CHAPTER 5

PARAMETRIC ANALYSIS

In the previous chapter empirical formula was developed to compute the parameters of grounding design using two layer soil model. There is need to understand the impact of various factors which affects the parameters of grounding design of any substation. All the parameters need to be discussed one by one in detail with suitable example to have better understanding on the subject. Further comparison between designing with uniform soil model and two layer soil model to be done to reach any conclusion.

5.1 Factors Affecting the Design [27-43]

A. Soil Resistivity

A piece of land which is being used for construction of substation may have multiple soil layers with different soil resistivity. Resistivity may vary vertically or horizontally in the substation. A soil model is derived from the site measurement which may or may not be accurate always. In uniform soil model the average of all measured values of resistivity is selected as resistivity of soil. However it has been proved that the two- layer model of soil gives good approximation of real soil condition than uniform soil model. Soil resistivity plays crucial role in designing of grounding system of substation.

B. Resistivity of Surface Material (Gravel)

The resistivity of surface material over the grounding grid mat plays important role in enhancing the safe touch and step potential of the operation and maintenance staff. Thus by using good quality of the surface material, value of safe potentials can be raised.

C. Height of Surface Material (Gravel)

The height of the surface material also helps in enhancing the safe touch and step potentials of the operation and maintenance staff.

D. Depth of Burial of Grounding Grid

There is great impact of decrease or increase in depth of burial grounding grid on the touch and step potential. Depth of burial of grounding grid changes the mesh potential i.e. it may results in increase or decrease depending upon the initial depth. But step potential always decreases with depth of burial of grounding grid.

E . Conductor Spacing

Reduction in conductor spacing increases the total number of conductors of the grounding grid. Mesh potential can be controlled by reducing the conductor spacing to some extent as too much reduction may results in rise in step potential in the substation.

F. Vertical Ground Rods

Penetrations of the vertical ground rods deep in the soil enhance the performance of grounding system in both uniform and two layer soil model as these rods help in easy discharge of fault current. Thus GPR, touch and step potentials can be controlled to safe limits as compared to grounding grid with vertical ground rods. Vertical ground rods are usually placed at the corners or periphery of the grounding grid as maximum potentials are experienced in this area.

G. Fault Level of Substation

With the increase in the fault level of the substation GPR, touch and step potential of the substation increases. So, accurate determination of fault level plays important role in accurate designing of the grounding grid of the substation.

5.2 Case Study for Parametric Analysis

To understand the impact of various parameters in the design of grounding system of substation, the data shown below (Table 5.1) is used. One parameter is varied at a time while all other parameters are kept constant for scenarios.

Table 5.1 Grounding Grid Data for Case Study

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/40 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

1. First of all, the soil resistivity of substation is varied from 50 ohm-m to 200 ohm-m (uniform soil model) as shown below:

Table 5.2 Effect of Soil Resistivity

Soil Resistivity (ohm-m)	E step (safe)	E mesh (safe)	E step (calculated)	E mesh (calculated)	Resistance of grid (Rg)-ohm
50	1730	520	340	293	0.336
80	1735	521	544	439	0.538
100	1738	522	680	540	0.673
150	1746	523	1020	797	1.010
160	1748	524	1088	850	1.077
180	1751	525	1224	953	1.212
200	1754	526	1360	1057	1.346

As shown in table 5.2 , change in soil resistivity result in change of resistance , step and mesh voltage i.e.GPR, step and mesh potential are directly propotional to soil resistivity.

The effect of change of soil resistivity on grid resistance is shown in figure 5.1. Similarly the effect of change of soil resistivity on step voltage and touch voltage are shown in figure 5.2

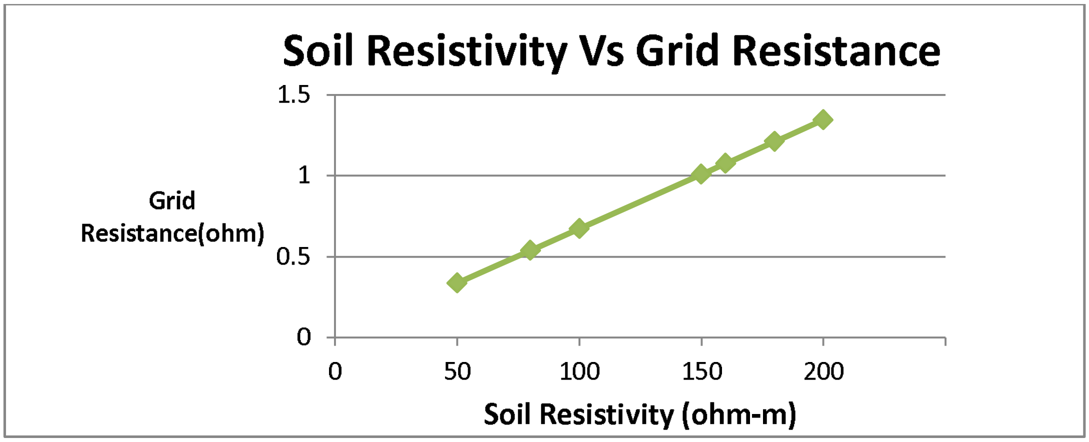

Fig 5.1 Soil Resistivity Vs. Resistance

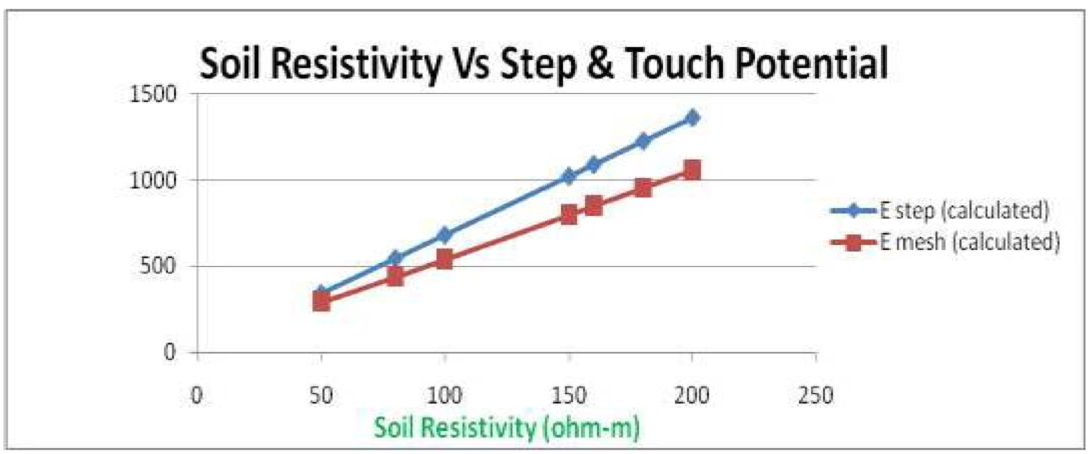

Fig 5.2 Soil Resistivity Vs Safe Potentials

2. Now height of surface material resistivity is varied in steps i.e. 10 cm to 25 cm to see the impact on safe or tolerabel step and touch potential in the substation. Different surface material with different resisitivity are used to notice the impact on safe step and touch potential.

Table 5.3 Effect of Height & Resistivity of Surface Layer Material

S NO	Height (hs) cm	Es(Safe)	Em(Safe)
1	10	1599	487
2	15	1754	526
3	20	1846	549
4	25	1907	564
SNO	**Surface Resistivity**	**Es(Safe)**	**Em(Safe)**
1	3000	1754	526
2	3500	2022	593
3	4000	2290	659
4	5000	2825	793

As shown in table 5.3 ,the change in height of surface material and resistivity of material will result in appreiciable change in both safe step and touch potential the substation . Thus it enhances the safety of working personnel in the substation.

The effect of change of height of gravel on grid on tolerable (safe) step voltage and touch voltage are shown in figure 5.3. Also the effect of change of resistivity of gravel on grid on tolerable (safe) step voltage and touch voltage are shown in figure 5.4.

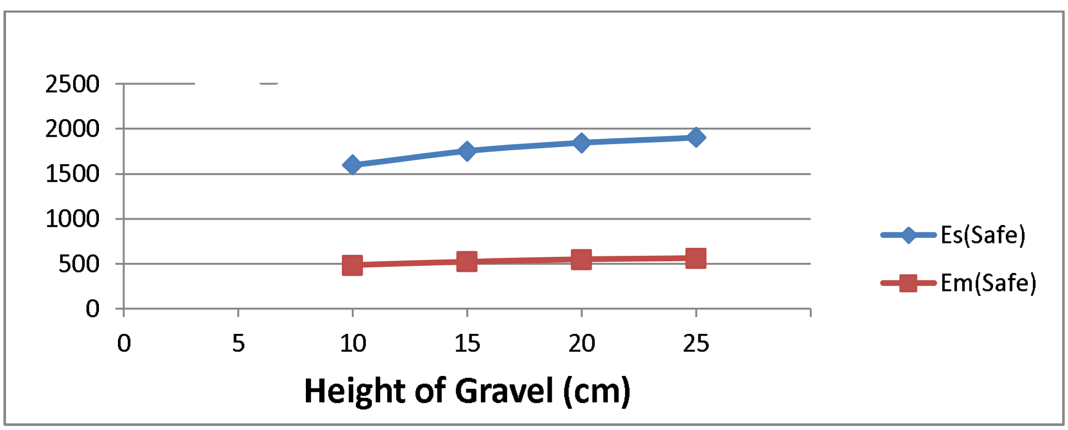

Fig 5.3 Height of Gravel Vs Safe Potentials

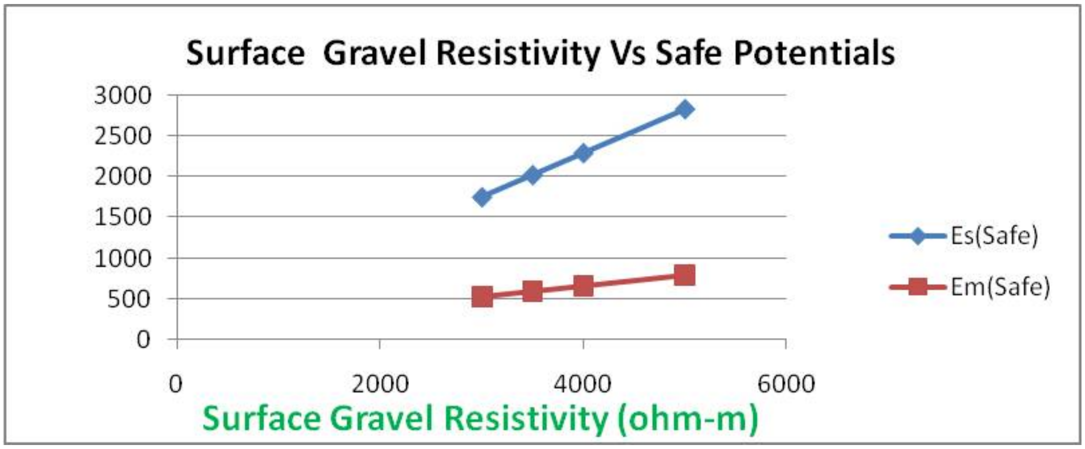

Fig 5.4 Surface Material Resistivity Vs. Safe Potentials

3. Next the depth of burial of ground grid is varied to see the effect on other parameters as shown below:

Table 5.4 Effect of Depth of Burial of Ground Grid

Depth of ground grid (h) cm	Rg (ohm)	GPR	E step (calculated)	E mesh (calculated)
50	1.350	54022	6201	4313
60	1.346	53873	5438	4197
70	1.343	53719	4890	4122
80	1.339	53571	4476	4075
90	1.335	53424	4151	4049
100	1.331	53279	3890	4041
110	1.3284	53136	3672	4045
120	1.3248	52994	3491	4061
140	1.3178	52716	3201	4118
160	1.3111	52443	2980	4198
180	1.304	52178	2804	4296
200	1.297	51918	2660	4407

As shown above in table 5.4, increase in depth of burial of ground grid always results in reduction of step potential but mesh potential may increase or decrease depending upon the initial depth of the burial of ground grid in the station. The same has been depicted in figure 5.5 below.

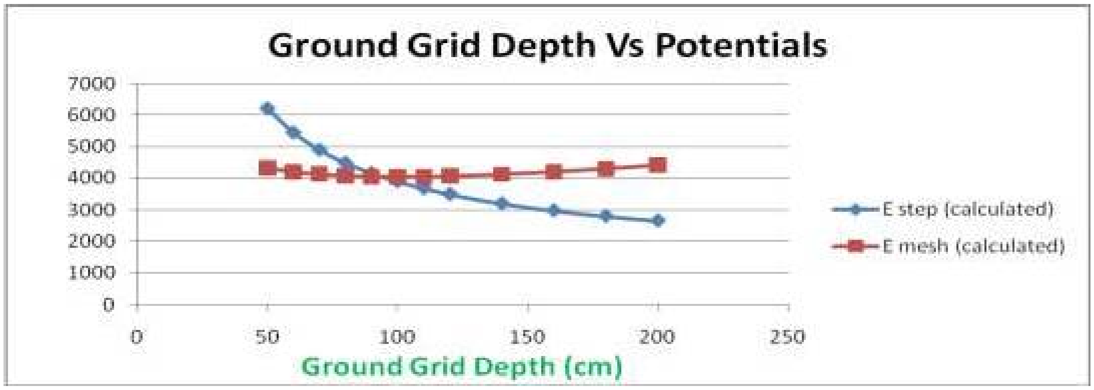

Fig 5.5 Ground Grid Depth Vs. Actual Potentials

Next the fault current which may flow in the substation during fault in the network is varied as shown in table 5.5 below.

Table 5.5 Effect of Fault Current on Safety

Fault Current (kA)	Rg(ohm)	GPR	E step (calculated)	E mesh (calculated)
10	1.346	13467.6	1360	1057
15	1.346	20201.4	2039	1579
20	1.346	26935.2	2719	2102
25	1.346	33669.1	3399	2625
30	1.346	40402.8	4079	3149
35	1.346	47136.6	4759	3673
40	1.346	53870.4	5438	4197

The effect of change of fault current on GPR in the substation is shown in figure 5.7 and the effect of change of fault current on calcualted step potential and touch potential are shown in figure 5.8 below.

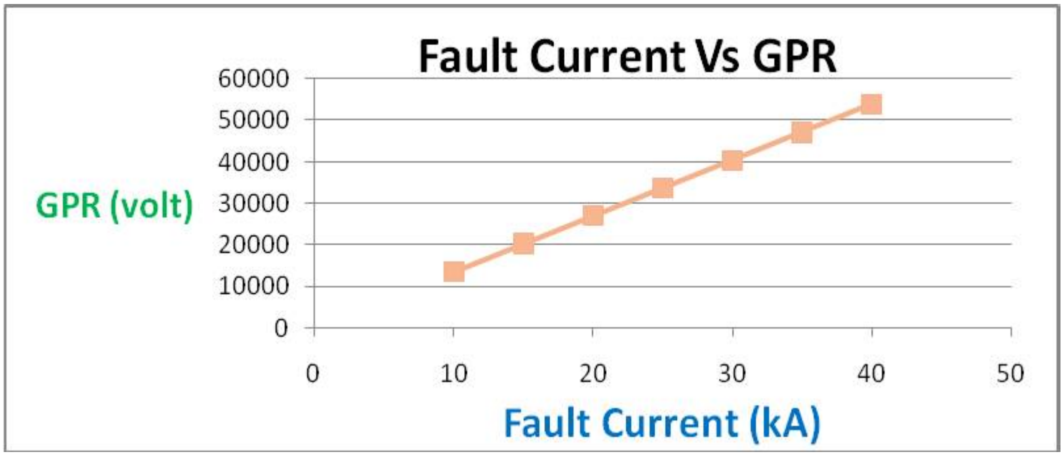

Fig 5.6 Fault Current Vs GPR

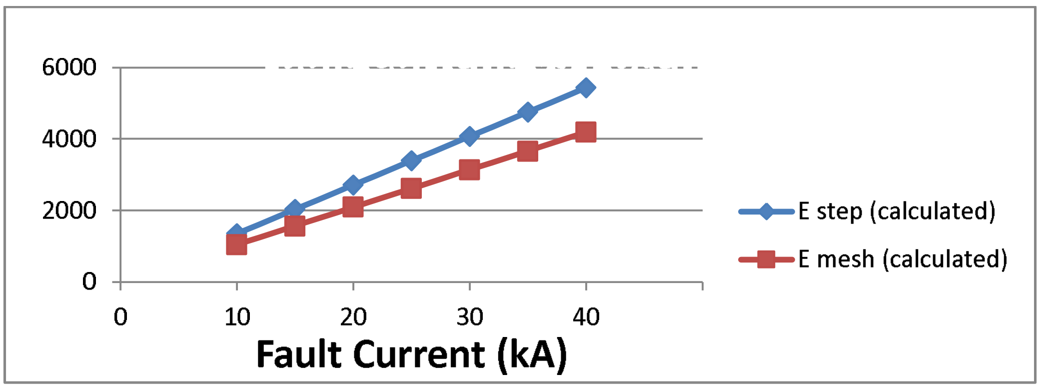

Fig 5.7 Fault Current Vs Actual Potentials

Next, the separation between grounding grid conductors is increased to observe the impact as shown below:

Table 5.6 Effect of Number of Mesh / Separation of Conductors

Mesh Separation (D) metre	Rg(ohm)	GPR	Estep (calculated)	E mesh (calculated)
2	1.293	12933.8	1705	223
5	1.346	13467.6	1360	1056
6	1.363	13632.6	1338	1285
8	1.394	13945.2	1328	1693
10	1.423	14236.6	1340	2054
12	1.450	14508.9	1362	2391
15	1.488	14885.4	1402	2846

It can be seen from the table 5.6 that the increase in the separtion results in appreciable increase in mesh potential whereas step voltage decreases appriciably for change from D=2 to D=5 but this change become small from D=6 to D=12. The step voltage starts rising for large value of separation between the conductors as depicted in the figure 5.8 below.

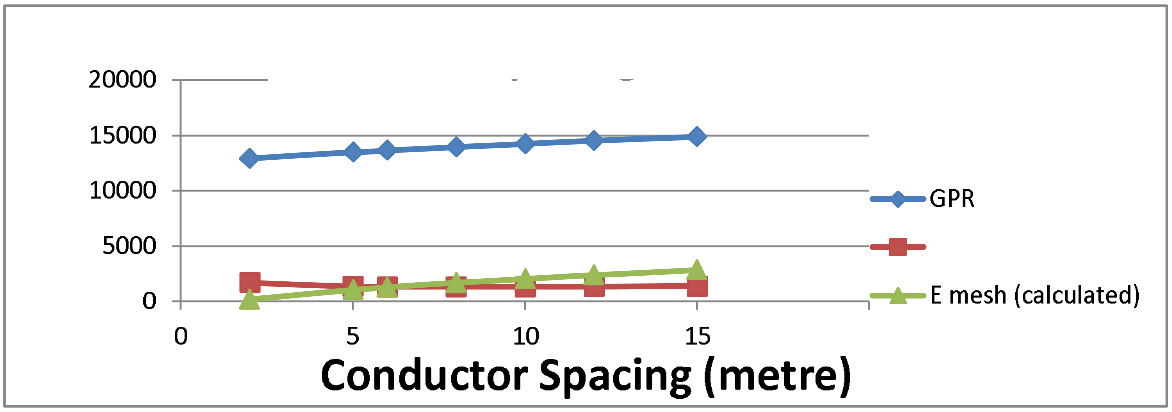

Fig 5.8 Conductor Spacing Vs. Actual Potentials

5.3. Uniform Vs Two Layers Soil Model

As mentioned earlier the uniform soil model is rarely found in the real condition so assumption of uniform soil model based on average value of soil resistivity may results in over or under design of the grounding system. The two layer soil model for substation is shown in figure 5.9 below.

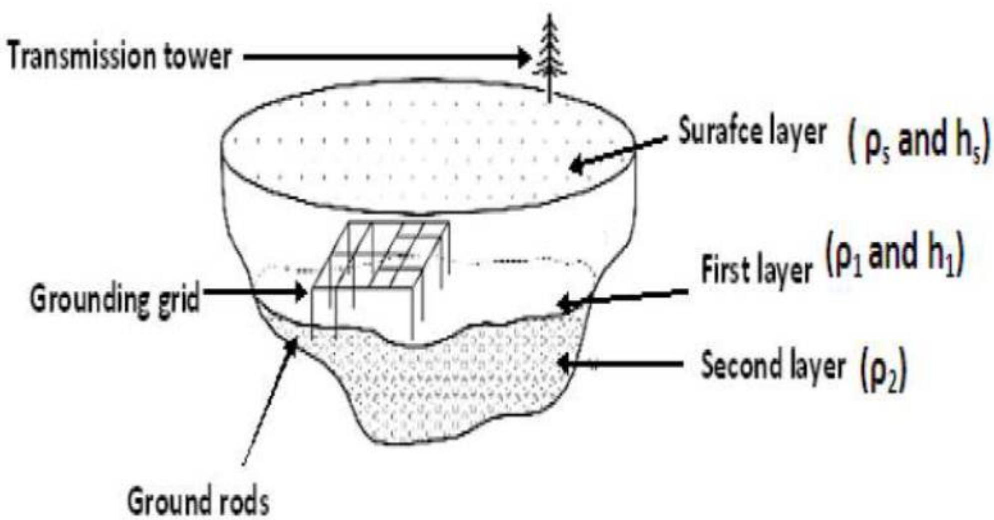

Fig 5.9 Two Layer Soil Model

Thus it makes necessary to compare the results obtained by assuming uniform soil model with two layer soil model for positive as well as negative reflection factors.The data of tabel 5.1 is taken for comparison and upper layer resistivity of two layer soil model is taken as the resistivity of uniform layer model. The results shown are given below:

Table 5.7 Comparison of Uniform Soil Model With Two Layer Soil (+K)

	UNIFORM LAYER SOIL MODEL	**TWO LAYER SOIL MODEL (+ K)**	
PARAMETERS	**Soil Resistivity (50 ohm-m)**	**Soil Restivity layer 1= 50 ohm-m Soil Resitivity layer 2 =200 ohm-m & H= 3m**	**% Difference**
Safe Step Potential (50kg) - volt	1730	1730	0
Safe Mesh Potential (50kg) - volt	520	520	0
GPR (volt)	3360	9411	-180
Cal. Step Potential - volt (Es)	340	337	0.88
Cal. Mesh Potential - volt (Em)	293	657	-124

As shown above in table 5.7, GPR and mesh potential vary appreciably in case of two layer soil model for positive refection factor i.e. when the resistivity of lower layer soil is more as compared to upper layer soil resistivity. Thus, uniform layer soil model in such cases will not give accurate design. The results are shown in figure 5.10 below.

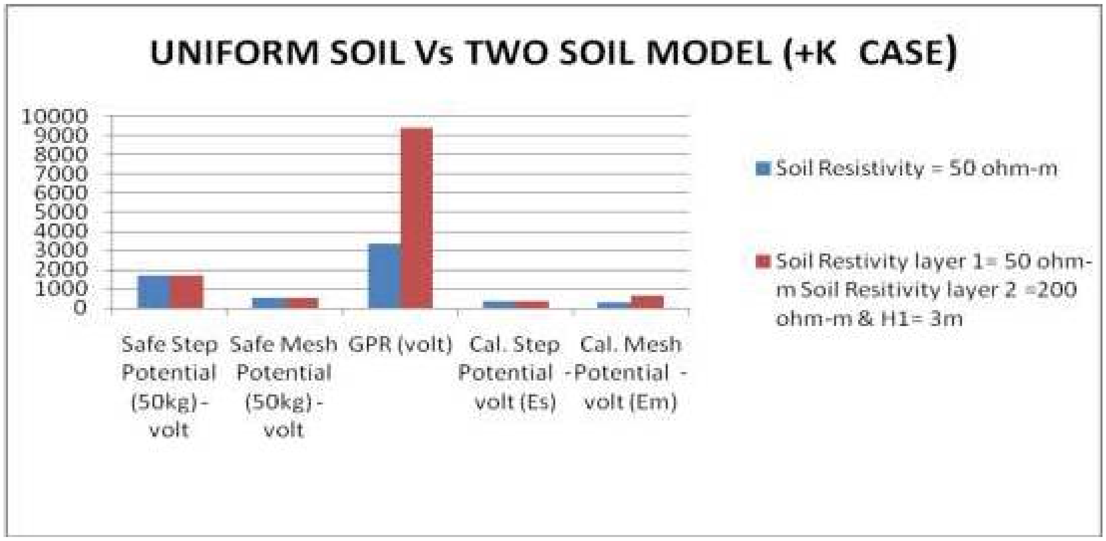

Fig 5.10 Uniform Vs. Two layers (Positive K case)

Now, let us take another case of negative reflection factor where the resistivity of upper soil is more as compare to resistivity of lower soil as shown in table 5.8 below:

Table 5.8 Comparison of Uniform Soil Model With Two Layer Soil (-K)

	UNIFORM LAYER SOIL MODEL	TWO LAYER SOIL MODEL (- K)	
PARAMETERS	**Soil Resistivity (200 ohm-m)**	**Soil Restivity layer 1= 200 ohm-m Soil Resitivity layer 2 =50 ohm-m & H= 3m**	**% Difference**
Safe Step Potential (50kg) - volt	1754	1754	0
Safe Mesh Potential (50kg) - volt	526	526	0
GPR (volt)	13460	4175	68.98
Cal. Step Potential - volt (Es)	1360	338	75.14
Cal. Mesh Potential - volt (Em)	1057	940	11.06

It is clear from the above that for the cases of negative refection factors, GPR and Step potential reduce appreciably. Thus, design of grounding system in such cases will not be accurate. The same is depicted by graph shown in figure 5.11 below.

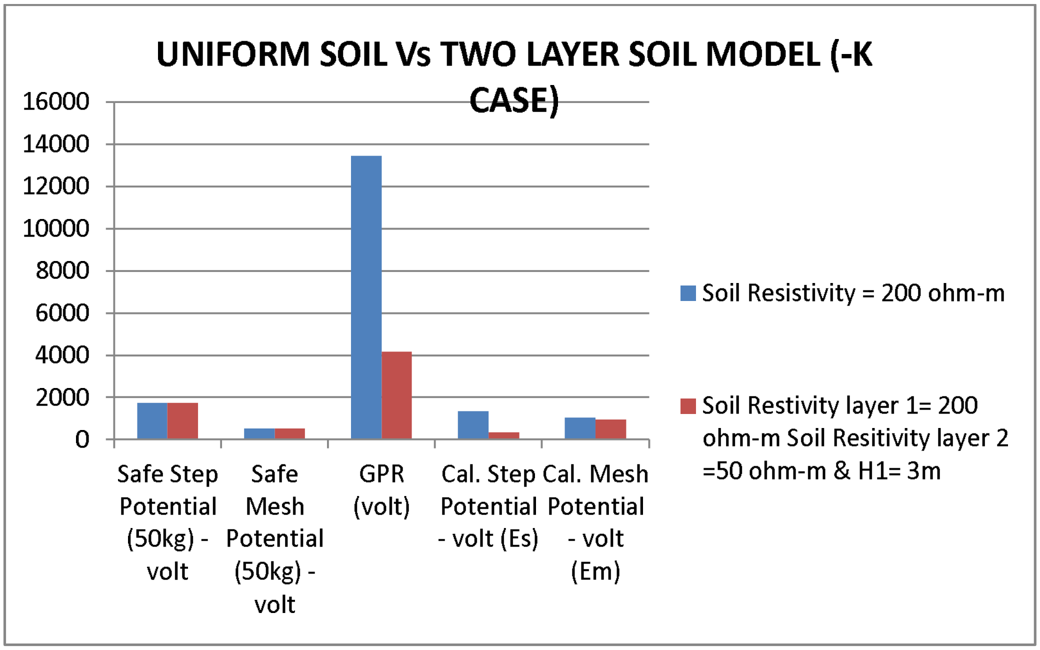

Fig 5.11 Uniform Vs. Two layers (Negative K case)

5.4 Conclusion

It is evident from the above study that where the soil resistivity of substation is not uniform i.e. the value of soil resistivity measurement at different locations are not equal and their variation is more than 30 percent , uniform layer soil model in such cases will not give accurate design. So use of appropriate soil model for designing of grounding system becomes very crucial for accurate designing of grounding system of the substation.