CHAPTER 4

EMPIRICAL FORMULAS FOR TWO LAYER SOIL RESISTIVITY MODEL AND SCALE MODEL

There is need to develop the empirical formulas to calculate parameters of design of grounding system using two layer soil resistivity model as discussed in the previous chapter. These empirical formulas can be used for complete designing of grounding system. These empirical formulas can be used in the developed program RPDGS and can be further validated with SES Autogrid software for case studies.

Scale model is the best method to understand the behavior of any grounding system which include impact of addition of electrodes, mesh size , length of electrodes, depth of grounding mesh , resistivity of soil, layers of soils etc. The main parameters of any grounding system like resistance, step and touch potential may be computed with the help of these scale models for both uniform and two layer soil resistivity model.

4.1 Empirical Formulas to Calculate Parameters of Design of Grounding System in Two Layer Soil Model

Parameters whichneed to be computed for accurate designing of grounding system in two layer soil model are tolerable (permissible) touch and step potential, grid resistance, actual touch and step potential.

The steps involved in development of empirical formulas for designin of the grounding of substation is given below :

1. Study of standards related to grounding system. [1-5].
2. Collection of DATA of different substation of 400 kV , 220 kV and 66 kV related to designing of grounding design.
3. Selection of safety parameters affecting design of the grounding system.

4. Study the impact of variation of each parameter in designing of grounding system
5. Development of Multiplying Factor which can be used with available formulas to give the desired results.
6. Development of Computer Program RPDGS with the help of MATLAB GUI.
7. Comparison of results with SES Software for Grounding i.e.ProAutogrid.

Empirical formulas which can be used to compute the apparent resistivity of two layer soil model of grounding grid has been developed based on experiments with different data available. These formulas as shown in table 4.1 are further used in computer program RPDGS[21-26].

Two constants are used in the available formulas for calculation of grid resistance of grounding system laid in two layer soil resistivity model i.e.

1. mf= $\frac{\rho_1}{\rho_2}$ **(4.1)**

2. $rr = \frac{\rho_2}{\rho_1}$ **(4.2)**

The other terms used in the empirical formula are given below :

$\rho 1$ = Resistivity of Layer 1

$\rho 2$ = Resistivity of Layer 2

ρa = Apparent Resistivity

Rg= Grid Resistance

L_T=Total Length of grid conductor

Table 4.1 Empirical Formulas for Apparent Resistivity and Grid Resistance

CASE	SUB-CASE	FORMULA/ EQUATION
$\rho 2 < \rho 1$ (NEGATIVE K)	1< mf≤ 3	$\rho_a = \dfrac{\rho_1}{\left[1+[(mf)-1]\left[1-e^{\frac{\mathrm{mf}}{K(0.9h+0.9H)}}\right]\right]}$
$\rho 2 < \rho 1$ (NEGATIVE K)	3< mf≤5	$\rho_a = \dfrac{\rho_1}{\left[1+[(mf)-1]\left[1-e^{\frac{\mathrm{mf}}{K(1.9h+1.9H)}}\right]\right]}$
$\rho 2 < \rho 1$ (NEGATIVE K)	mf > 5	$\rho_a = \dfrac{\rho_1}{\left[1+[(mf)-1]\left[1-e^{\frac{\mathrm{mf}}{K(4.5h+4.5H)}}\right]\right]}$
$\rho 2 > \rho 1$ (POSITIVE K)	1<rr≤ 3	$\rho_a = \rho 2 \times \left[1+[(rr)-1]\left[1-e^{\frac{-1}{K*\mathrm{mf}\,(1.5h+1.5H)}}\right]\right]$
$\rho 2 > \rho 1$ (POSITIVE K)	3<rr≤5	$\rho_a = \rho 1 \times \left[1+[(rr)-1]\left[1-e^{\frac{-1}{K*\mathrm{mf}\,(2.1h+2.1H)}}\right]\right]$
$\rho 2 > \rho 1$ (POSITIVE K)	rr> 5	$\rho_a = \rho 1 \times \left[1+[(rr)-1]\left[1-e^{\frac{-1}{K*\mathrm{mf}\,(4.5h+4.5H)}}\right]\right]$
GRID RESISTANCE ($\boldsymbol{R_g}$)	$\rho = \rho_a$	$\boldsymbol{R_g = \rho_a \left[\frac{1}{L_T} + \frac{1}{\sqrt{20.A}}\left(1 + \frac{1}{1 + h.\sqrt{20/A}}\right)\right]}$

4.2 Example / Case Study for Designing of Grounding System:

First of all resistivity of soil is measured in all direction with different electrode spacing and soil model is derived from all these measurements. In this study six cases of two layer resistivity models are considered with positive and negative reflection factors as shown in Table 4.2& 4.3 respectively.

Table 4.2Case Studies of Two Layer Soil Model (+K)

CASE NO.	ρ_1 (OHM-M) RESISTIVITY OF LAYER 1	ρ_2 (OHM-M) RESISTIVITY OF LAYER 2	H (Meter) HEIGHT OF LAYER 1
1	100	200	3
2	100	500	3
3	100	1000	3

Table 4.3Case Studies of Two Layer Soil Model (- K)

CASE NO.	ρ_1 (OHM-M) RESISTIVITY OF LAYER 1	ρ_2 (OHM-M) RESISTIVITY OF LAYER 2	H (Meter) HEIGHT OF LAYER 1
4	200	100	3
5	500	100	3
6	1000	100	3

Complete data and dimensions of 220/33 kV Air Insulated Substation (AIS) & Gas Insulated Substation (GIS) with two layer soil resistivity model is given below in Table 4.4.

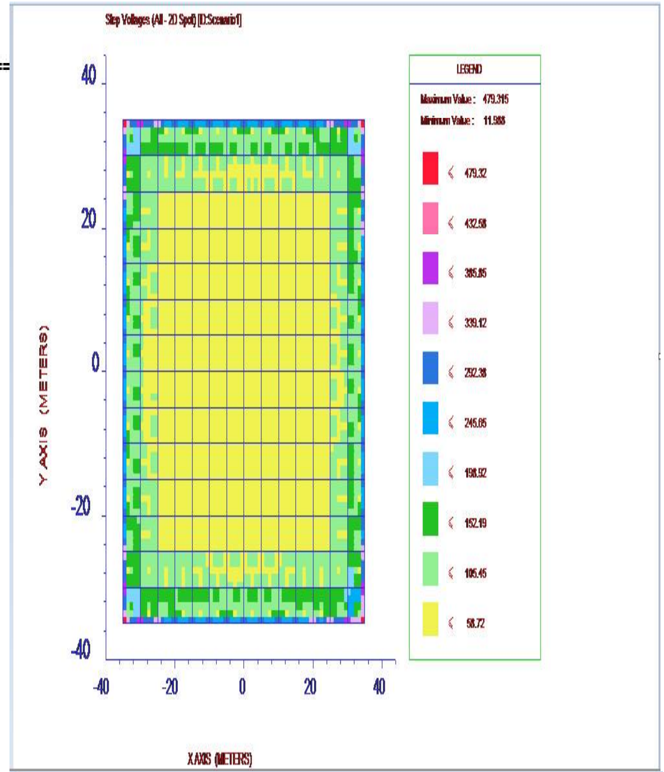
Table 4.4 Data of Substation for Designing of Grounding System

Length of Grounding Grid (Lx)	70 m
Breadth of Grounding Grid (Ly)	70 m
Number of Ground rods (L_R)	23 no
Length of Ground rod (Lr)	3 m
Fault Current (Isc)	10 kA
Duration of Fault Current (t_f)	1 sec.
Duration of Shock Current (t_s)	1 sec.
Ambient Temperature	50 degree Celsius
Resistivity of Surface Material (Gravel)	3000 Ohm- m
Height of the Gravel (hs)	15 cm
Conductor spacing (D)	5 m
Depth of Burial of Grounding Grid (h)	0.6 m
Diameter of Ground rod of Mild Steel (d)	40 mm
Split factor of SCC	1

Above mentioned data is used to compute parameters for grounding grid design for high voltage substations. In our study conductor spacing of 5 meter for designing of grounding system is taken. However, RPDGS can compute optimum spacing required to meet all the parameters for safe designing of grounding system.

The output results given by Computer software SES Autogrid Pro for case 1 i.e. GPR, Step Potential and Touch Potential are shown in figure 4.1 (a), 4.1 (b) and 4.3(c) respectively.

```
===========< G R O U N D I N G   ( SYSTEM INFORMATION SUMMARY ) >=======

Run ID.................................: Scenario1
System of Units .......................: Metric
Earth Potential Calculations...........: Single Electrode Case
Type of Electrodes Considered..........: Main Electrode ONLY
Soil Type Selected.....................: Multi-Layer Horizontal
SPLITS/FCDIST Scaling Factor...........:   1.0000
1
1

    MULTI-LAYER EARTH CHARACTERISTICS USED BY PROGRAM


    LAYER  TYPE  REFLECTION    RESISTIVITY    THICKNESS
     No.         COEFFICIENT   (ohm-meter)     (METERS)
    ----- ------ ------------ ------------ -------------
      1   Air      0.00000    0.100000E+11    Infinite
      2   Soil   -0.999990      100.000      3.00000
      3   Soil    0.333333      200.000       Infinite
1

CONFIGURATION OF MAIN ELECTRODE
===============================

Original Electrical Current Flowing In Electrode..:  10000.    amperes
Current Scaling Factor (SPLITS/FCDIST/specified)..:  1.0000
Adjusted Electrical Current Flowing In Electrode..:  10000.    amperes
Number of Conductors in Electrode.................:   53
Resistance of Electrode System....................:  1.0866    ohms


SUBDIVISION
===========
Grand Total of Conductors After Subdivision.:   468


Total Current Flowing In Main Electrode......:  10000.    amperes
Total Buried Length of Main Electrode........:  2169.0    meters


EARTH POTENTIAL COMPUTATIONS
============================

Main Electrode Potential Rise (GPR).....:  10866.    volts
```



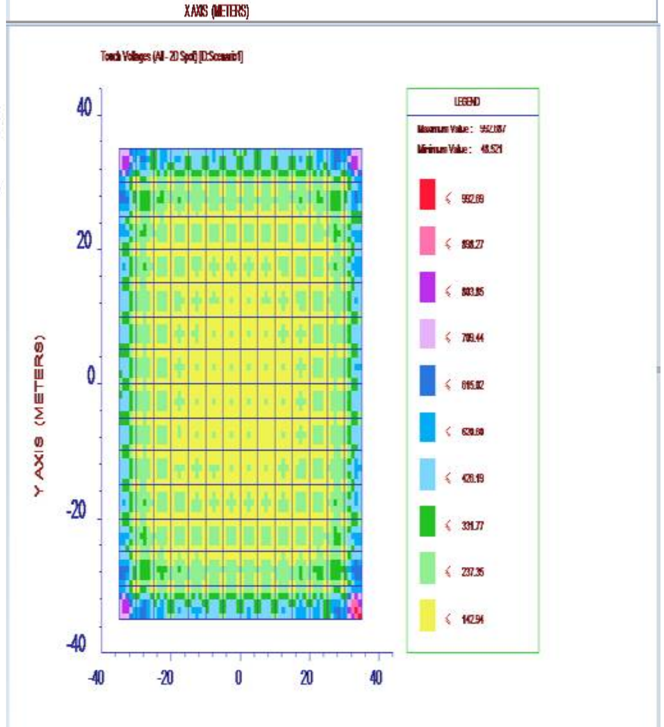


Fig 4.1 (a) GPR Computation by Autogrid Software ,(b)Step Potential Plot by Autogrid Software , (c) Touch Potential Plot by Autogrid Software-Case 1

The output results given by developed program RPDGS for case 1 is shown in figure 4.2 (a) and 4.2 (b) respectively.

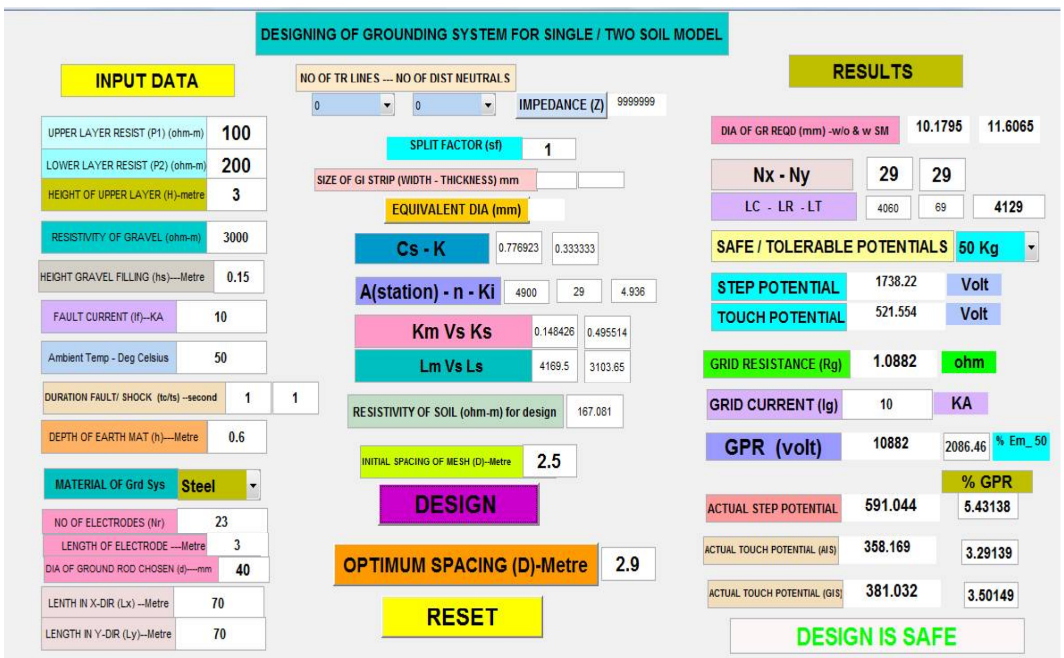
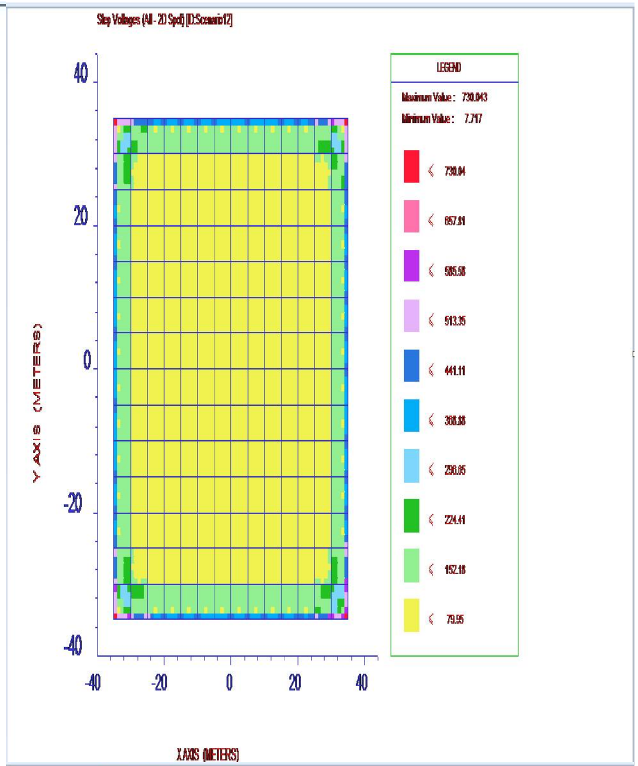


Fig 4.2 Complete Design by RPDGS CASE-1 (a) Unsafe , (b) Safe

The output results given by Computer software SES Autogrid Pro for case 2 i.e. GPR, Step Potential and Touch Potential are shown in figure 4.3(a), 4.3(b) and 4.3(c) respectively.

```
DATE OF RUN (Start)= DAY 25 / Month  2 / Year 2016
STARTING TIME= 16:56:58:23


==========< G R O U N D I N G   ( SYSTEM INFORMATION SUMMARY ) >==========

Run ID..................................: Scenario12
System of Units .........................: Metric
Earth Potential Calculations................: Single Electrode Case
Type of Electrodes Considered...............: Main Electrode ONLY
Soil Type Selected.........................: Uniform or Two-Layer Horizontal
SPLITS/FCDIST Scaling Factor................:   1.0000
1



                 EARTH PARAMETERS FOR HORIZONTALLY-LAYERED SOIL
                 ----------------------------------------------

         TOP LAYER RESISTIVITY    =  100.00      ohm-meters
         BOTTOM LAYER RESISTIVITY =  500.00      ohm-meters
         REFLECTION COEFFICIENT   =    0.666667  per unit
         TOP LAYER HEIGHT         =  3.0000      METERS

1

CONFIGURATION OF MAIN ELECTRODE
===============================

Original Electrical Current Flowing In Electrode..:  10000.    amperes
Current Scaling Factor (SPLITS/FCDIST/specified)..:  1.0000
Adjusted Electrical Current Flowing In Electrode..:  10000.    amperes
Number of Conductors in Electrode................:   53
Resistance of Electrode System...................:  2.2305    ohms


SUBDIVISION
===========
Grand Total of Conductors After Subdivision.:   468


Total Current Flowing In Main Electrode......:  10000.    amperes
Total Buried Length of Main Electrode........:  2169.0    meters


EARTH POTENTIAL COMPUTATIONS
============================

Main Electrode Potential Rise (GPR).....:  22305.    volts
```



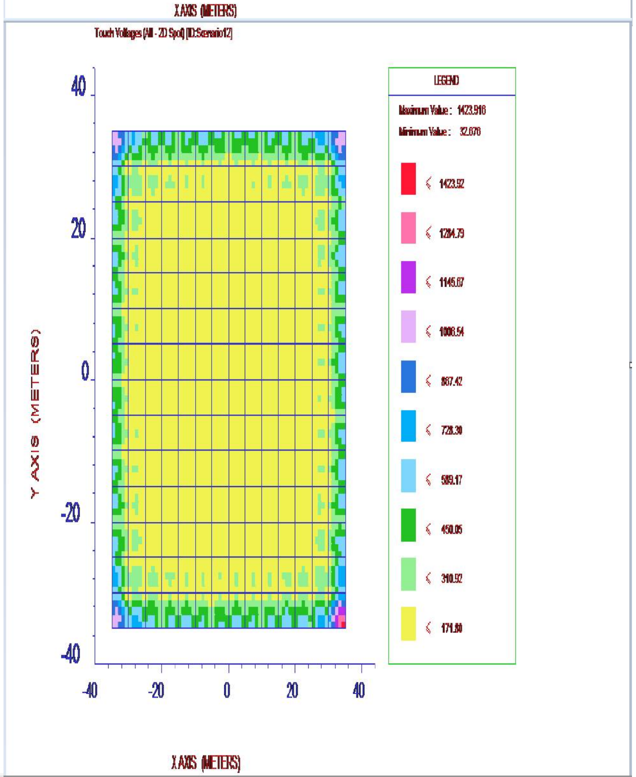


Fig 4.3 (a) GPR Computation by Autogrid Software ,(b)Step Potential Plot by Autogrid Software , (c) Touch Potential Plot by Autogrid Software-Case 2

The output results given by developed program RPDGS for case 2 are shown in figure 4.4 (a) and 4.4 (b) respectively.

Fig 4.4Complete Design by RPDGS CASE-2 (a) Unsafe , (b) Safe

The output results given by Computer software SES Autogrid Pro for case 3 i.e. GPR, Step Potential and Touch Potential are shown in figure 4.5(a), 4.5(b) and 4.5(c) respectively.

```
STARTING TIME= 17:05:23:84

===========< G R O U N D I N G   ( SYSTEM INFORMATION SUMMARY ) >==========

Run ID.....................................: Scenario16
System of Units ...........................: Metric
Earth Potential Calculations...............: Single Electrode Case
Type of Electrodes Considered..............: Main Electrode ONLY
Soil Type Selected.........................: Multi-Layer Horizontal
SPLITS/FCDIST Scaling Factor...............:   1.0000
1
1


    MULTI-LAYER EARTH CHARACTERISTICS USED BY PROGRAM


    LAYER  TYPE  REFLECTION    RESISTIVITY    THICKNESS
     No.         COEFFICIENT   (ohm-meter)     (METERS)
    ----- ------ ------------ ------------ ------------
      1   Air     0.00000      0.100000E+11     Infinite
      2   Soil  -0.999990       100.000      3.00000
      3   Soil   0.818182       1000.00         Infinite
1

CONFIGURATION OF MAIN ELECTRODE
===============================

Original Electrical Current Flowing In Electrode..:  10000.    amperes
Current Scaling Factor (SPLITS/FCDIST/specified)..:  1.0000
Adjusted Electrical Current Flowing In Electrode..:  10000.    amperes
Number of Conductors in Electrode.................:   53
Resistance of Electrode System....................:  3.6442    ohms


SUBDIVISION
===========
Grand Total of Conductors After Subdivision.:  468


Total Current Flowing In Main Electrode......:  10000.    amperes
Total Buried Length of Main Electrode........:  2169.0    meters


EARTH POTENTIAL COMPUTATIONS
============================

Main Electrode Potential Rise (GPR).....:  36442.     volts
```

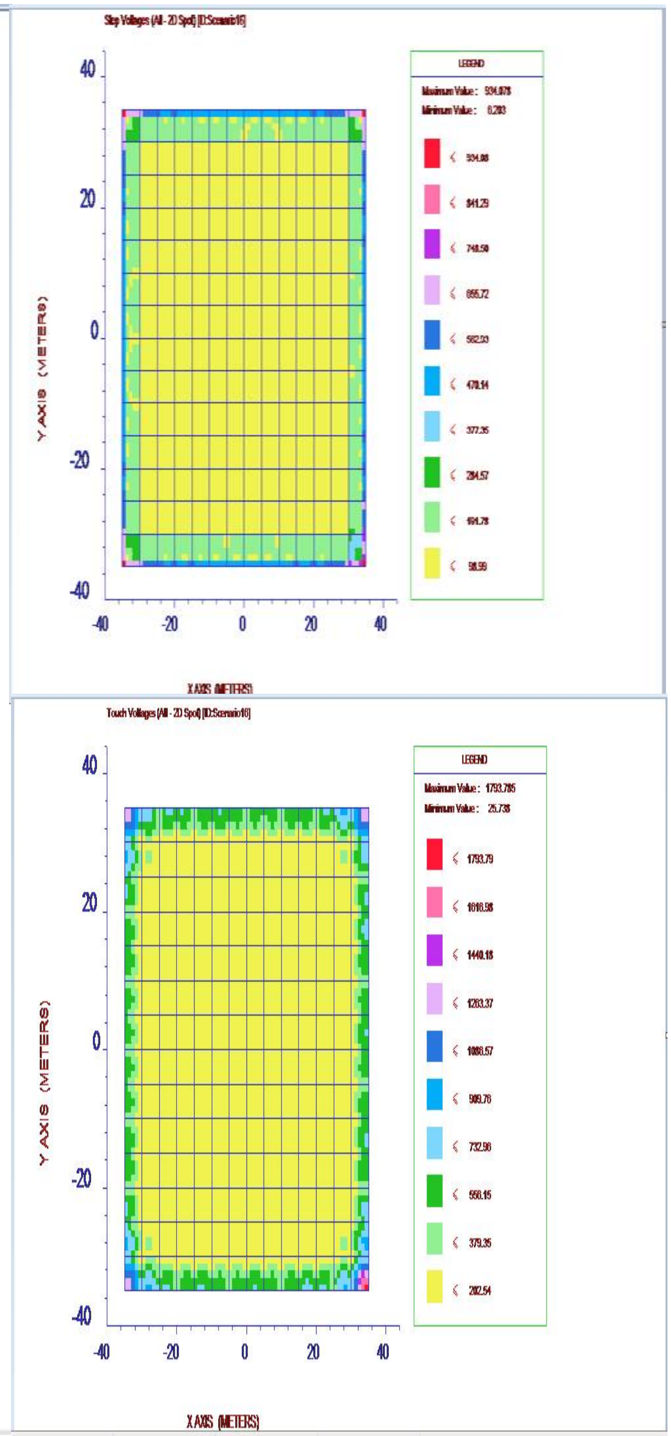


Fig 4.5 (a) GPR Computation by Autogrid Software ,(b)Step Potential Plot by Autogrid Software , (c) Touch Potential Plot by Autogrid Software-Case 3

The output results given by developed program RPDGS for case 3 are shown in figure 4.6(a) and 4.6(b) respectively.

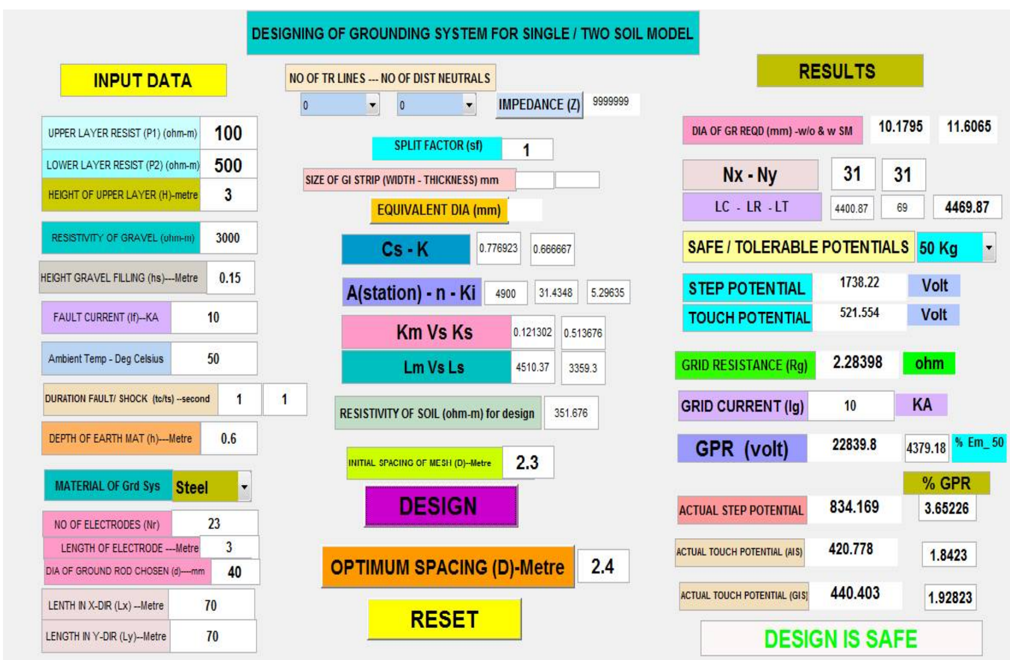


Fig 4.6Complete Design by RPDGS CASE-3 (a) Unsafe , (b) Safe

The output results given by Computer software SES Autogrid Pro for case 4 i.e. GPR, Step Potential and Touch Potential are shown in figure 4.7(a), 4.7(b) and 4.7(c) respectively.

```
==========< G R O U N D I N G   ( SYSTEM INFORMATION SUMMARY ) >==========

Run ID.................................: Scenario2
System of Units .........................: Metric
Earth Potential Calculations...............: Single Electrode Case
Type of Electrodes Considered.............: Main Electrode ONLY
Soil Type Selected.......................: Multi-Layer Horizontal
SPLITS/FCDIST Scaling Factor..............:   1.0000
1
1

   MULTI-LAYER EARTH CHARACTERISTICS USED BY PROGRAM

   LAYER  TYPE  REFLECTION    RESISTIVITY    THICKNESS
    No.         COEFFICIENT   (ohm-meter)     (METERS)
   ----- ------ ------------ ------------ ------------
     1   Air     0.00000     0.100000E+11    Infinite
     2   Soil   -0.999990     200.000      3.00000
     3   Soil   -0.333333     100.000        Infinite
1

CONFIGURATION OF MAIN ELECTRODE
===============================

Original Electrical Current Flowing In Electrode..:  10000.    amperes
Current Scaling Factor (SPLITS/FCDIST/specified)..:  1.0000
Adjusted Electrical Current Flowing In Electrode..:  10000.    amperes
Number of Conductors in Electrode................:    53
Resistance of Electrode System...................:  0.70335   ohms

SUBDIVISION
===========
Grand Total of Conductors After Subdivision.:   468

Total Current Flowing In Main Electrode......:  10000.    amperes
Total Buried Length of Main Electrode........:  2169.0    meters

EARTH POTENTIAL COMPUTATIONS
============================

Main Electrode Potential Rise (GPR).....:  7033.5    volts
```

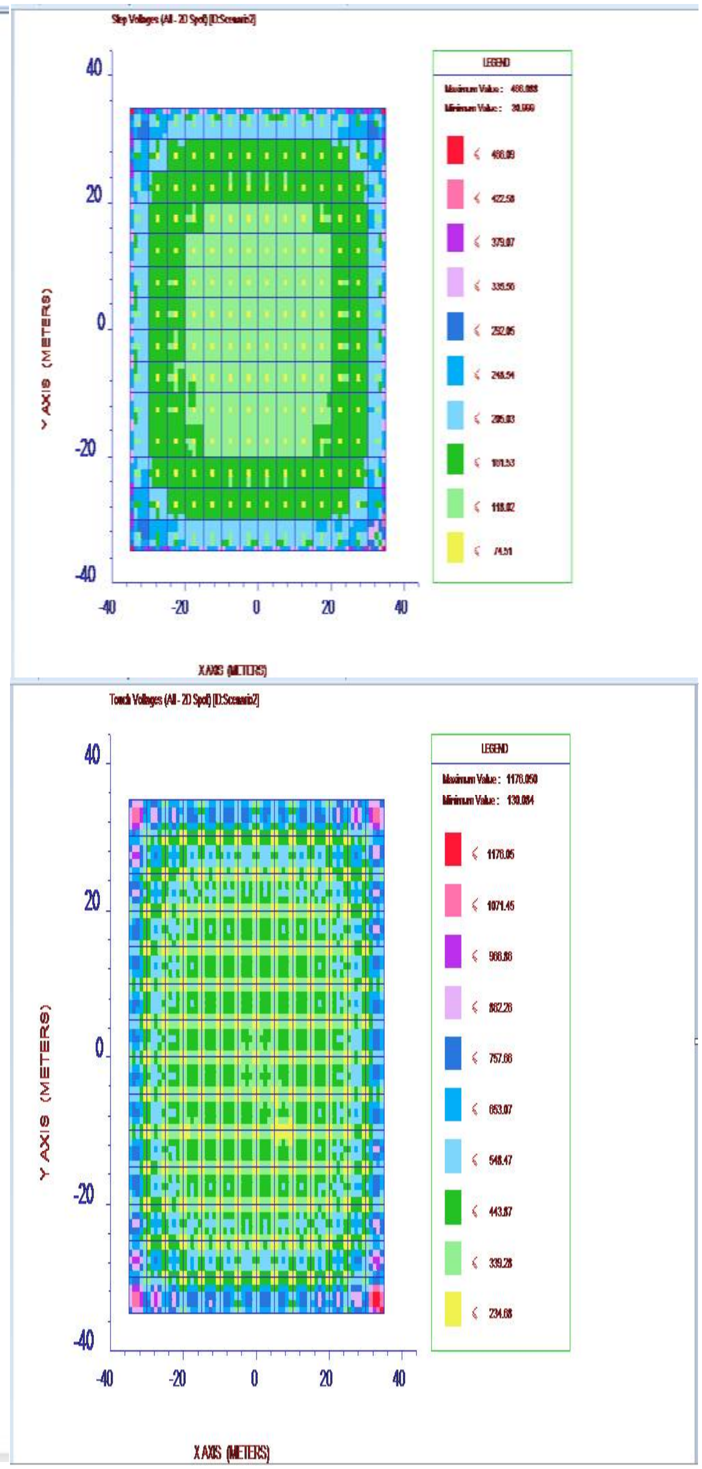


Fig 4.7 (a) GPR Computation by Autogrid Software, (b) Step Potential Plot by Autogrid Software , (c) Touch Potential Plot by Autogrid Software-Case 4

The output results given by developed program RPDGS for case 4 are shown in figure 4.8(a) and 4.8(b)respectively.

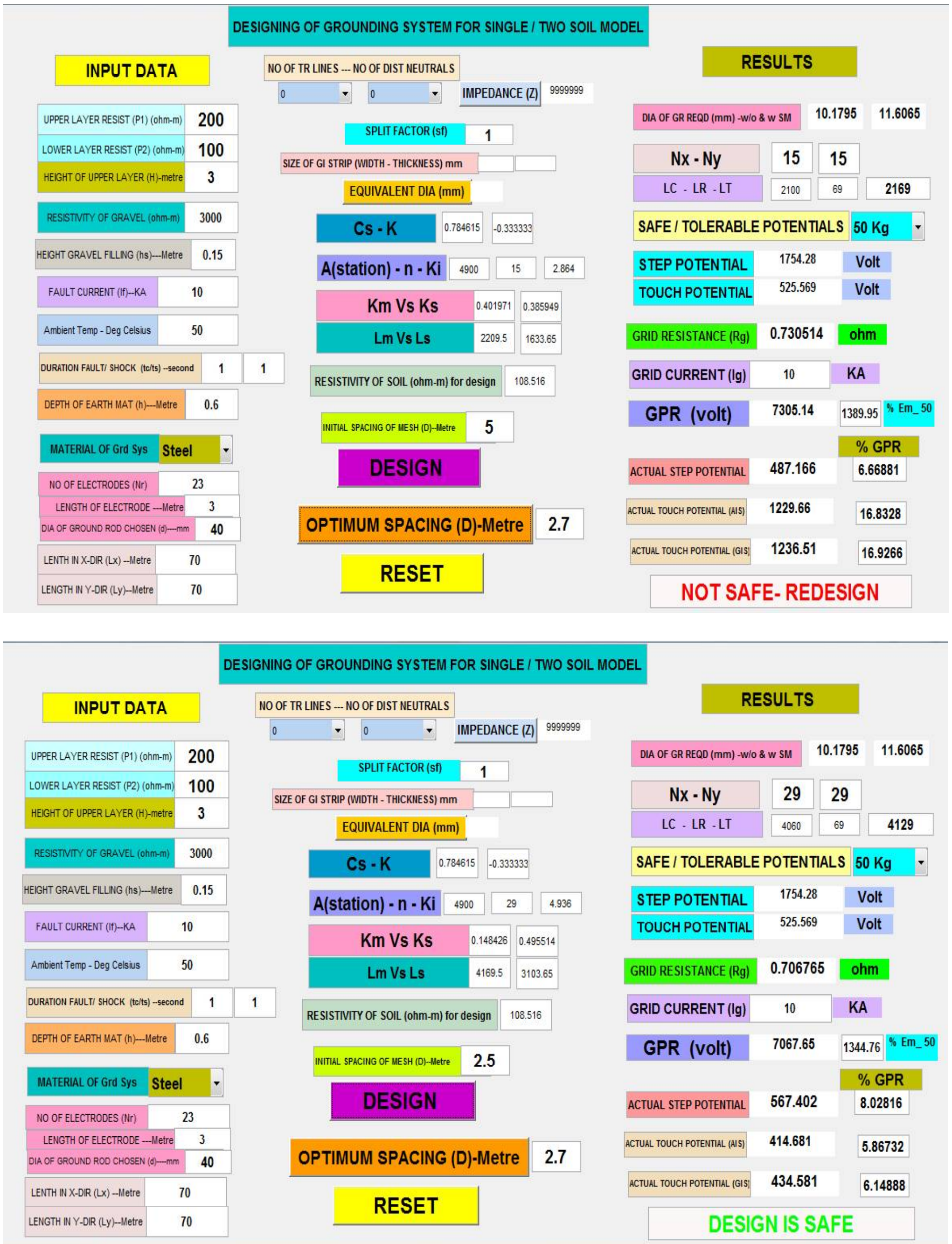
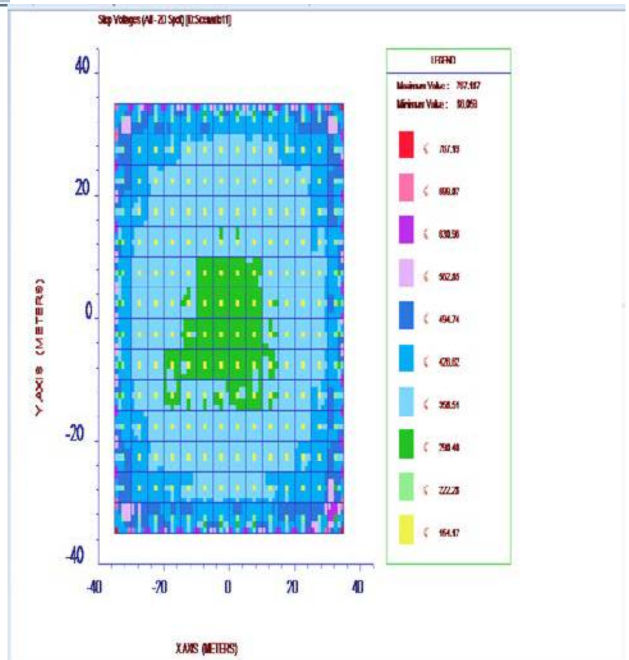


Fig 4.8Complete Design by RPDGS CASE-4 (a) Unsafe , (b) Safe

The output results given by Computer SES Autogrid Pro for case 5 i.e. GPR, Step Potential and Touch Potential are shown in figure 4.9(a), 4.9(b) and 4.9(c) respectively.

```
DATE OF RUN (Start)= DAY 25 / Month  2 / Year 2016
STARTING TIME= 16:55:57:17


===========< G R O U N D I N G   ( SYSTEM INFORMATION SUMMARY ) >===========

Run ID....................................: Scenario11
System of Units ..........................: Metric
Earth Potential Calculations..............: Single Electrode Case
Type of Electrodes Considered.............: Main Electrode ONLY
Soil Type Selected........................: Uniform or Two-Layer Horizontal
SPLITS/FCDIST Scaling Factor..............:   1.0000
1


             EARTH PARAMETERS FOR HORIZONTALLY-LAYERED SOIL
             ----------------------------------------------

      TOP LAYER RESISTIVITY    =   500.00      ohm-meters
      BOTTOM LAYER RESISTIVITY =   100.00      ohm-meters
      REFLECTION COEFFICIENT   =   -0.666667   per unit
      TOP LAYER HEIGHT         =   3.0000      METERS

1

CONFIGURATION OF MAIN ELECTRODE
===============================

Original Electrical Current Flowing In Electrode..:  10000.     amperes
Current Scaling Factor (SPLITS/FCDIST/specified)..:  1.0000
Adjusted Electrical Current Flowing In Electrode..:  10000.     amperes
Number of Conductors in Electrode.................:   53
Resistance of Electrode System....................:  0.92167    ohms


SUBDIVISION
===========
Grand Total of Conductors After Subdivision.:   468


Total Current Flowing In Main Electrode......:  10000.    amperes
Total Buried Length of Main Electrode........:  2169.0    meters


EARTH POTENTIAL COMPUTATIONS
============================

Main Electrode Potential Rise (GPR).....:   9216.7     volts
```



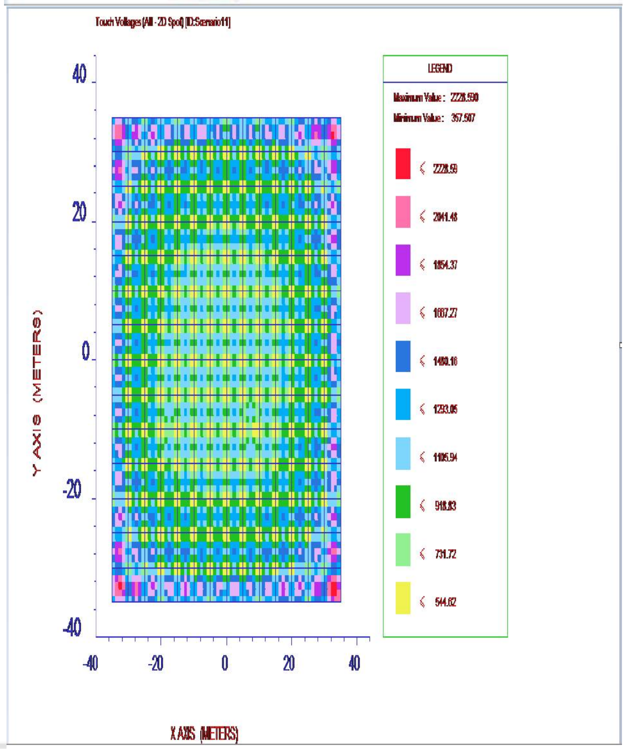


Fig 4.9 (a) GPR Computation by Autogrid Software (b) Step Potential Plot by Autogrid Software (c) Touch Potential Plot by Autogrid Software-Case 5

The output results given by developed program RPDGS for case 5 are shown in figure 4.10(a) and 4.10(b) respectively.

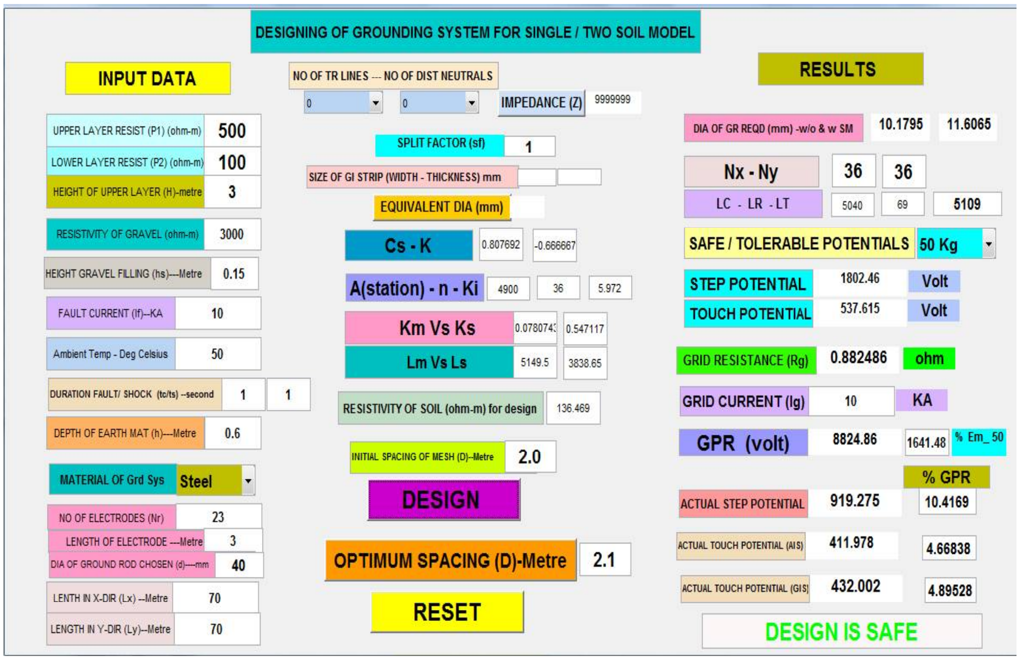
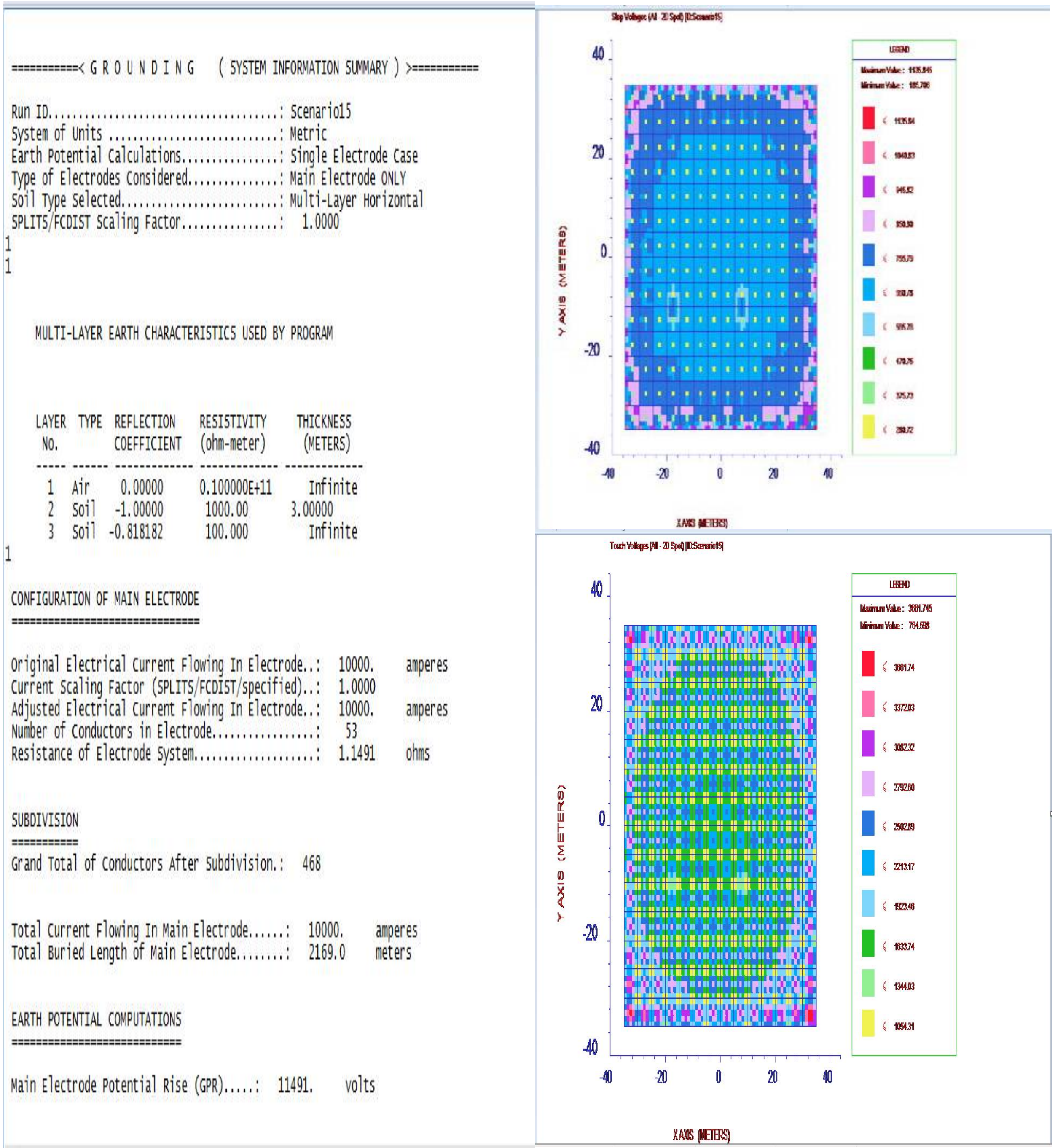


Fig 4.10 Complete Design by RPDGS CASE-5 (a) Unsafe , (b) Safe

The output results given by Computer software SES Autogrid Pro for case 6 i.e. GPR, Step Potential and Touch Potential are shown in figure 4.11(a), 4.11(b) and 4.11(c) respectively.



```
===========< G R O U N D I N G   ( SYSTEM INFORMATION SUMMARY ) >===========

Run ID.................................: Scenario15
System of Units .......................: Metric
Earth Potential Calculations...........: Single Electrode Case
Type of Electrodes Considered..........: Main Electrode ONLY
Soil Type Selected.....................: Multi-Layer Horizontal
SPLITS/FCDIST Scaling Factor...........:   1.0000
1
1

    MULTI-LAYER EARTH CHARACTERISTICS USED BY PROGRAM

    LAYER  TYPE  REFLECTION    RESISTIVITY    THICKNESS
     No.         COEFFICIENT   (ohm-meter)     (METERS)
    ----- ------ ------------ ------------ ------------
      1    Air     0.00000     0.100000E+11    Infinite
      2    Soil   -1.00000      1000.00      3.00000
      3    Soil   -0.818182     100.000        Infinite
1

CONFIGURATION OF MAIN ELECTRODE
===============================

Original Electrical Current Flowing In Electrode..:  10000.     amperes
Current Scaling Factor (SPLITS/FCDIST/specified)..:  1.0000
Adjusted Electrical Current Flowing In Electrode..:  10000.     amperes
Number of Conductors in Electrode.................:    53
Resistance of Electrode System....................:  1.1491     ohms

SUBDIVISION
===========
Grand Total of Conductors After Subdivision.:   468

Total Current Flowing In Main Electrode......:  10000.    amperes
Total Buried Length of Main Electrode........:  2169.0    meters

EARTH POTENTIAL COMPUTATIONS
============================

Main Electrode Potential Rise (GPR).....:  11491.     volts
```


Fig 4.11 (a) GPR Computation by Autogrid Software (b) Step Potential Plot by Autogrid Software (c) Touch Potential Plot by Autogrid Software-Case 6

The output results given by developed program RPDGS for case 6 are shown in figure 4.12(a) and 4.12(b) respectively.

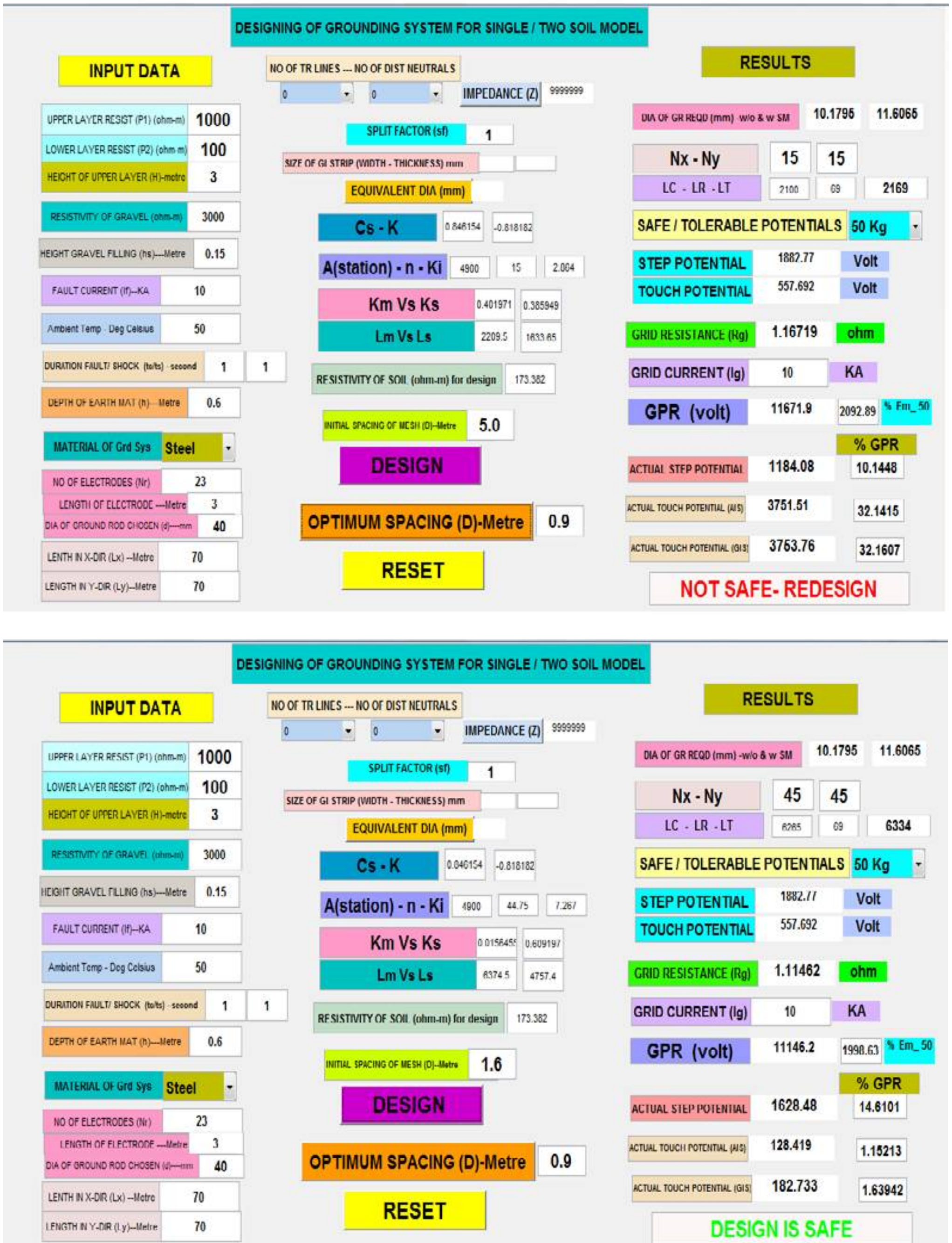


Fig 4.12 Complete Design by RPDGS CASE-6 (a) Unsafe , (b) Safe

4.3 RESULTS: Comparison of results obtained from RPDGS and SES software AutoAutogrid is shown Table 4.5. Touch and step potential are calculated based on case studies and earth surface calculations of the substations.

Table 4.5 Results of Case Studies by RPDGS Software

Case number	Parameter	Results of Developed Program - RPDGS	Results given by SES Grounding Software Autogrid	% Error
1	1.Ground Potential Rise (GPR) (volt)	11248.00	10866.00	3.52
	2.Mesh Potential- Em (volt)	1062.09	992.69	7.05
	3.Step Potential- Es (volt)	507.40	479.30	5.85
2.	1.Ground Potential Rise (GPR) (volt)	23674.00	22305.00	6.14
	2.Mesh Potential- Em (volt)	1539.17	1423.92	8.15
	3.Step Potential- Es (volt)	696.90	730.04	4.65
3.	1.Ground Potential Rise (GPR) (volt)	38826.90	36442	6.54
	2.Mesh Potential- Em (volt)	1803.10	1793.79	0.55
	3.Step Potential- Es (volt)	947.26	934.08	1.41
4.	1.Ground Potential Rise (GPR) (volt)	7305.14	7033.50	3.86
	2.Mesh Potential- Em (volt)	1229.66	1176.00	4.42
	3.Step Potential- Es (volt)	487.16	466.00	4.50
5.	1.Ground Potential Rise (GPR) (volt)	9186.10	9216.10	3.25
	2.Mesh Potential- Em (volt)	2370.74	2228.59	3.94
	3.Step Potential- Es (volt)	730.74	767.18	4.82
6.	1.Ground Potential Rise (GPR) (volt)	11671.90	11491.00	1.57
	2.Mesh Potential- Em (volt)	3751.51	3661.74	2.45
	3.Step Potential- Es (volt)	1184.08	1135.84	4.30

4.3.1 Conclusion:

There are three parameters of grounding design i.e. GPR, Mesh Potential (Em) and Step Potential (Es) calculated by RPDGS which are compared with SES Auto grid pro.

It is clear from above case studies that the percentage errors (maximum)of RPDGS software are in the range of 0.55 to 8.15

4.4 Experiment for Single / Uniform Layer and Two Layer Soil Model: The Following Experiments [2, 22-25] were Carried Out:

4.4.1 Name and Objective of Experiment: Analysis of potential distribution of substation using Scale Model for both uniform and two layer soil resistivity models to calculate the earth surface potential, step potential, mesh potential and earth resistivity testing by making a model of the substation.

4.4.2 Apparatus Required:

1. 45cm X 45cm mesh made of GI wire (for Uniform Layer Soil Model)
2. 25cm X 25cm mesh made of GI wire (for Two Layer Soil Model)
3. Acrylic sheet model 60cm X 60cm and 40cm X 40cm for substation Grounding.
4. Acrylic sheet pot for Water Resistivity Measurement
5. Water as soil for grounding scale model
6. Ammeters and voltmeters
7. Auto transformer.
8. Power supply.
9. Connecting wires

4.4.3 Different Phases of Experiment: The experiment is performed in 4 phases.

In the first phase, the Resistivity of water which is used in place of soil is computed.

In the second phase, the Earth surface potential is recorded for the electrode without any mesh.

In the third phase, the Earth surface potential is recorded for a grounding mat without any electrode.

In the fourth phase, the Earth surface potential is recorded for grounding mat with electrodes at corners.

4.4.4 Important Points of Experiment:

(a) The voltage level is maintained by an auto-transformer. Multi meters are used at required points to check the voltage level and currents. The readings are consequently taken.

(b) The experiment is repeated for two layer soil model with two different cases i.e. positive reflection factor and negative reflection factor respectively.

(c) The resistance offered by different types of grounding conductor like wire / rod and strip and the formula to compute the resistance are shown in figures 4.13 and 4.14 respectively .

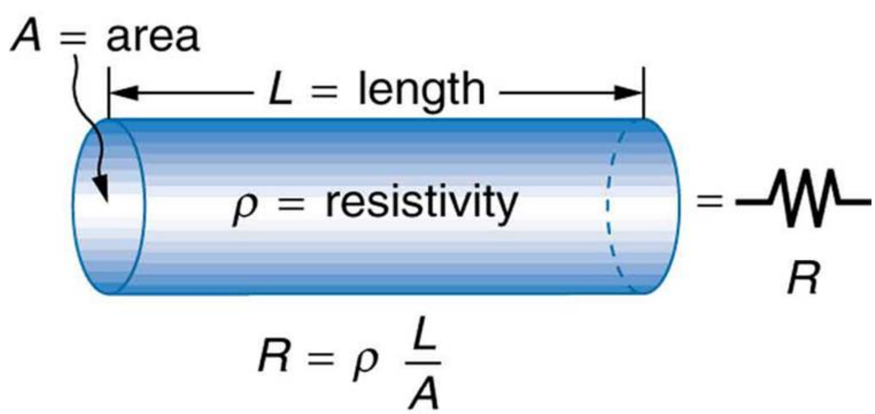


Fig 4.13 Basic of Resistance of Any Conductor

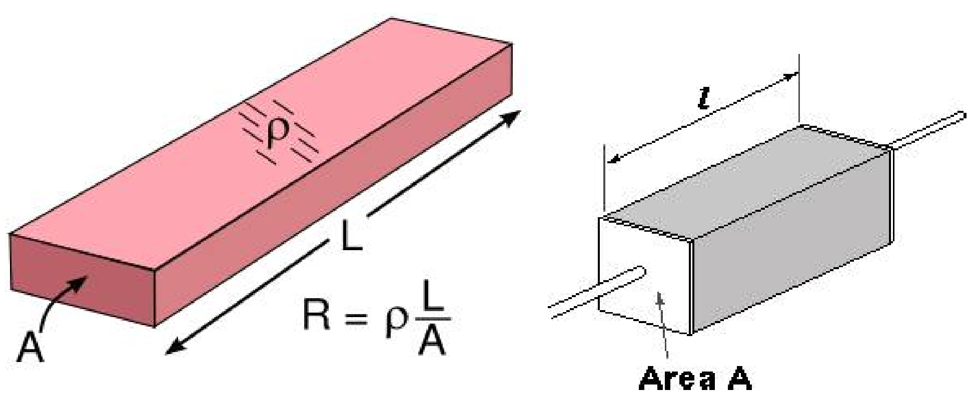


Fig 4.14Basic of Resistance of Any Strip or Rod

(d) The circuit diagram for measurement of resistivity of water is shown in figure 4.15. Also, the experimental set up for Earth surface potential (ESP) calculation of single electrode for uniform layer model is shown in figure 4.16 below:

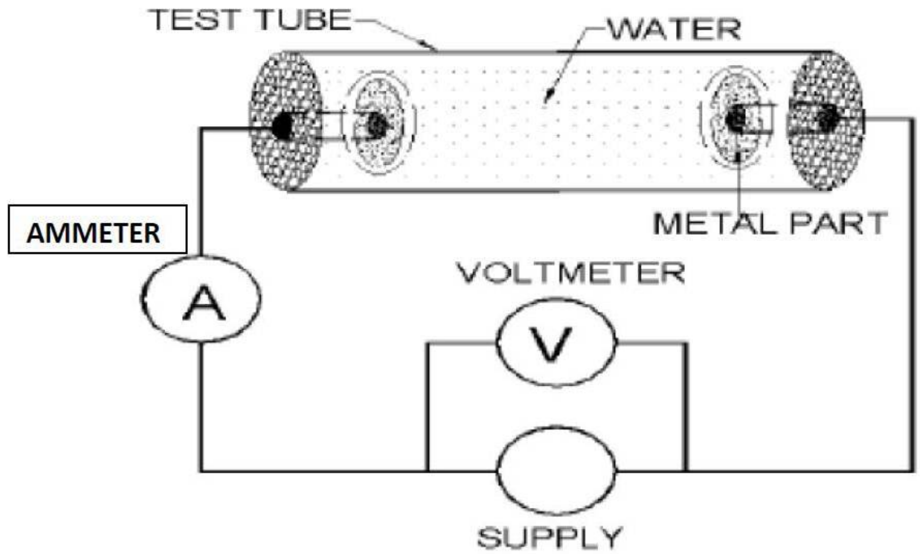


Fig 4.15 Measurement of Resistivity of Water

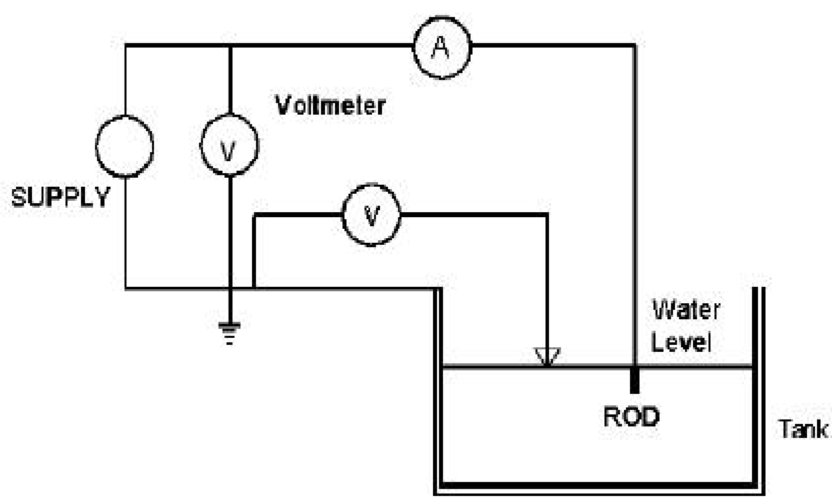


Fig 4.16 Circuit Diagramfor ESP Calculation of One Rod

(e) The circuit diagram for Earth surface potential (ESP) calculation of grounding mat for uniform layer model is shown in figure 4.17 below:

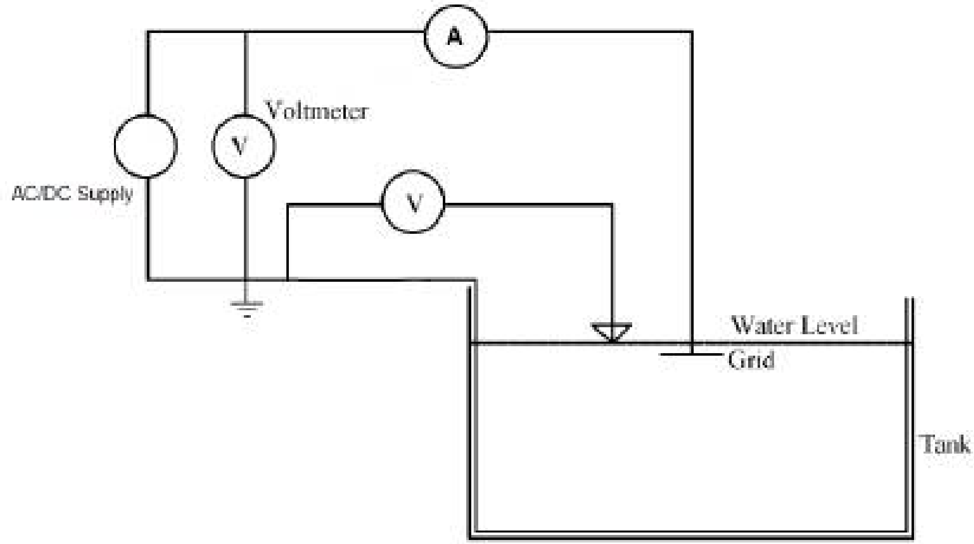


Fig 4.17 ESP Calculation forEarth Mat (Uniform Soil Model)

(f) The circuit diagram for Earth surface potential (ESP) calculation of single electrode for two layer model is shown in figure 4.18 below:

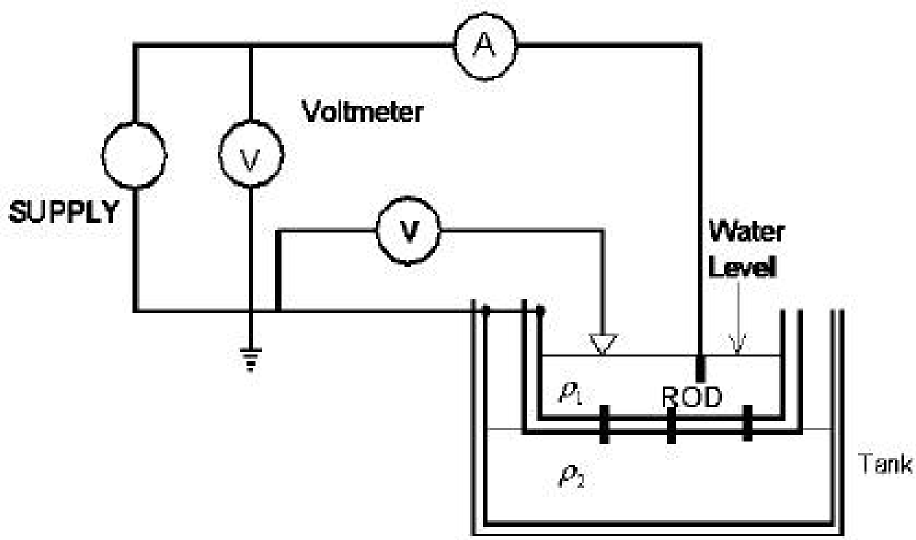


Fig 4.18 ESP Calculation for Single Electrode (Two Layer Soil Model)

(g) The scale model experiment was conducted in the Lab of 220 kV WazirPur substation Delhi. The picture depicting the experiment preparation process is shown in figure 4.19 below:

Fig 4.19 Experimental Setup Preparation

(h) The actual experimental set up for measurement of resistivity of water is shown in figure 4.20 below:

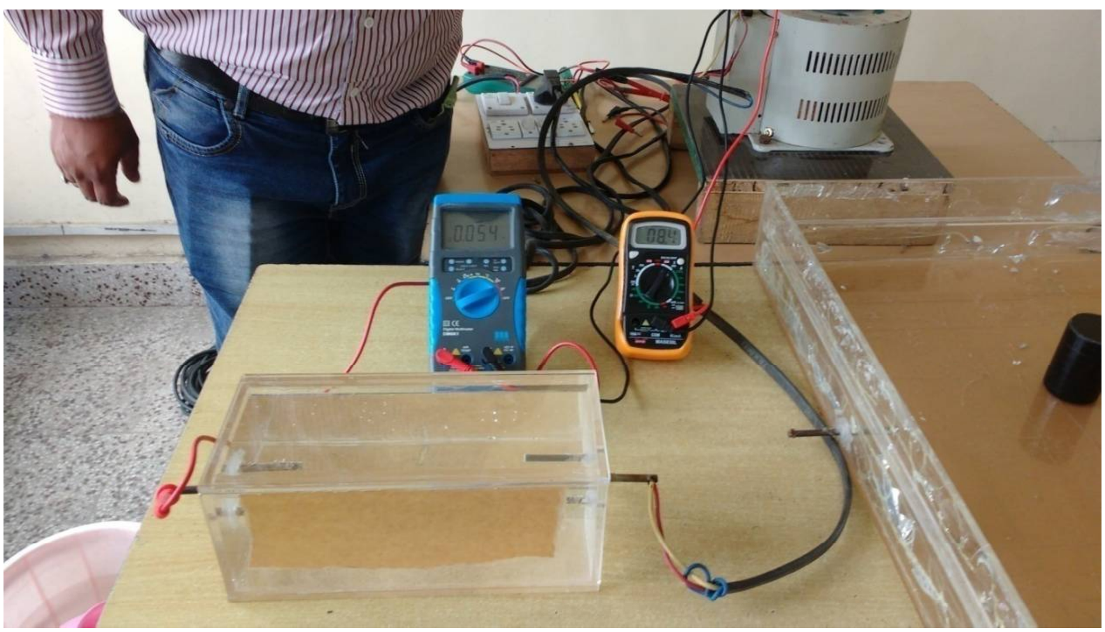


Fig 4.20Experimental Set up for Water Resistivity Measurement

(i) The plan prepared for measurement of voltage in the experiment at different locations in different directions i.e. P1, P2 ,P3etc is shown in figure 4.21 below:

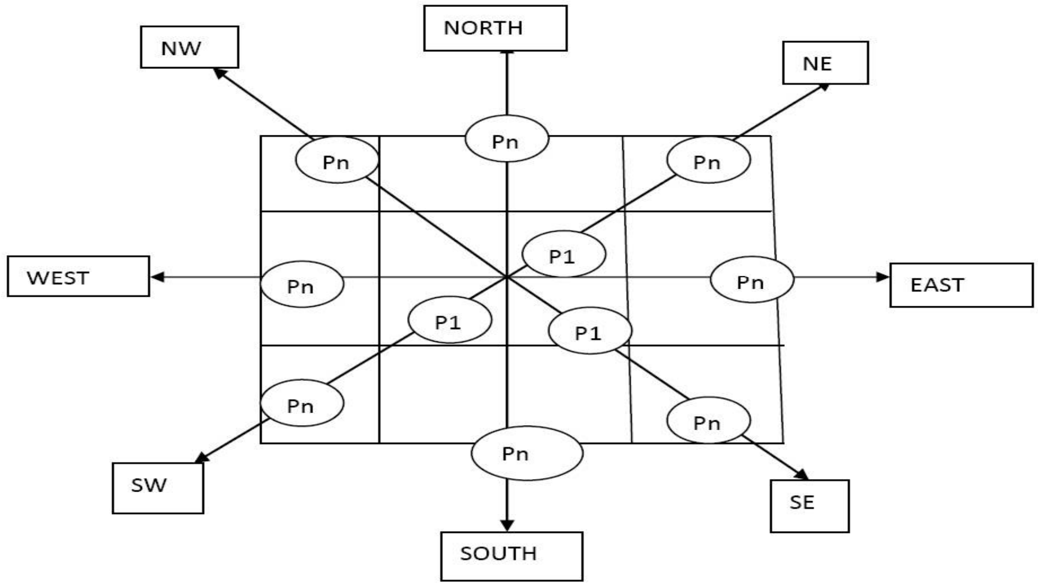


Fig 4.21Voltage Measurement Location for Experiment

(j) The experimental setup and measurement method for ESP measurement for uniform layer model is shown in figure 4.22 below:

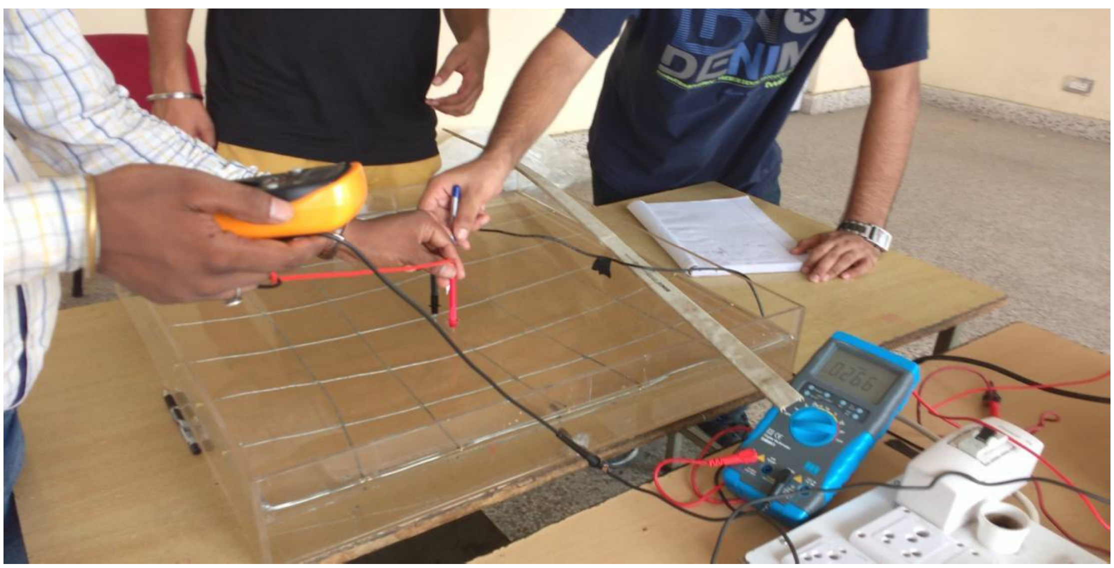


Fig 4.22 Experimental Setup for ESP Measurement for Uniform Layer Model

(k) The measurement values shown by multimeter for ESP measurement for uniform layer model are shown in figure 4.23 below:

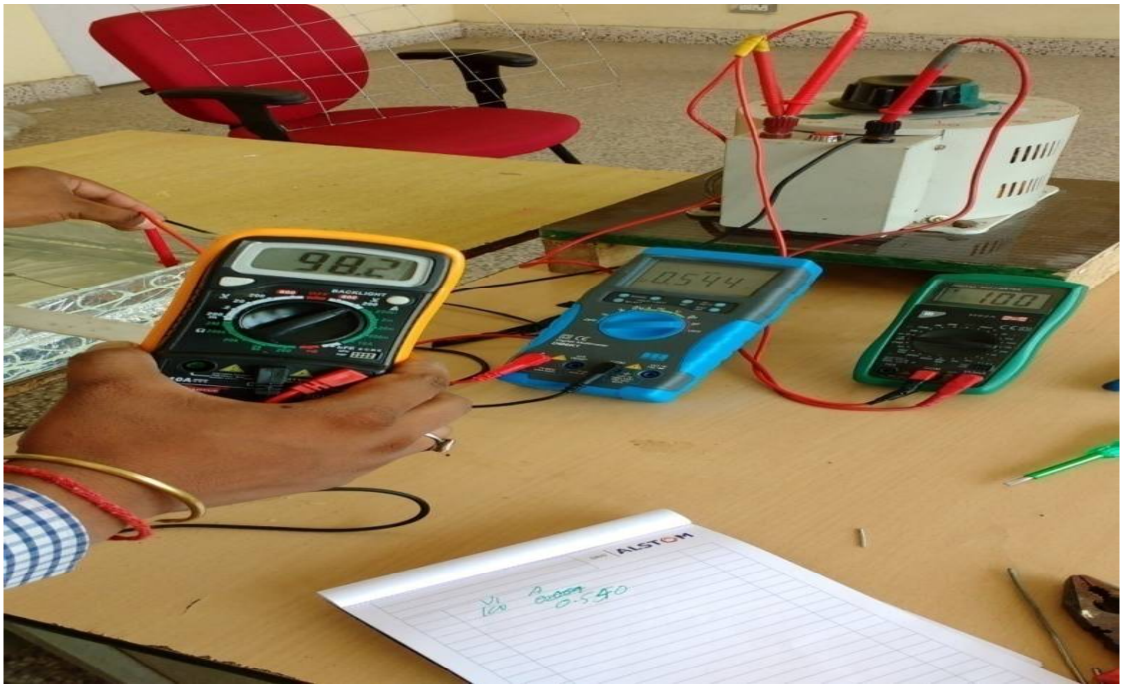


Fig 4.23 Measurement Values for Uniform Layer Model

4.5 Results of Uniform Layer Model: (1) The results obtained for water resistivity measurement and ESP measurement with single electrode are given in table 4.6 , 4.7 and table 4.8 respectively.

TABLE 4.6 Resistivity Measurement of Water

V (applied)	I(amp)	R(Resist)ohm	L (meter)	W(meter)	H(meter)	Resistivity (ohm-m)
200	0.215	930.23	0.25	0.1	0.1	37.20930233

TABLE 4.7ESP Measurement of Single Rod (L=6mm)

DIRECTION	V	I	P1 (volt)	P2 (volt)	P3 (volt)	P4 (volt)
South	100	0.085	78.7	52.6	50.3	50
West	100	0.085	78.7	57.5	55.9	55.3
North	100	0.085	76.5	54.5	51.6	50.5
East	100	0.085	82.5	52.8	40.8	20.6
		AVERAGE	79.1	54.35	49.65	44.1

RESISTANCE (ohms) = 1176.47

(2) The Earth Surface Distribution of above case is shown by the graph in figure 4.24 below.

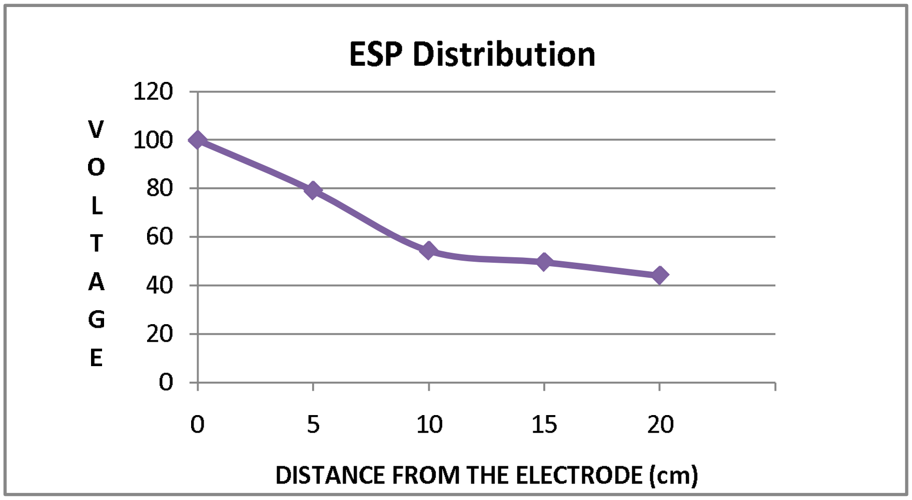


Fig. 4.24 ESP Distribution Graph (1)

TABLE 4.8 ESP Measurement of Single Rod (L=10mm)

DIRECTION	V	I	P1 (volt)	P2 (volt)	P3 (volt)	P4 (volt)
South	66	0.085	57.1	43.3	38.2	37.3
East	66	0.085	56.8	40.8	28.4	16.8
West	66	0.085	57.1	43.6	41.9	41.2
North	66	0.085	56.9	41.4	38.6	38.4

RESISTANCE (ohms) = 776.47

(3) The ESP measurement of earth mesh without and with corners electrodes of different lengths are given in table 4.9, 4.10, 4.11 and table 4.12 respectively.

TABLE 4.9 ESP Measurement for 45X45cm Mesh (14 SWG) w/o Electrodes

DIRECTION	V	I	P1 (volt)	P2 (volt)	P3 (volt)	P4 (volt)
South	100	0.265	97.8	97.7	98.2	97.7
East	100	0.265	98.1	91.1	94.8	81.7
West	100	0.265	98.3	98.5	98.1	99
North	100	0.265	98.5	99.1	98.5	99.1

RESISTANCE (ohms) = 377.35

TABLE 4.10 ESP Measurement for 45X45cm Mesh (14 SWG) with Electrodes at the corners (L=6cm)

DIRECTION	V	I	P1 (volt)	P2 (volt)	P3 (volt)	P4 (volt)
South	100	0.29	98.34	98.3	98.7	98.3
West	100	0.29	98.9	98.6	98.3	98.3
East	100	0.29	98.2	97.7	95.5	98.3
North	100	0.29	98.3	98.4	98.6	98.9
N-E	100	0.29	98.3	98.1	98.2	98.1
S-E	100	0.29	98.3	98.2	98.1	98.6
S-W	100	0.29	98.4	98.3	98.5	98.6
N-W	100	0.29	98.3	98.4	98.5	98.4

RESISTANCE (ohms) = 344.82

TABLE 4.11 ESP Measurement for 45X45cm Mesh (14 SWG) with Electrodes at the corners (L=10cm)

DIRECTION	V	I	P1 (volt)	P2 (volt)	P3 (volt)	P4 (volt)
South	100	0.297	98.4	98.4	98.3	98.2
East	100	0.297	98.7	97.6	94.6	93.8
North	100	0.297	98.7	98.4	98.6	98.4
West	100	0.297	98.4	98.2	98.4	98.4
S-E	100	0.297	98.3	98.4	98.3	98.2
S-W	100	0.297	98.2	98.5	98.4	98.6
N-W	100	0.297	98.4	98.3	98.3	98.4
N-E	100	0.297	98.8	97.7	98.2	98.4

RESISTANCE (ohms) = 336.70

TABLE 4.12 ESP Measurement for 45X45cm Mesh (14 SWG) with Electrodes at the corners (L=12cm)

DIRECTION	V	I	P1 (volt)	P2 (volt)	P3 (volt)	P4 (volt)
SOUTH	100	0.302	98.6	98.6	98.7	98.7
NORTH	100	0.302	98.3	98.4	98.4	98.5
EAST	100	0.302	98.4	97.7	95.7	92.8
WEST	100	0.302	98.6	98.6	98.6	98.6

RESISTANCE (ohms) = 331.12

4.6 Results of Two Layer Soil Models : (1) The results obtained for resistivity measurement of water are given in table 4.13 below:

TABLE 4.13 Resistivity Measurement of Water

	V (applied)	I(amp)	R(resist)ohm	L (meter)	W(meter)	H (meter)	Resistivity (ohm-m)
CASE 1	100	0.646	154.80	0.25	0.1	0.1	**6.19**
CASE 2	100	1.419	70.47	0.25	0.1	0.1	**2.82**
CASE 3	50	5.1	9.80	0.25	0.1	0.1	**0.39**

(2) The ESP measurement of earth mesh without corners electrodes for uniform soil model are given in table 4.14 and ESP distribution graph is shown in figure 4.25 respectively.

TABLE 4.14 ESP Measurement for 25X25cm Mesh (14 SWG) w/o Electrodes for Uniform Soil Model

DIRECTION	V	I	P1 (volt)	P2 (volt)	P3 (volt)	P4 (volt)
South	100	1.28	**98.6**	**97.2**	**97.1**	**96.8**
West	100	1.28	**98.4**	**97.5**	**97.4**	**97.1**
North	100	1.28	**98.5**	**97.8**	**97.4**	**97.2**
East	100	1.28	**98.2**	**97.8**	**97.3**	**97**

RESISTANCE (ohms) = 78.125

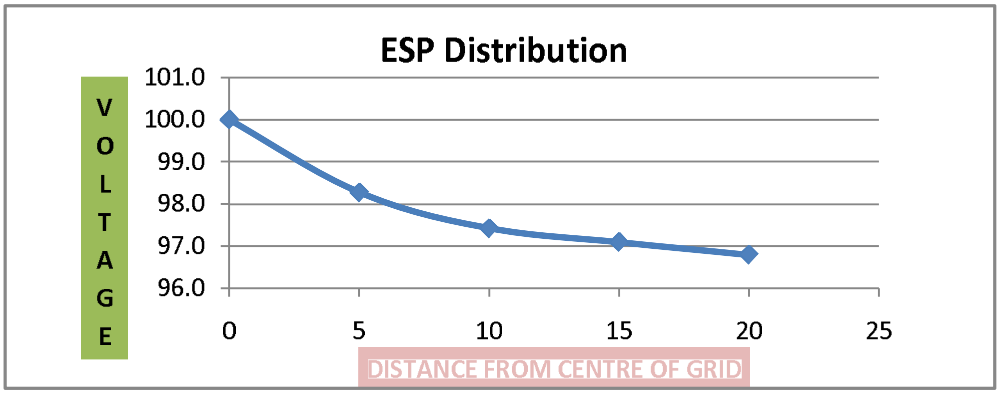


Fig. 4.25 ESP Distribution Graph (2)

(3) The ESP measurement of earth mesh without corners electrodes for two layer soil model (Negative reflection factor) are given in table 4.15 and ESP distribution graph is shown in figure 4.26 respectively.

TABLE 4.15 ESP Measurement for 25X25cm Mesh (14 SWG) w/o Electrodes for Two Soil Model (-K, Reflection factor)

rho1=6.19 ohm-m & rho2=2.82 ohm-m

DIRECTION	V	I	P1 (volt)	P2 (volt)	P3 (volt)	P4 (volt)
South	100	1.31	**98.5**	**97.6**	**97**	**96.8**
East	100	1.31	**98.6**	**97.4**	**97.2**	**96.7**
West	100	1.31	**97.9**	**97.4**	**97.1**	**96.8**
North	100	1.31	**98.1**	**97.3**	**97.1**	**96.9**

RESISTANCE (ohms) = 76.33

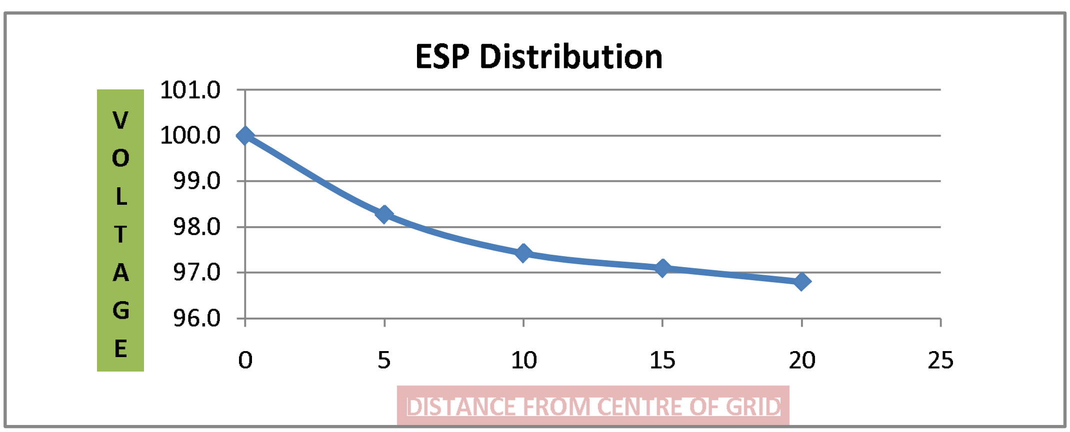


Fig. 4.26 ESP Distribution Graph (3)

(4) The ESP measurement of earth mesh without corners electrodes for two layer soil model (Positive reflection factor) are given in table 4.16 and ESP distribution graph is shown in figure 4.27 respectively.

TABLE 4.16ESP Measurement for 25X25cm Mesh (14 SWG) w/o Electrodes for Two Layer Soil Model (+K, Reflection factor)

rho1=0.39 ohm-m & rho2=2.82 ohm-m

DIRECTION	V	I	P1 (volt)	P2 (volt)	P3 (volt)	P4 (volt)
South	20	3.8	19.2	18.9	18.6	18.1
East	20	3.8	19.3	18.8	18.5	18
West	20	3.8	19.4	18.9	18.4	18.2
North	20	3.8	19.3	18.7	18.3	17.9

RESISTANCE (ohms) = 5.26

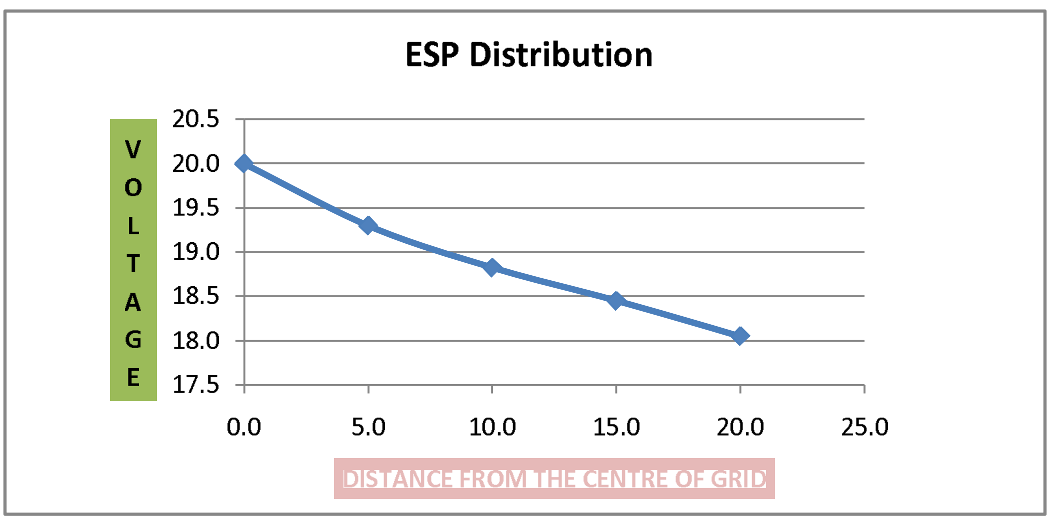


Fig. 4.27 ESP Distribution Graph (4)

(5) The experimental setup and measurement method for ESP measurement for two layer models are shown in figure 4.28 and figure 4.29 below.

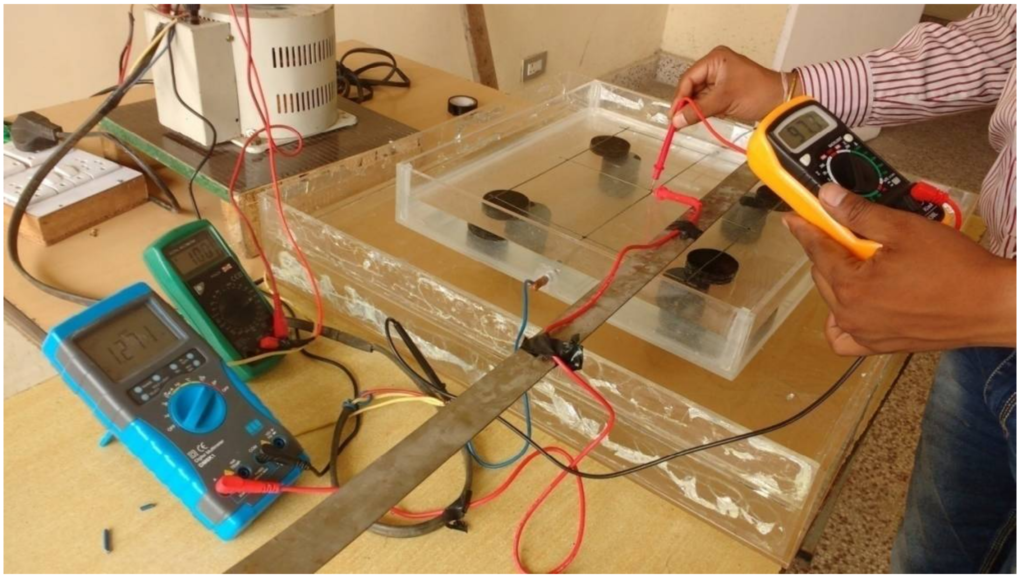


Fig 4.28 ESP Measurement (Two Layer Soil Model)-1

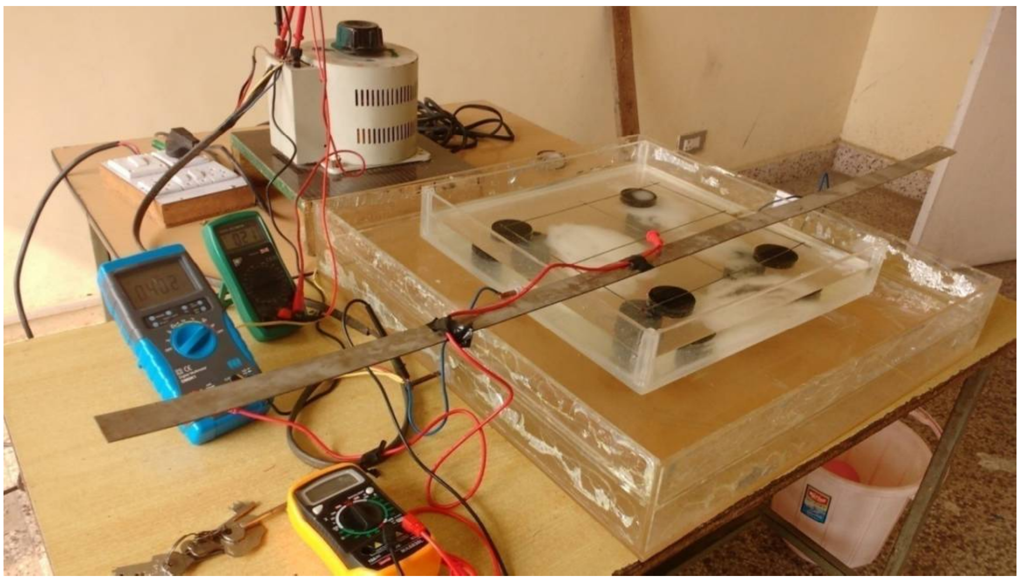


Fig 4.29 ESP Measurement (Two Soil Layer Model)-2

4.7 Conclusion:

Scale model is the best method to understand the behavior of any grounding system which include impact of addition of electrodes, grounding mesh size (spacing of conductors), length of electrodes, depth of grounding mesh, resistivity of soil, layers of soils etc.

All the above parameters can be computed by measurement of ESP as measured in the experiment for different configurations like single electrode of different sizes, single layer soil model and two layer soil model. The main parameters of any grounding system like resistance, step and touch potential may be computed with the help of these scale models.