CHAPTER 3

SOIL RESISTIVITY AND SOIL MODELING

It is very important to understand the concept of soil resistivity and its types. Further the derivation of the relevant soil model from the field data of soil resistivity measurement plays crucial role in the designing of the grounding system of substation. Soil modeling can be done easily with the help of computer program using MATLAB GUI which need to be validated using data and outcome of previous research in this area.

3.1 Concept of Soil Resistivity

Soil resistivity of substation plays very important role in designing of the grounding system. Values of soil resistivity of substation vary site to site, depending on the type of terrain near the substation; e.g., substation near the bank of any river may have a very low resistivity value of 1.5 Ω-m, whereas soil of substation constructed near dry sand or granite found on the mountain may have very high resistivity of 10,000 Ω-m. The factors that may affect resistivity are as follows [6-11]:

1. Type of earth.
2. Soil model i.e. soil resistivity layers or structure.
3. Moisture content: resistivity may come down rapidly as the moisture content is increased, but after a value of about 20%, the rate of fall is much less. Soil having moisture content more than 40% is usually not found.
4. Temperature: with rise in temperature the value of resistivity decreases. While for temperatures below $0^{o}C$, the resistivity increases rapidly.
5. Chemical composition and concentration of dissolved salts. Presence of metal and railway tracks or metal conduit may affect the resistivity.

Figure 3.1 shows how resistivity varies with salt content, moisture, and temperature.

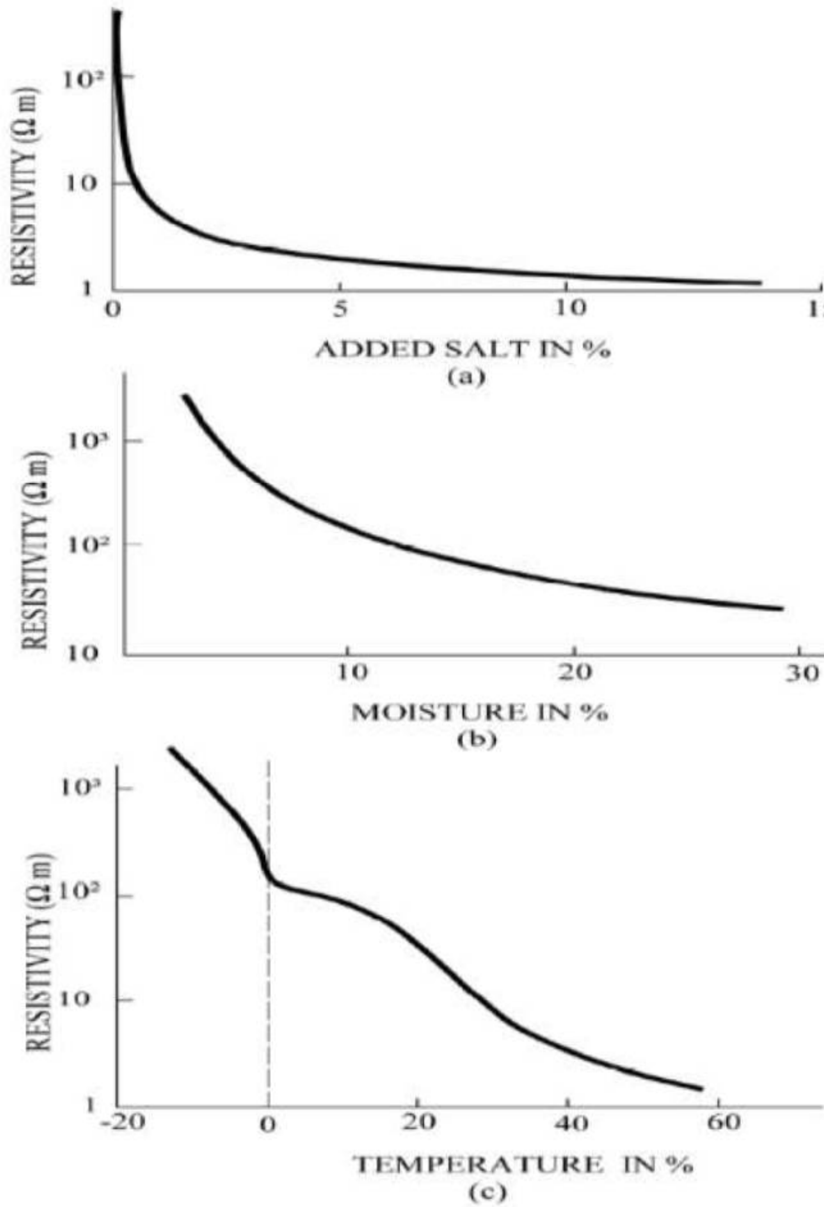

Fig 3.1 Impact of Salt, Moisture and Temperature on Soil Resistivity

Table 3.1 shows the resistivity values for various soils and rocks that might occur in different grounding system designs [1-5].

TABLE 3.1 Typical Resistivity of Various Soil

S.No.	Type of Soil	Resistivity (Ω-m)	
		Average	Usual Variation
01	Surface soil (loam-clay and sand and decayed organic matter)		5-50
02	Clay itself (stiff viscous earth chiefly aluminum silicate) Black clay	30	8-100
03	Sand and gravel	100	40-300
04	Sand clay and gravel mixture	150	50-250
05	Shale (fine grained sedimentary rock of mild and clay), sandstone wet (sedimentary rock chiefly quartz cemented together) slate		5-500
06	Sandstone dry		1000 -10000
07	Surface limestone (chiefly calcium carbonate)		100-10000
08	Deep lime stone		5-4000
09	Granite (crystalline rock , quartz, mica etc)	3000	1000-10000
10	Basalt (dark colored fine grained rock)		1000
11	Decomposed gneiss (rock containing mineral and quartz)		50-500
12	Gravel	3000	1000-10000
13	Primary rock	3000	1000-10000
14	Lake water non polluted lakes in hilly terrains		200+
15	Tap water		0.01 to 500
16	Sea water		0.02-20
17	Concrete, new or buried in earth	100	25-500
18	Concrete dry	10000	200->1000000
19	Asphalt wet		10000-600000

3.2 Different Soil Models

The electrical properties of the soil are decided by the thicknesses of layers and their resistivity which is dependent upon factors mentioned above. Usually there are many layers of soil with different resistivity and the soil resistivity model is said to be non-uniform as shown in figure 3.2 below. Horizontal (lateral) changes in the resistivity may also be found but these changes are gradual and usually negligible in the field.

Uniform soil model is seldom found in the field. Grounding design engineers usually come across the following types of soil models [6-11].

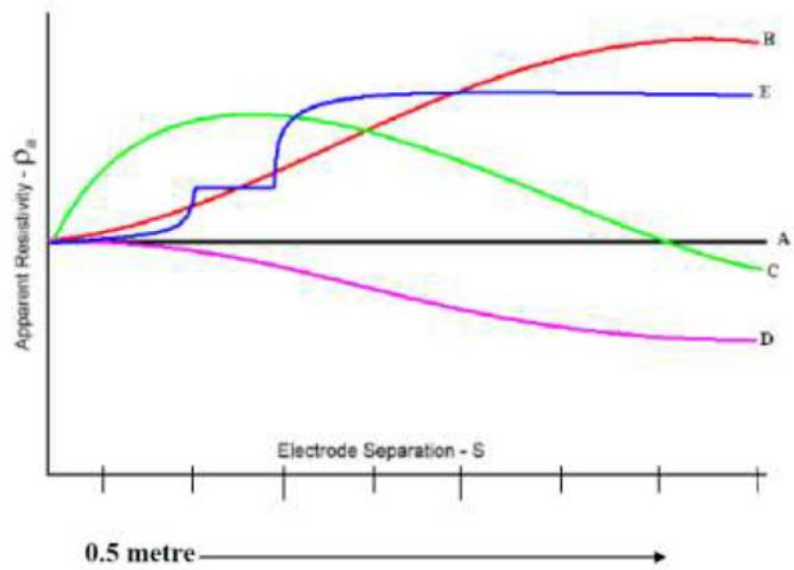

Fig 3.2 Soil Resistivity Vs Electrode Separation Curve

1. Curve (A) represents uniform model of soil resistivity.
2. Curve (B) represents a two layer soil resistivity model in which upper layer has low resistivity.
3. Curve (C) represents a three layer soil resistivity model in which upper and lower layer have low resistivity and middle layer has high resistivity respectively.
4. Curve (D) represents a two layer soil resistivity model in which upper layer has high resistivity.
5. Curve (E) represents a case of multilayer resistivity model in which upper layers have low resistivity with vertical stratification.

3.3 Various Resistances of an Earth Electrode

During the flow of fault current through a ground/earth electrode three types of resistance [6-11] appear in the circuit as shown in figure 3.3.

1. Resistance of the ground electrode itself and connection terminal or hardware fitting joining it with cable or riser.

2. Resistance at the point of contact between the ground electrode and the soil.
3. Resistance offered by the surrounding ground/earth.

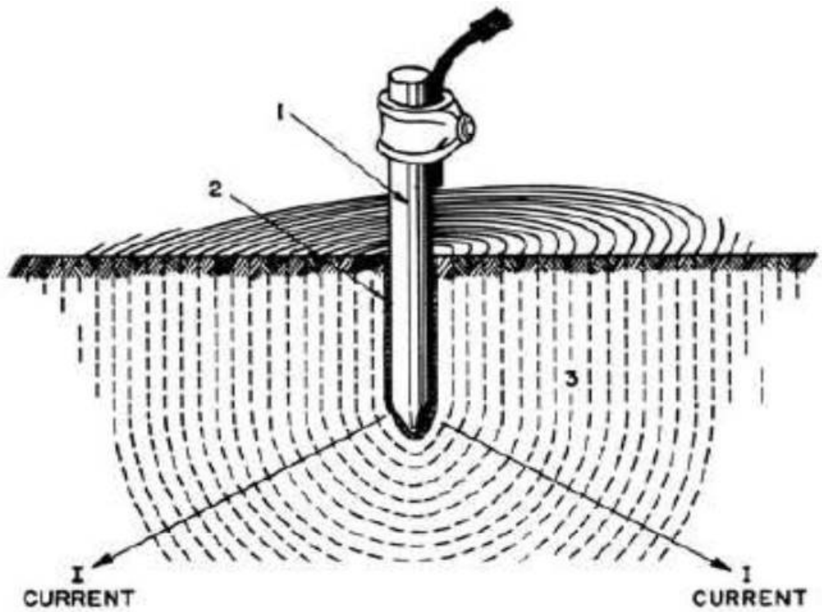

Fig 3.3 Different Components of Grounding Resistance

1. **Electrode Resistance:** Rods, pipes, strips are usually used for making connections. These connections are made of sufficient size so that their resistance becomes very low and their contribution to the total resistance is negligible.

2. **Contact Resistance of Electrode-Earth/Ground :** This part of resistance is also very less.

3. **Resistance offered by Surrounding Earth:** During the fault the electrode surrounded by soil of uniform resistivity radiates current in all directions. The earth shell touching the electrode offers the smallest surface area and so it contributes the highest resistance. The next earth shell is comparatively larger in size and this shell has less resistance. Finally a distance will be reached where addition of more earth shells does not contribute much to them total resistance of the earth surrounding the electrode.

Generally, the resistance offered by the earth surrounding the electrode will be the highest of all the components discussed above.

3.4 Derivation of Soil Model of Substation (Two Layer Soil Resistivity Structure)

In case the measured values of apparent resistivity of a substation found to be non-uniform, these values of resistivity need be analyzed further to derive the equivalent two layer soil model. This process of modeling demands an iterative search for three parameters ρ_1, ρ_2, and h which fit the measured values of resistivity by the least squares criterion. This resistivity data using infinite series expression or one of the finite series are used to derive the desired model. It is pertinent to mention here that use of the finite term expressions makes the search for three parameters of two layer soil model much quicker with negligible compromise with accuracy. The objective function used in the process is given by the equation below [6-11]:

$$f(\rho_1, \rho_2, h) = \sum_{j=1}^{n} \left[\frac{\rho_{m(j)} - \rho_{c(j)}(\rho_1, \rho_2, h)}{\rho_{m(j)}}\right]^2 \quad \textbf{(3.1)}$$

Where,

n = number of spacing of spikes for the measurement of apparent resistivity.

$\rho_{m(j)}$ = actual measured apparent resistivity for jth spacing of spikes .

$\rho_{c(j)}$ = computed apparent resistivity for jth spacing of spikes

The soil model with two layers is shown in figure 3.4 below:

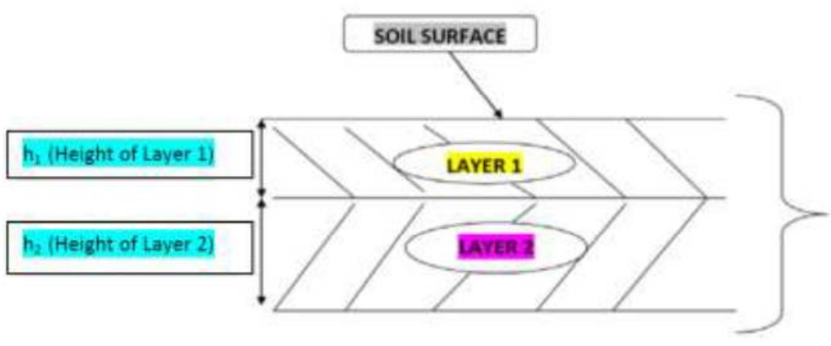

Fig 3.4 Two Layer Soil Model

3.4.1. Equations for apparent resistivity for two layer soil with infinite series expression [6]

$$\rho_a = \rho_1 \left[1 + 4 \sum_{n=1}^{\infty} k^n \left(\frac{1}{\sqrt{1+(2nh/a)^2}} - \frac{1}{\sqrt{4+(2nh/a)^2}}\right)\right] \qquad (3.2)$$

Where,

ρ_a = Apparent Resistivity Ohm- meter
ρ_1 = soil resistivity of top layer

ρ_2 = soil resistivity of bottom layer

h = height of the top layer (m)

k = reflection factor $(\rho_2 - \rho_1) / (\rho_2 + \rho_1)$

a = Separation of electrode in meters

3.4.2. Apparent resistivity for two layer soil with finite series expression $\rho_2 > \rho_1$ [6]

$$\rho_a = \rho_1 + 4\rho_1 k\, a\left(\frac{1}{\sqrt{a^2+4h^2}} - \frac{1}{\sqrt{4a^2+4h^2}}\right) + 4\pi V_b a\left(\sqrt{\frac{c}{c+\left(\frac{a}{h}\right)^{\beta}}} - \sqrt{\frac{c}{c+\left(\frac{2a}{h}\right)^{\beta}}}\right)$$

(3.3)

Where,

$$V_b = \frac{\rho_1[-k - \ln(1-k)]}{(2\pi h)}$$

$$c = x_1 \left(\ln\left(\frac{\rho_2}{\rho_1}\right)\right)^{x_3}$$

$$\beta = 2.0 - x_2 \ln\left(\frac{\rho_2}{\rho_1}\right)$$

x_1 **= 16.4133**

x_2**= 0.136074**

x_3**=0.393468**

3.4.3. Equations for apparent resistivity for two layer soil with finite series expression $\rho_{2} < \rho_1$ [6]

$$\rho_a = \rho_2 + (\rho_1 - \rho_2)\left[2e^{-ba} - e^{-b(2a)}\right] \quad (3.4)$$

Where

$$b = \frac{\left[b_m - (b_m - x_1)e^{-x_2\left(\frac{a}{h}\right)}\right]}{h}$$

$$b_m = x_3 - x_4\left(\frac{\rho_2}{\rho_1}\right)^{x_5}$$

x_1 = **0.673191**
x_2 = **0.479513**
x_3= **1.33335**
x_4 = **0.882645**
x_5 = **0.697106**

The above written equations can be used to get two soil model of any substation area.

3.5 Designing of Grounding System - *220/33 KV GIS (Uniform Layer Soil Model)*

In order to understand the process involved in the designing of the substation, an example for grounding system design of 220/33 kV GIS substation is given below [1,3,5]:

STEP 1 : First of all measure the earth resistivity of the substation soil [4] at different locations by four pin wenner method and take the average of these values . let us take resistivity =**50 ohm-meter**.

Measure the total area of the substation , let us assume **90x90 metre**.

STEP 2 Input Parameters cum data for design:

<u>Input Data required for designing as mentioned in Table 3.2 consist of the followings</u>:

1. System / network data (system fault current, fault duration, and ambient temperature etc.).
2. Field data like average earth resistivity, surface layer type and resistivity

and thickness of surface layer etc.

3. Grounding conductor type and constants.

4. Earth mat design parameters [5] like duration of shock, weight of human working in the station, max grid current, no of electrodes required / to be buried and spacing of earth mat conductor (initial value) etc.

Table 3.2 Input Data for Designing of Grounding System

S.NO.	Description	Symbol	INPUT Value	Unit
1	Symmetrical fault current of substation	I_f	40000	A
2	Fault current diversion factor	S_f	1	
3	Duration of shock	t_s	1	s
4	Surface Gravel layer resistivity	ρs	3000	Ω-m
5	Surface Gravel layer thickness	hs	0.15	m
6	Soil resistivity	ρ	50	Ω-m
7	Depth of Burial of earth material	h	0.65	m
8	Number of Rods in Switchyard	N_r	40	no
9	Length of electrode	L_r	3	m
10	Arrangement of ground rod in grid	Rods throughout grid area		
11	Maximum length in X-Direction	Lx	90	m
12	Maximum length in Y-Direction	Ly	90	m

STEP 3. Ampacity Calculation

Table 3.3 gives the detail of grounding conductor for grounding system.

Table 3.3 Grounding Conductor Detail

Description	**Conductivity (%)**	**α_r (at 20 ^oC)**	**Ko**	**Fusing Temp. (Tm-^oC)**	**ρ_r20 ^oC**	**TCAP thermal capacity {J/(cm^3, ^oC}**
Steel 1020	10.8	0.0016	605	1510	15.9	3.28

Required area of conductor is given by

$$A_{mm^2} = I.\frac{1}{\sqrt{\left(\frac{TCAP.10^{-4}}{t_c.\alpha_r.\rho_r}\right)\ln\left(\frac{K_0+T_m}{K_0+T_a}\right)}} \quad \textbf{(3.5)}$$

Where

Ta=Ambient temperature (^oC)

Actual area required comes out to be **325 sq mm.**

And after considering 30% margin for corrosion net area required becomes **423 sq mm.**

We have chosen area **of 1256 sq mm** of MS rod (40 mm dia) which is sufficient.

STEP 4. Calculations for Tolerable touch and step Potential:

The reduction factor **(de-rating factor) Cs** can be approximated by the equation:-

$$C_s = 1 - \frac{0.09.(1-\rho/\rho_s)}{2.h_s + 0.09} \quad \textbf{(3.6)}$$

The value of de rating factor comes out to be :

Cs=0.77

Following equation can be used to calculate the tolerable touch and step potentials respectively:-

$$E_{touch70} = \frac{(100 + 1.5 * C_s . p_s).0.157}{\sqrt{t_s}}$$

$$E_{step70} = \frac{(100 + 6 * C_s . p_s).0.157}{\sqrt{t_s}}$$

(3.7 and 3.8)

E step 70 tolerable= 2342 V

E touch 70 tolerable =703 V

We can also calculate the tolerable touch and step potentials for body weight of 50 kg also by replacing 0.157 with 0.116

E touch 50 =520 V

E Step 50 =1730 V

STEP 5. Grid Configuration and related calculations : Calculate the area of earth mat based on the dimension given in Table 3.2 above.

STEP 6. Determination of Grid resistance:

$$R_g = \rho . \left[\frac{1}{L_T} + \frac{1}{\sqrt{20.A}} \left(1 + \frac{1}{1 + h.\sqrt{20/A}} \right) \right]$$

(3.9)

Rg= 0.254 ohm

STEP 7: Calculation of GPR = $I_G = S_f$ x I_f **(3.10)**

where S_f= Fault current diversion factor=1

Ig= 40000 A

GPR= IgxRg=10188 V

GPR is more than tolerable touch voltage.

The flow of current in the substation during the fault is depicted by figure 3.5 below.

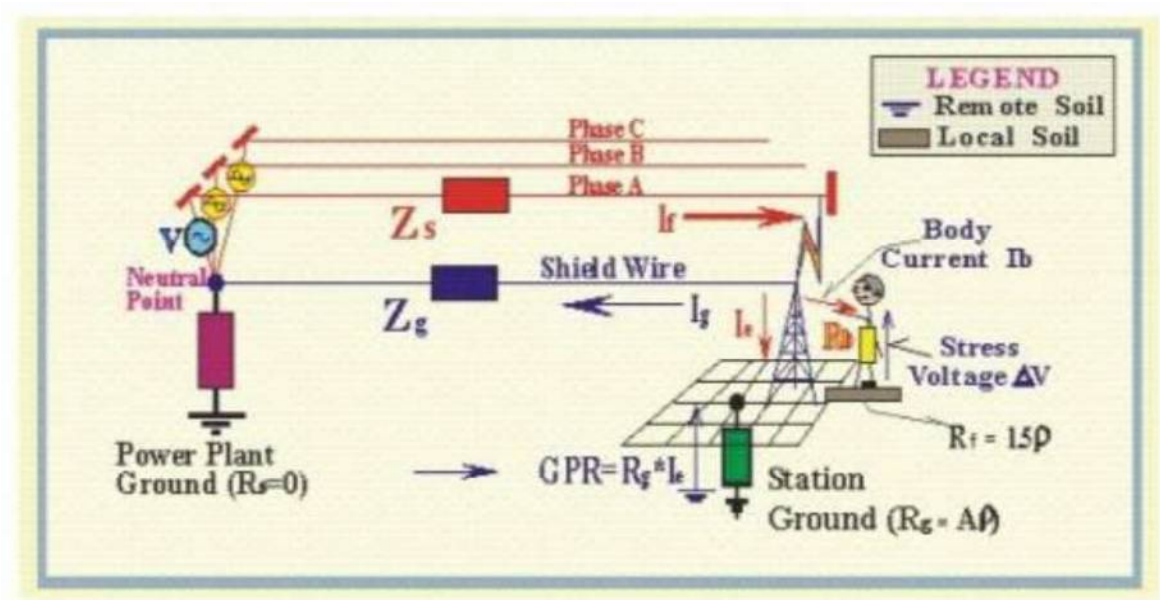

Fig 3.5 Flow of Current During Fault

STEP 8. Calculation of Attainable step and touch voltage:

Kii= 1 for grid with ground

D = Spacing between two conductor = 3.5 m

<u>Geometric Factor</u>

$$n = n_a * n_b * n_c * n_d$$

$$n_a = \frac{2 * L_c}{L_p} \qquad n_b = \sqrt{\frac{L_p}{4 \times \sqrt{A}}} \qquad n_c = \left[\frac{L_x \times L_y}{A}\right]^{\frac{0.7 \times A}{L_x \times L_y}} \qquad \textbf{(3.11)}$$

Where

L_p = Peripheral Length of the substation

n_d = 1 for square, rectangular & L-Shaped substation

na=26.71,nb=1,nc=1,n=26.71

(A) Attainable touch(mesh) voltage is given by:

$$E_m = \frac{\rho \times I_G \times K_m \times K_i}{L_M} \tag{3.12}$$

Spacing factor for mesh voltage (Km) is given by:

$$K_m = \frac{1}{2\times\pi}\left[\ln\left[\frac{D^2}{16\times h\times d}+\frac{(D+2\times h)^2}{8\times D\times d}-\frac{h}{4\times d}\right]+\frac{K_{ii}}{K_h}\ln\left[\frac{8}{\pi\times(2\times n-1)}\right]\right] \tag{3.13}$$

Km=0.23

Correction factor for grid geometry (ki) is given by

Ki=0.644+0.148n= 4.60

$K_h = \sqrt{1+\frac{h}{h_0}}$ =1.28

Effective length for mesh voltage (Lm) is given by:

$$L_M = L_C + \left[1.55 + 1.22\times\left(\frac{L_r}{\sqrt{L_x^2+L_y^2}}\right)\right]\times L_R \tag{3.14}$$

Lm=4998.02 & Em=432 V

But for GIS the criterion of safety is given by:

$$\sqrt{E_t^2 + (E'_{to\max})^2} < E_{touch} \tag{3.15}$$

Where

E_t =max touch voltage

$E'_{to\max}$ = max metal - metal potential difference on or between GIS enclosure

The value for E tomax as per IEEE-80 is ***taken as 130 volt***

$$\sqrt{E_t^2 + (E'_{to\max})^2} = E_{m(\mathrm{GIS})}$$

Em $_{(GIS)}$ =451 V

(B) Attainable step voltage is given by:

$$E_S = \frac{\rho \times I_G \times K_S \times K_i}{L_S}$$

Es= 1023 V

Spacing factor for step voltage is given by (Ks) :

$$K_s = \frac{1}{\pi} \times \left[\frac{1}{2 \times h} + \frac{1}{D+h} + \frac{1}{D} \times (1 - 0.5^{n-2}) \right]$$

Ks=0.41

Ki=0.644+0.148.n= 4.60

Effective length for mesh voltage (Ls) is given by:

Ls= 0.75Lc+0.85L_R

STEP 8 (Final) for Safety check:

For the safe grounding grid design, Attainable Step & Touch potentials should be less than the permissible values respectively. All the inputs are entered in the MATLAB GUI program which calculates the desired values as per IEEE-80 (2000).

The results given by MATLAB GUI program for designing of grounding system as per IEEE-80 is shown below in figure 3.6:

Fig 3.6 MATLAB GUI –Grounding Design

3.6 Example of Two layer Soil Resistivity Modeling

In order to get clarity or understand the impact of soil modeling, an arbitrary data of soil resistivity measurement for three different locations within the premises of the HV substation is taken [6-20]. The tables 3.4, 3.5and 3.6 provide the resistivity measurement data of location 1, 2 and 3 respectively.

Table 3.4 Resistivity Measurement Data Location 1

SEPARATION OF SPIKES (S) Meter	N	NE	E	SE	S	SW	W	NW	AVG RESISTIVITY
0.5	33.45	14.38	17.67	30.77	11.52	8.44	9.63	40.66	**20.82**
1	36.73	17.96	21.47	19.84	9.54	6.84	10.99	34.79	**19.77**
2	6.65	14.06	17.2	12.43	6.02	2.26	6.28	12.05	**9.62**
3	7.34	9.04	9.79	8.85	5.08	1.884	3.39	8.47	**6.73**
5	0.94	7.85	7.53	6.9	6.59	3.14	2.19	6.59	**5.22**
10	1.25	10.04	6.28	6.28	9.42	7.53	3.24	5.65	**6.21**
15	1.88	5.65	3.76	6.59	5.65	4.56	2.13	4.57	**4.35**
AVG RESISTIVITY	**12.61**	**11.28**	**11.96**	**13.09**	**7.69**	**4.95**	**5.41**	**16.11**	

Table 3.5 Resistivity Measurement Data Location 2

SEPARATION OF SPIKES (S) Meter	N	NE	E	SE	S	SW	W	NW	AVG RESISTIVITY
0.5	227.96	39.59	46.22	36.48	39.72	34.1	15.26	241.46	**85.10**
1	71.59	40.94	37.42	24.61	38.55	27.5	17.39	20.09	**34.76**
2	30.14	26.37	20.72	20.09	22.85	2.51	19.34	2.51	**18.07**
3	16.95	12.81	16.2	16.39	8.85	0.75	9.23	15.07	**12.03**
5	25.12	7.22	12.56	15.38	6.59	4.39	7.53	9.4	**11.02**
10	12.56	6.28	10.67	13.18	8.16	2.51	6.28	12.56	**9.03**
15	9.42	4.71	8.93	11.3	3.76	18.84	3.76	9.42	**8.77**
	56.25	**19.70**	**21.82**	**19.63**	**18.35**	**12.94**	**11.26**	**44.36**	

Table 3.6 Resistivity Measurement Data Location 3

SEPARATION OF SPIKES (S) Meter	N	NE	E	SE	S	SW	W	NW	AVG RESISTIVITY
0.5	39.25	49.8	49.07	21	194.68	45.93	18.87	149.15	**70.97**
1	61.6	30.58	11.86	53	63.42	19.40	23.55	153.23	**52.08**
2	20.84	19.71	4.39	4.14	16.32	6.40	5.52	3.39	**10.09**
3	8.85	8.28	3.23	3.95	13.18	7.72	5.46	5.65	**7.04**
5	0.62	5.43	3.12	2.45	12.56	5.96	4.39	6.28	**5.10**
10	11.3	4.32	2.21	2.34	12.56	1.88	3.14	6.28	**5.50**
15	10.8	3.51	2.09	2.01	6.28	5.65	4.71	9.42	**5.56**
AVG RESISTIVITY	**21.89**	**17.38**	**10.85**	**12.7**	**45.57**	**13.28**	**9.377**	**47.63**	
	N	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**	**AVG RESISTIVITY**
location 1	12.60	11.28	11.95	13.09	7.68	4.95	5.40	16.11	**10.39**
location 2	56.24	19.70	21.81	19.63	18.35	12.94	11.25	44.35	**25.54**
location 3	21.89	17.37	10.85	12.69	45.57	13.27	9.37	47.62	**22.33**
AVG RESISTIVITY	**30.25**	**16.12**	**14.88**	**15.14**	**23.87**	**10.39**	**8.68**	**36.03**	**19.42**

From the above data, it is clear that if single soil model is considered the grounding system is designed based on the average resistivity of the soil as shown above and this value in this comes out to be 19.42 ohm-meter.

3.6.1 Derivation of Two Layer Soil Model :

Using the above data of soil resistivity measurement for two soil modeling with the help of computer program developed in the MATLAB GUI & the results obtained are shown in table 3.7:

Table 3.7 Resistivity Measurement Data for Two Layer Soil Model

AVERAGE RES FOR LOCATION AT GIVEN SEPARATION	0.5	1	2	3	5	10	15		
location 1	20.81	19.77	9.61	6.73	5.21	6.21	4.34		
location 2	85.09	34.76	18.06	12.03	11.02	9.02	8.76		
location 3	70.96	52.08	10.08	7.04	5.10	5.50	5.55		
AVG RESISTIVITY	**58.96**	**35.54**	**12.59**	**8.60**	**7.11**	**6.91**	**6.23**	**19.42**	**AVERAGE VALUE**

3.6.2 RESULTS: Final results of the two soil model for above resistivity measurement data is as follows:

1.Resistivity of Top layer (ohm-meter)	69.79
2.Resistivity of Bottom layer (ohm-meter)	6.13
3.Height of Top layer (meter)	0.7

The output of the MATLAB GUI program for the above data is given in figure 3.7 below.

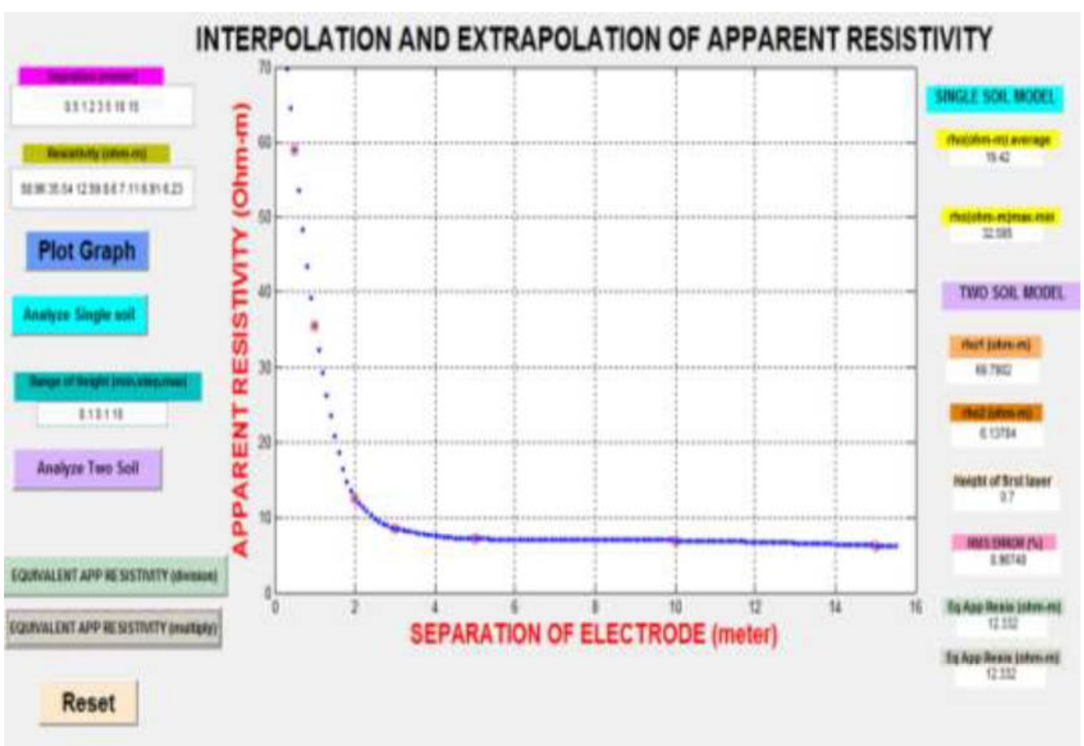

Fig 3.7 MATLAB GUI- Soil Modeling

3.6.3 Conclusion : From the above it can be observed that with single soil model the resistance of the substation grounding system which depends on resistivity of soil in the above case (case of Negative K, reflection factor) is less as compare with two soil model. It further reduces the calculated GPR, Step Potential and Step Potential for the substation.

Grounding of all GIS equipment at a station is planned by the manufacturer of the equipments. Main problem about design of the earth grid electrode for a GIS is reduced area of land required for such a station. This makes it all the more important to calculate grid current correctly. The earth resistance cannot be less than a certain value. The deciding factor GIS is the maximum permissible magnitude TEV and transient ground potential rise (TGPR).

3.7 Case Studies of Soil Modeling

The importance of accurate soil structure for optimal designing of grounding system has already been discussed. To understand the procedure involved in the soil modeling, the 6 cases may be considered [6-10]. The data of six cases are shown in table 3.8 below.

In each case, spacing S is the equal spacing of spikes of resistivity tester and resistivity shown are the resistivity corresponding to these spacing respectively.

Table 3.8 Data for Case Studies of Soil Modeling

CASE- 1							
Spacing	**S**	2.5	5	7.5	10	12.5	15
Resistivity	**Ω-m**	320	245	182	162	168	152
CASE- 2							
Spacing	**S**	1	2	3	4	5	
Resistivity	**Ω-m**	693.74	251.62	84.56	37.64	25.32	
CASE- 3							
Spacing	**S**	2	4	6	8	10	
Resistivity	**Ω-m**	123.38	189.99	258.93	320.27	374.13	
CASE- 4							
Spacing	**S**	2	4	6	8	10	
Resistivity	**Ω-m**	102.26	113.07	129.77	147.52	163.95	
CASE- 5							
Spacing	**S**	2.5	5	7.5	10	12.5	15
Resistivity	**Ω-m**	451.6	366.7	250.2	180	144.2	120.2
CASE- 6							
Spacing	**S**	1	2	4	10	20	40
Resistivity	**Ω-m**	136	140	214	446	685	800

The output given by RPDGS for case 1 using uniform soil model and two layer soil model are shown in figure 3.8 and figure 3.9 respectively.

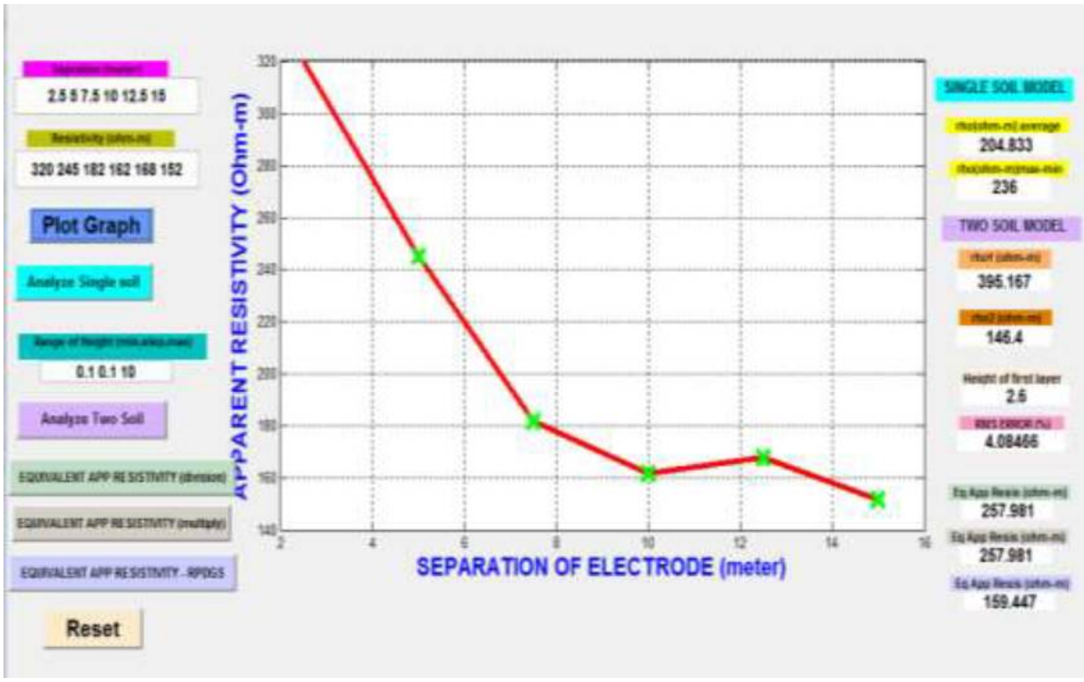

Fig 3.8 Uniform Soil model module of RPDGS - Case 1

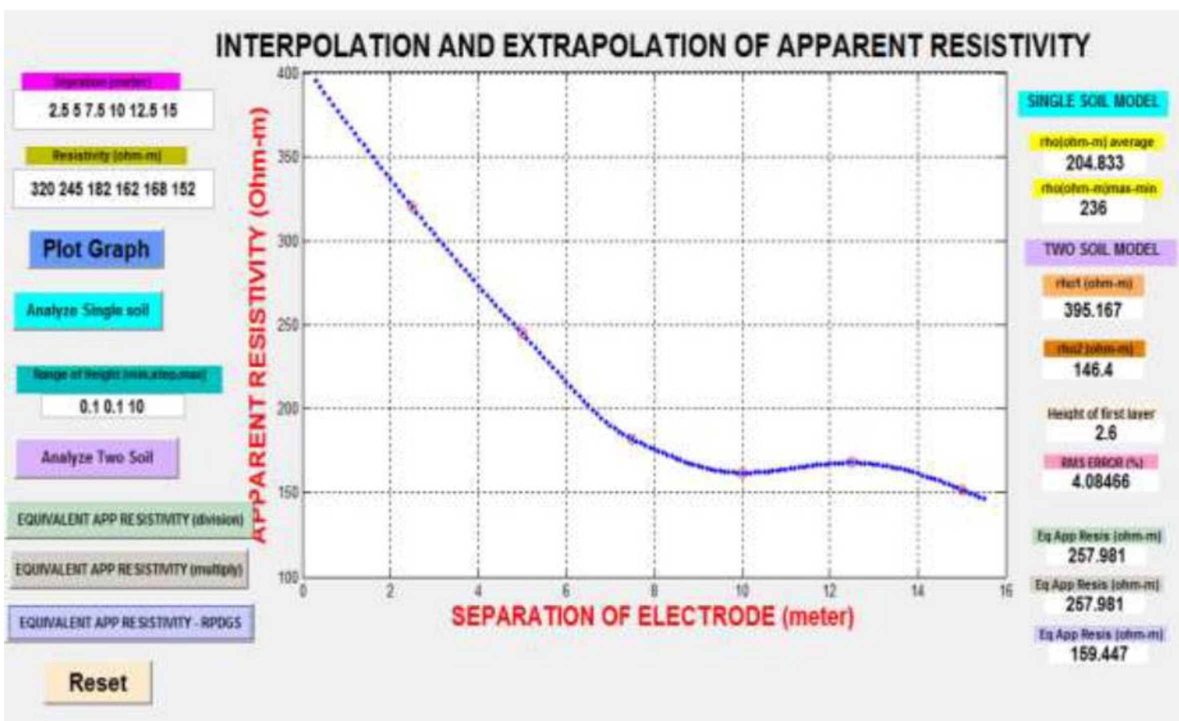

Fig 3.9 Two layer Soil model module of RPDGS -Case 1

The output given by RPDGS for case 2 using uniform soil model and two layer soil model are shown in figure 3.9 and figure 3.10 respectively.

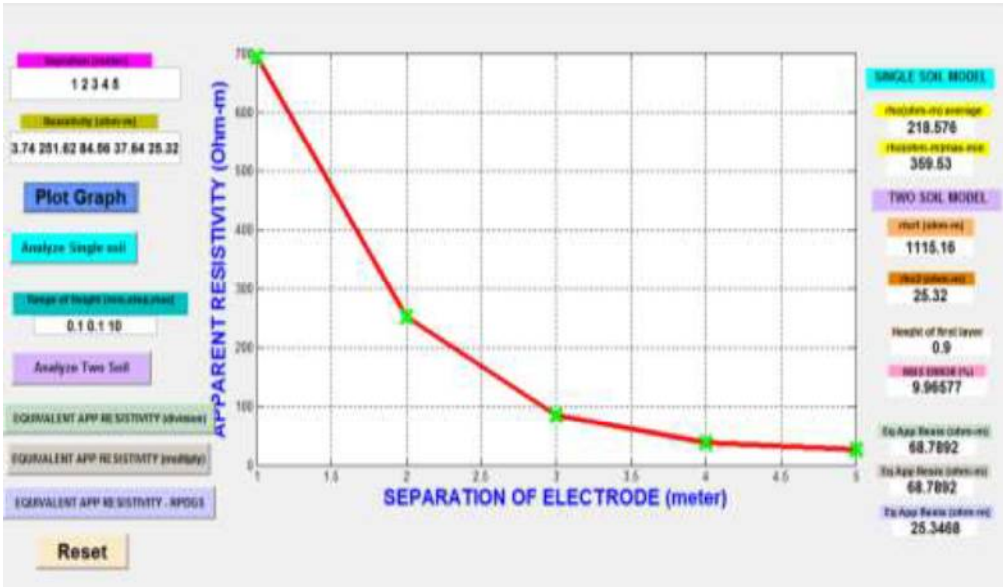

Fig 3.10 Uniform Soil model module of RPDGS - Case 2

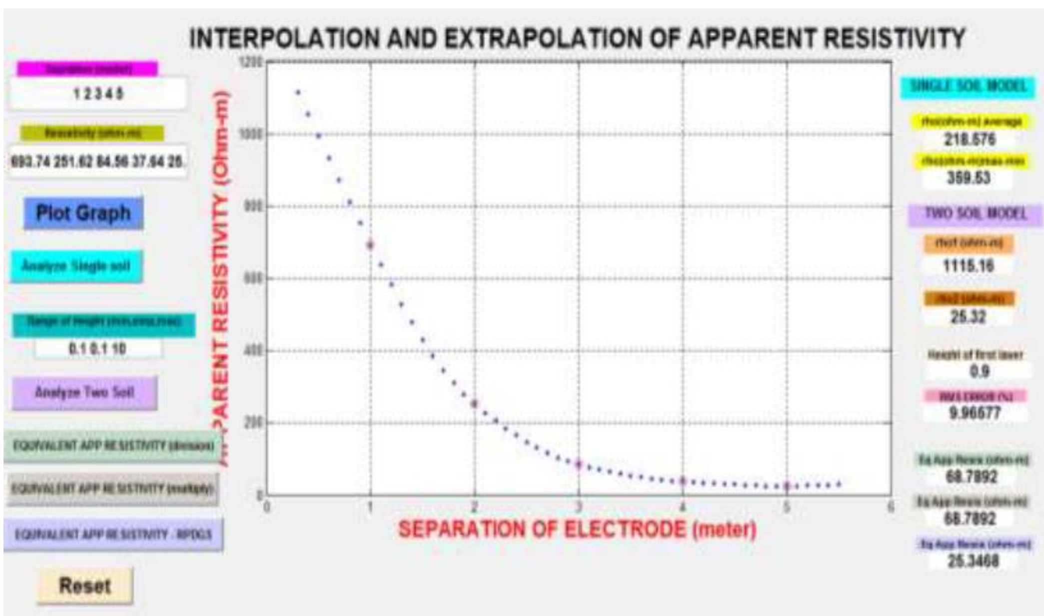

Fig 3.11 Two layer Soil model module of RPDGS – Case 2

The output given by RPDGS for case 3 using uniform soil model and two layer soil model are shown in figure 3.12 and figure 3.13 respectively.

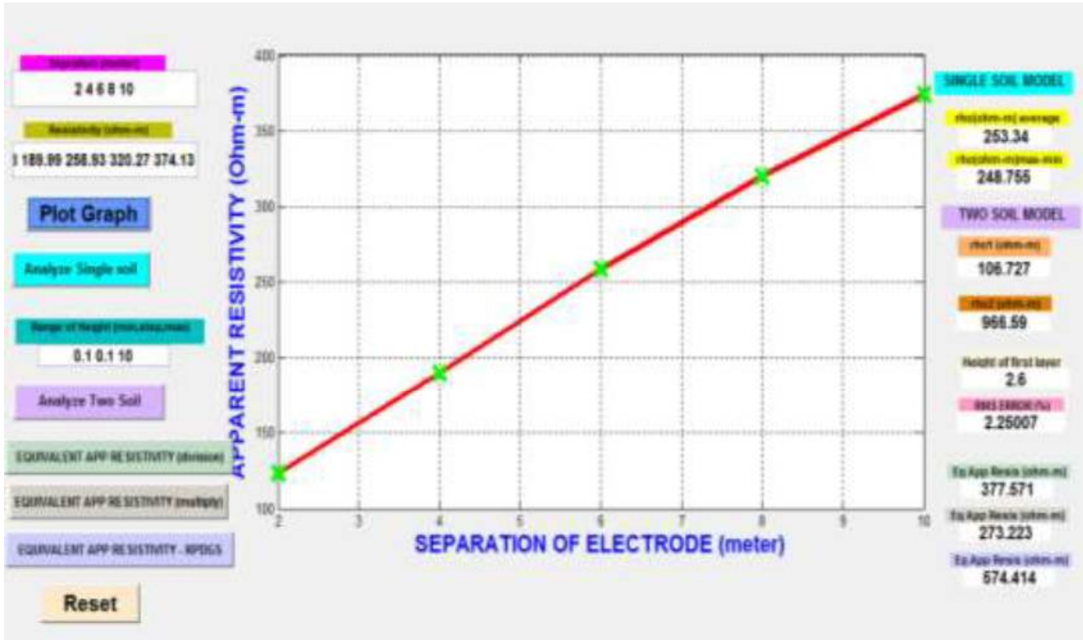

Fig 3.12 Uniform Soil model module of RPDGS -Case 3

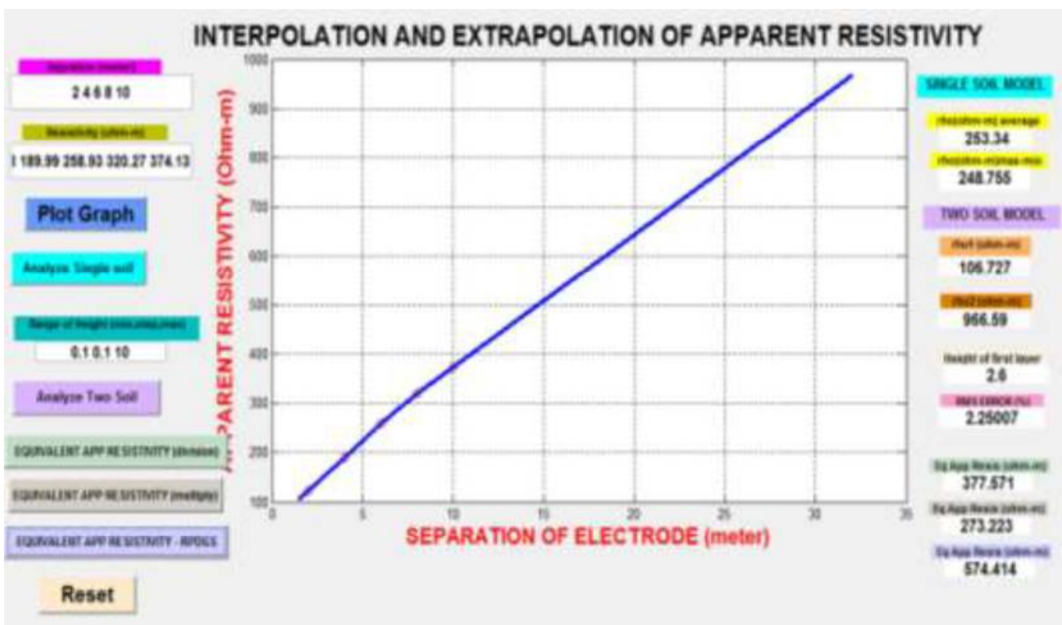

Fig 3.13 Two layer Soil model module of RPDGS –Case 3

The output given by RPDGS for case 4 using uniform soil model and two layer soil model are shown in figure 3.14 and figure 3.15 respectively.

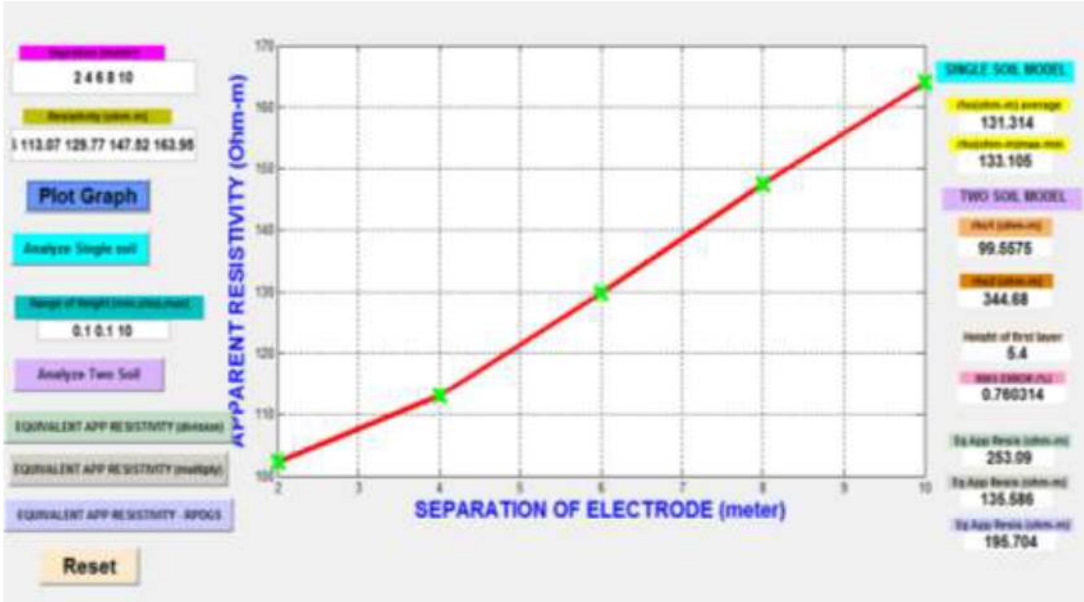

Fig 3.14 Uniform Soil model module of RPDGS - Case Study 4

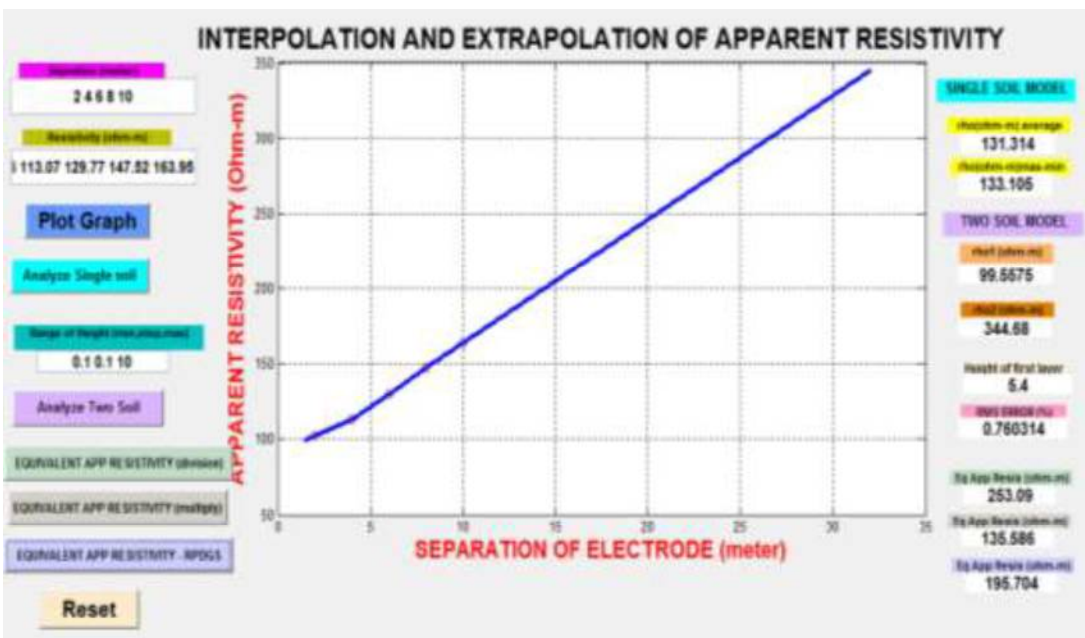

Fig 3.15 Two layer Soil model module of RPDGS - Case 4

The output given by RPDGS for case 5 using uniform soil model and two layer soil model are shown in figure 3.16 and figure 3.17 respectively.

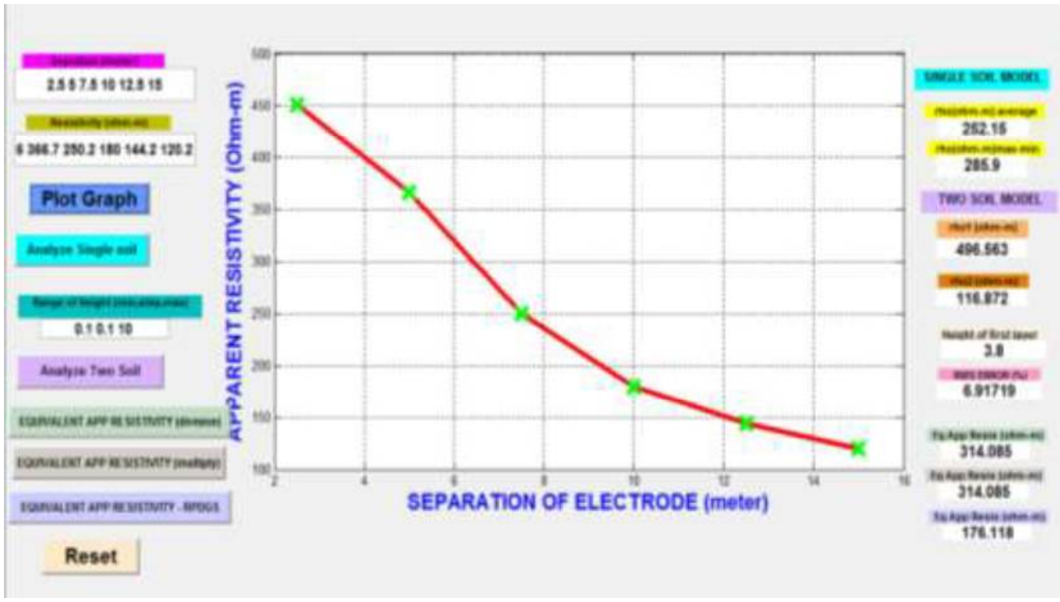

Fig 3.16 Uniform Soil model module of RPDGS - Case 5

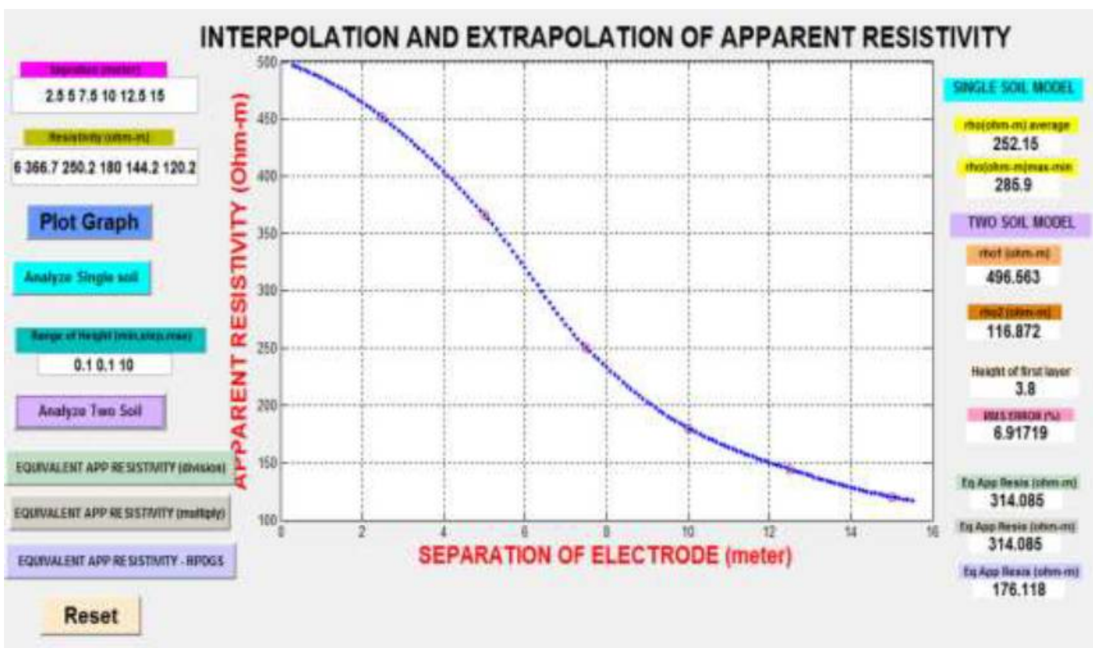

Fig 3.17 Two layer Soil model module of RPDGS - Case 5

The output given by RPDGS for case 6 using uniform soil model and two layer soil model are shown in figure 3.18 and figure 3.19 respectively.

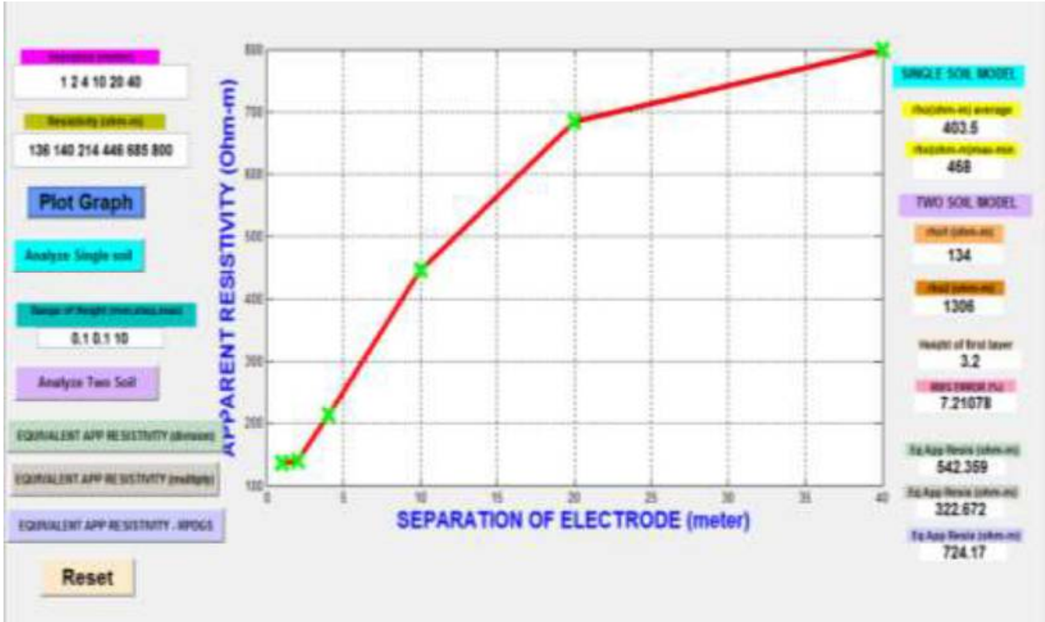

Fig 3.18 Uniform Soil model module of RPDGS - Case 6

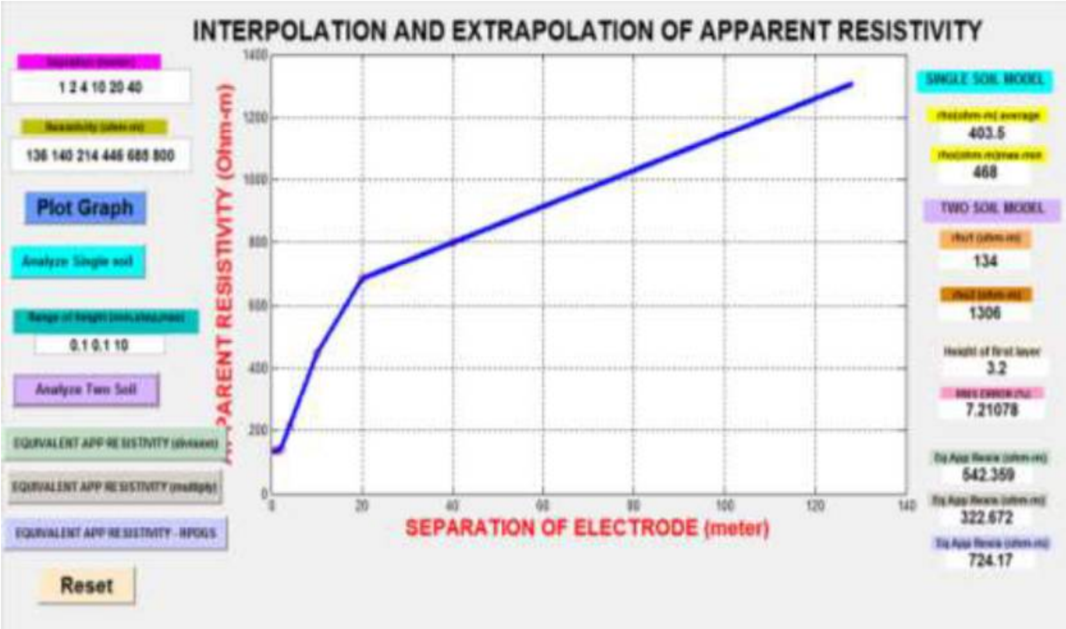

Fig 3.19 Two layer Soil model module of RPDGS - Case 6

3.8 Results and Comparison: The results of RPDGS soil modeling module are given in Table 3.9 below.

Table 3.9 Results of Case Studies of Soil Modeling

CASE NO 1		REF PAPER	RPDGS	R.M.S. ERROR
	ρ_1 (ohm-m) RESISTIVITY OF LAYER 1	389.49	395.16	
	ρ_2 (ohm-m) RESISTIVITY OF LAYER 2	153	146.4	**4.08**
	H (meter) HEIGHT OF LAYER 1	2.4	2.6	
CASE NO 2				
	ρ_1 (ohm-m) RESISTIVITY OF LAYER 1	1003.4	1115.16	
	ρ_2 (ohm-m) RESISTIVITY OF LAYER 2	21.14	25.32	**9.96**
	H (meter) HEIGHT OF LAYER 1	0.99	0.9	
CASE NO 3				
	ρ_1 (ohm-m) RESISTIVITY OF LAYER 1	98.3	106.72	
	ρ_2 (ohm-m) RESISTIVITY OF LAYER 2	1018.8	966.59	**2.25**
	H (meter) HEIGHT OF LAYER 1	2.44	2.6	
CASE NO 4				
	ρ_1 (ohm-m) RESISTIVITY OF LAYER 1	99.99	99.56	
	ρ_2 (ohm-m) RESISTIVITY OF LAYER 2	302.64	344.68	**0.76**
	H (meter) HEIGHT OF LAYER 1	5.04	5.4	
CASE NO 5				
	ρ_1 (ohm-m) RESISTIVITY OF LAYER 1	492.25	496.56	
	ρ_2 (ohm-m) RESISTIVITY OF LAYER 2	93.32	116.87	**6.91**
	H (meter) HEIGHT OF LAYER 1	4.4	3.8	
CASE NO 6				
	ρ_1 (ohm-m) RESISTIVITY OF LAYER 1	124.5	134	
	ρ_2 (ohm-m) RESISTIVITY OF LAYER 2	1133.5	1306	**7.21**
	H (meter) HEIGHT OF LAYER 1	2.7	3.2	

3.8.1 Conclusion: There are three parameters of soil resistivity modeling calculated by RPDGS software include ρ_1 (Resistivity of Layer 1), ρ_2 (Resistivity of Layer 2) and H (Height of Layer 1) respectively.

It is clear from above case studies that the overall RMS errors of RPDGS software are in the range of 0.76 to 9.96.

Both cases of positive and negative reflection factors have been compared with the outputs given in the research papers [6-10]. This RPDGS software is capable of deriving two layer soil resistivity models from the field resistivity measurement data.