5KHz trends to inductive and at frequency f = 5KH-10KHz the grounding impedance trends to capacitive
7. The pattern of equipotential and elctric field in the grounding surface can be used for analyzing the characteristics of current that make the low or huigh of grounding impedance.

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