Design and Analysis of Substation Grounding Grid with and without Considering Seasonal Factors using EDSA Software

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Abstract- The grounding grid provides a common ground for the electrical equipment as well all the metallic structures in the substation. Effective Grounding system design is important as it deals with personnel safety and protection of electrical equipment. Earth Fault gives rise to potential gradient within and around the substation. This voltage gradient should not exceed the tolerable human body limit. Substation grounding grid design therefore requires calculating of parameters related to earth and grounding with a great concern for the safety of the persons who may come under the influence of the potential gradient due to severe earth fault. In this paper design of the grounding grid for square and rectangular configuration is done and analysis is done by EDSA software. The paper presents the seasonal effects on grounding by taken into consideration the design without considering seasonal factor and after considering the seasonal factor. The methodology adopted for designing is based on IEEE Std. 80-2000.

Keywords: Step and Touch Potentials, Ground potential rise, Absolute potential, IEEE Std. 80-2000, Ground grid, EDSA software.

I. INTRODUCTION

The design consideration of substation grounding is important for providing low resistance path to ground, to allow discharge path for lightning strike and protection of equipment and personnel against transferred potential [1]. The ground potential rise (GPR) can be minimized by providing low resistance path to ground. Earth fault give rise to voltage gradient which should be properly calculated to not to exceed the tolerable human limit. In situation of lightning and earth fault give rise to high current in substation resulting in potential difference which causes severe electric current to flow through human body. Effective design in substation grounding should have low ground resistance with tolerable step and touch voltage limit [2-3]. The purpose of this paper is to bring a brief compilation of grounding system calculation using the methodology of IEEE 80-2000 standard and simulated by means of EDSA[4] software. The substation ground grid design also takes into consideration of the freezing and raining season.

II. DESIGN PARAMETERS

Grounding grid design analysis consists of [5]:

- Grounding system Modeling, grounding grid representation, earth conductivity and connected power system
- Determining easy procedures to determine ground potential rise for particular fault type and location.
- Method of determination of step, touch and transfer potentials.
- Developing easy procedures for grid analysis.

III. SAFETY CRITERIA FOR SUBSTATION GROUNDING DESIGN AS PER IEEE Std. 80-2000

A person working in substation may be subjected to five shock situations namely, Step voltage, Touch voltage, Mesh voltage, Metal to metal touch voltage and Transferred voltage [6]. Step and Touch voltage are used to derive the safety criteria for Grounding grid design. A good grounding system should have the actual mesh and step voltages well below tolerable touch and step voltages respectively. Fibrillation discharge limit of body current is used to determine the tolerable safety criteria for grounding system design [7]. The main consideration that is taken into account for substation grounding design is that under any circumstance actual step and mesh voltages must not exceed the tolerable Voltage limits. Figure 1. Shows the basic shock situations for the substation ground grid.

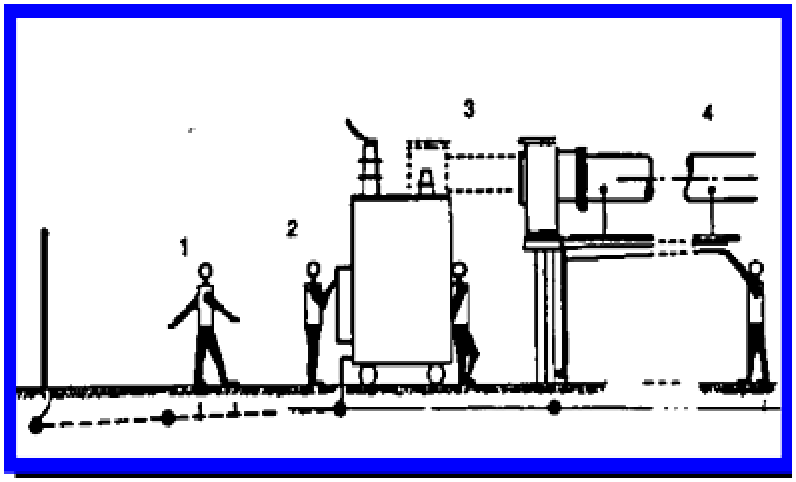

Figure 1. Basic shock situations

1. Step voltage	2. Touch voltage
3. Mesh voltage	4. Transferred voltage

IV. COMPUTATION OF BODY CURRENT

The non-fibrillating current (I_B) is related to the shock energy (S_B) by the expression:

$$I_B = \frac{K}{\sqrt{ts}} \quad (1)$$

Where K= $\sqrt{S_B}$

$I_{B=}$ RMS magnitude of the current through the body

ts = duration of the current exposure in seconds

S_B = constant related to the electric shock energy tolerated by a certain percent of a given population

For persons of an approximate weight of 50 kg, $k_{50} = 0.116$, and

For persons of an approximate weight of 70 kg, $k_{70} = 0.157$.

For a person of average weight who could withstand current (I) without ventricular fibrillation, the equation is:

$$I = \frac{116.0}{\sqrt{t_s}} \text{ mA} \tag{2}$$

V. USE OF CRUSHED ROCK LAYER (ρ_s)

A layer of crushed rock on surface helps in limiting the human body current by adding resistance to the equivalent body resistance. The values of ρ_s vary from 1000-5000 Ω -m.

VI. RESISTANCE OF THE HUMAN BODY

The human body can be represented by a non-inductive resistance (R_B) for both DC and AC at normal power frequency. A value of $R_B = 1000$ is selected as a resistance of a human body from hand to both feet, and also from hand to hand, or from one foot to the other as per IEEE Std 80-2000.

VII. RESISTANCE OF THE GROUND BENEATH THE TWO FEET

The resistances of the ground beneath the two feet in series and parallel are:

$$R2FS = 6.0\, C_s\, (h_s, k)\rho_s \tag{3}$$

$$R2FP = 1.5\, C_s\, (h_s, k)\, \rho_s \tag{4}$$

Where: C_s = Reduction factor for derating the surface layer resistivity, and C_s is a function of (h_s, k)

h_s = Thickness of crushed rock surface layer in meters

k = Reflection factor

ρ_s = Crushed rock resistivity in ohm-meter

ρ = Resistivity of the soil in ohm-meter

VIII. COMPUTATION OF ALLOWABLE STEP AND TOUCH POTENTIALS

The maximum driving voltage of any substation should not exceed the limits defined below:

For step voltage the limit is

$$Estep = (R_B + R2FS)\, I_B \tag{5}$$

Combining equations 5, 2, 3

$$E_{step50} = [1000 + 6Cs\, (h_s, k)\, \rho_s]\, 0.116 / t_s \tag{6}$$

$$E_{step70} = [1000 + 6Cs\, (h_s, k)\, \rho_s]\, 0.157 / t_s \tag{7}$$

To ensure safety, the actual step voltage E_S should be less than the maximum allowable step voltage Estep.

Similarly, the touch voltage limit is:

$$E_{touch} = (R_B + R2FP)\, I_B \tag{8}$$

Combining equations 8, 2, 4

$$E_{touch50} = [1000 + 1.5\, Cs\, (h_s, k)\, \rho\, s]\, 0.116 / t\, s \tag{9}$$

$$E_{touch70} = [1000 + 1.5\, Cs\, h_s, k)\, \rho\, s]\, 0.157 / t\, s \tag{10}$$

IX. DETERMINATION OF MAXIMUM GRID CURRENT

The design value of maximum grid current is defined as follows:

$$I_G = C_p\, D_f\, I_g \tag{11}$$

Where:

I_G = Maximum grid current in Amperes

D_f = Decrement factor for entire duration of fault in seconds

C_p = Projection factor for future system growth

I_g = RMS symmetrical grid current in Amperes

Again,

$$I_g = S_f I_f \quad (12)$$

Where:

I_f = RMS value of symmetrical ground fault current in Amperes

S_f = Current division factor relating the magnitude of fault current to that of its

Portion flowing between the grounding grids and surrounding earth

X. DESIGN OF GROUNDING GRID USING EDSA TOOL

The following data given in the table is considered for the substation ground grid design

Table 1. Data considered for the grid design

S.No.	Components	Values
1	Fault current (amp.)	1908
2	Parallel impedance(ohm)	10000
3	Fault current division factor	1.00
4	Body weight(Kg)	70
5	Fault duration(sec.)	0.500
6	Thickness of surface material(m)	0.102
7	Surface material description	Crushed rock
8	Resistivity of surface material(ohm-m)	2500

A. Square grounding grid without rods

A Square grid configuration with dimension 70 m × 70 m with 7 m spacing between the grid and no ground rod is designed. Here, two layer soil models are considered with upper and lower layer soil resistivity of 400 ohm-m each is used. Thickness of upper soil layer is 100 m (i.e. two layer soil model with equivalent homogenous soil is used).Allowable touch voltage limit is 500 volts and allowable step voltage limit is 1000 volts. The Ground potential rise comes to be 5086.3 which is very much high than the tolerable limits. Hence, it results in the failure of the designed grounding grid.

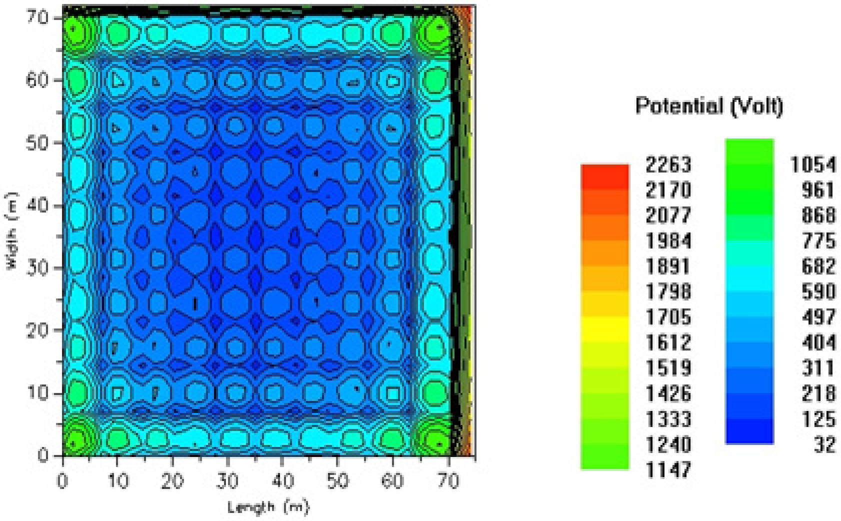

Figure 2. Touch potential equipotential lines for square grid without ground rods

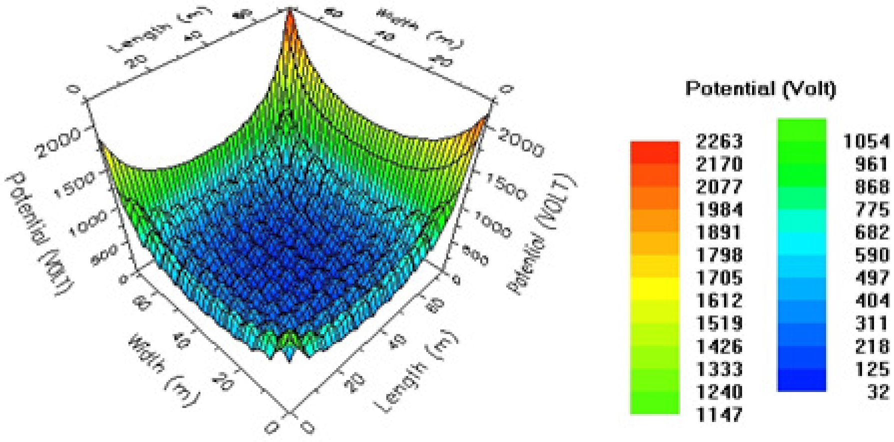

Figure 3. Touch potential 3D graph for square grid without ground rods

B. Square grounding grid with rods

A Square grid configuration with dimension 70 m × 70 m with ground rods is used. In this case homogenous soil model is considered with soil resistivity 400 ohm-m and limiting values of touch and step voltage are same as in the previous case, as these values do not depend upon the considered grounding grid configuration .The Ground potential rise comes to be 459.7 volts which is lower than the tolerable limits. Hence, the grid is considered to be within safe limits.

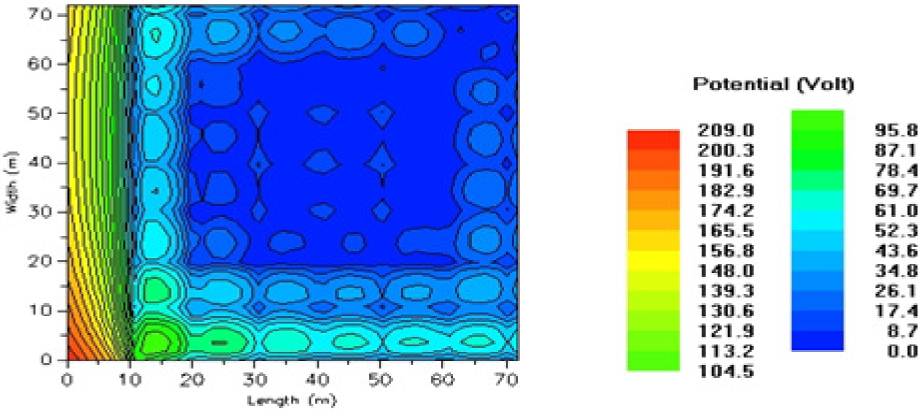

Figure 4. Touch potential equipotential lines for square grid with ground rods

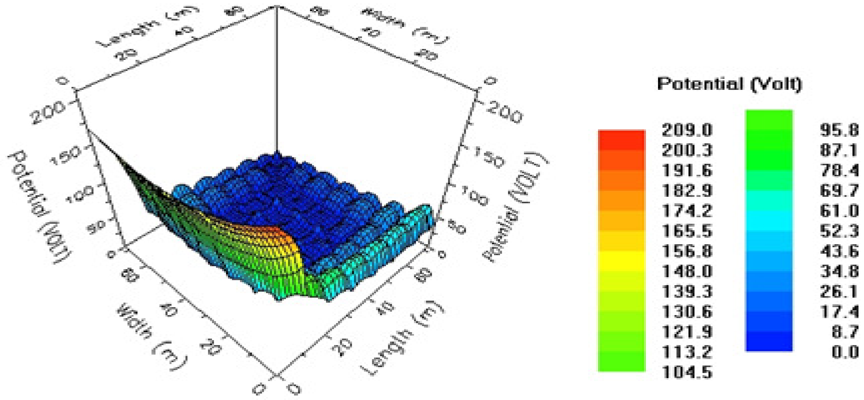

Figure 5. Touch potential 3D Graph for square grid with ground rods

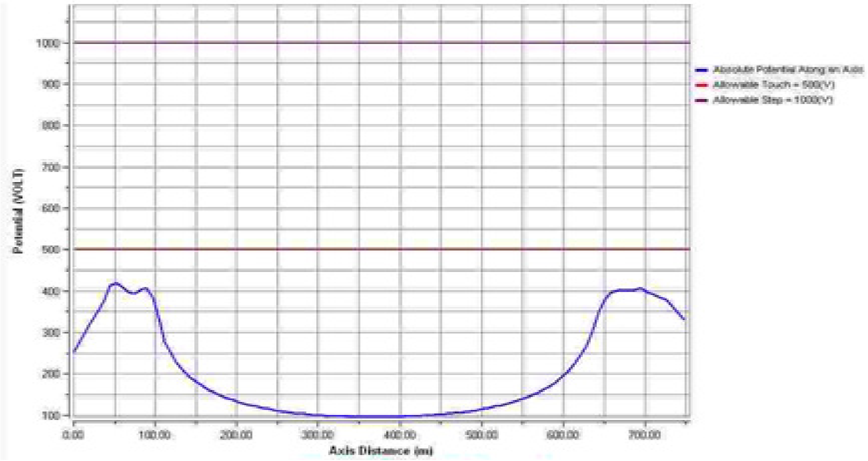

Figure 6. Absolute potential along an axis for square grid with ground rods

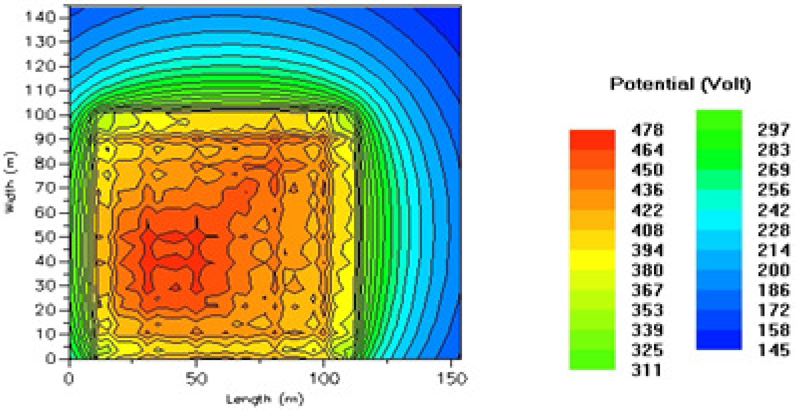

Figure 7. Absolute potential equipotential lines for square grid with ground rods

C. *Rectangular grounding grid without rods*

A Rectangular grid configuration with dimension 150 m × 100 m and no ground rod is designed. Here, two layer soil models are considered with upper and lower layer soil resistivity of 400 ohm-m each is used. Thickness of upper soil layer is 100 m (i.e. two layer soil model with equivalent homogenous soil is used).Allowable touch voltage limit is 500 volts and allowable step voltage limit is 1000 volts. The Ground potential rise comes to be 1867.7 which is very much high than the tolerable limits. Hence, it results in the failure of the designed grounding grid.

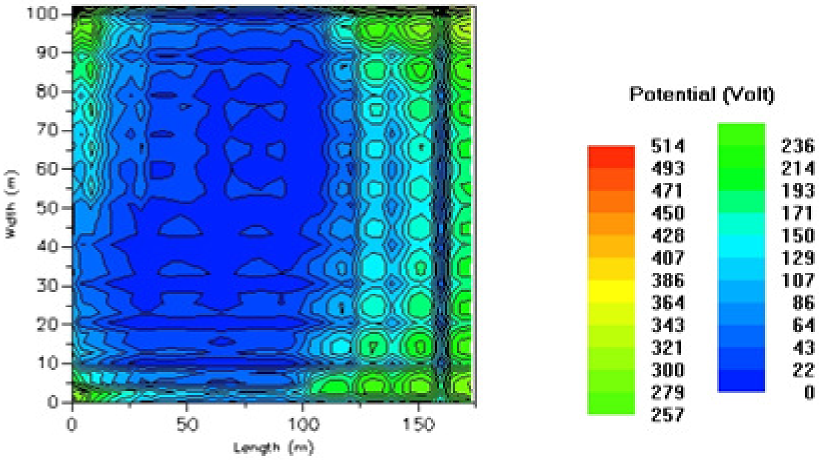

Figure 8. Touch potential equipotential lines for rectangular grid without ground rods

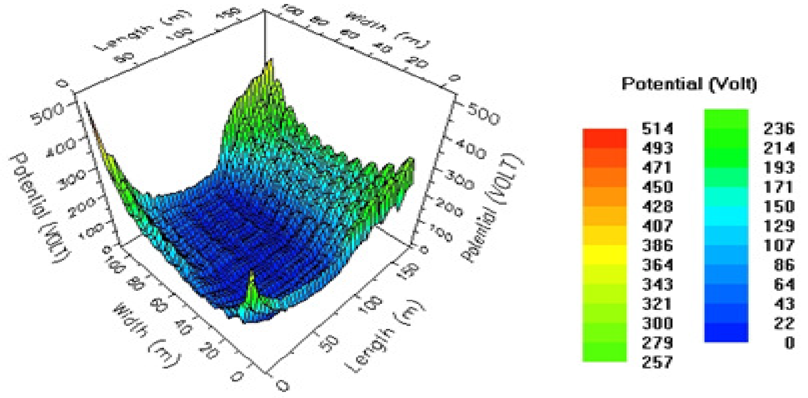

Figure 9. Touch potential 3D Graph for rectangular grid without ground rods

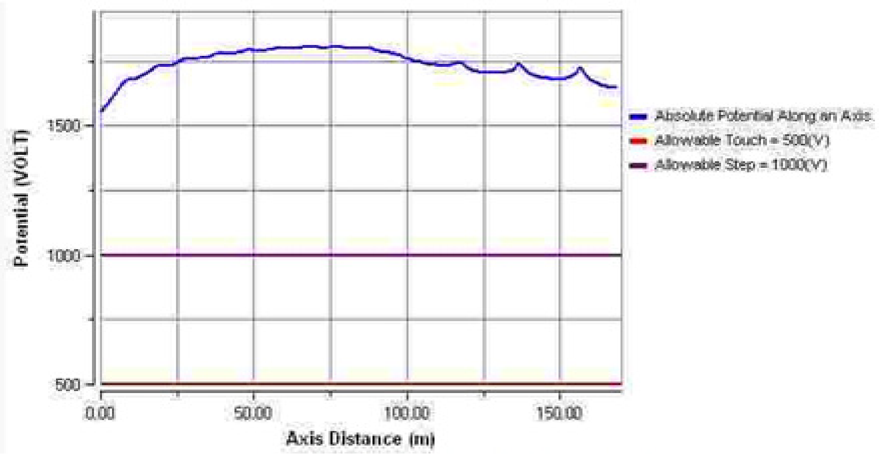

Figure 10. Absolute potential along an axis for rectangular grid without ground rods

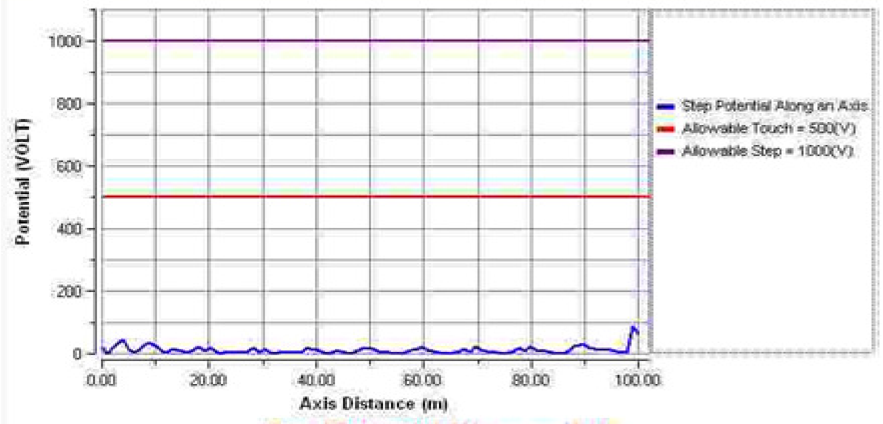

Figure 11. Step potential along an axis for rectangular grid without ground rods

D. Rectangular grounding grid with rods

A Rectangular grid configuration with dimension 150 m × 100 m with ground rods is used. In this case homogenous soil model is considered with soil resistivity 400 ohm-m and limiting values of touch and step voltage are same as in the previous case, as these values do not depend upon the considered grounding grid configuration .The Ground potential rise comes to be 2311.5 volts which is greater than the tolerable limits. Hence, it results in the failure of the grid design.

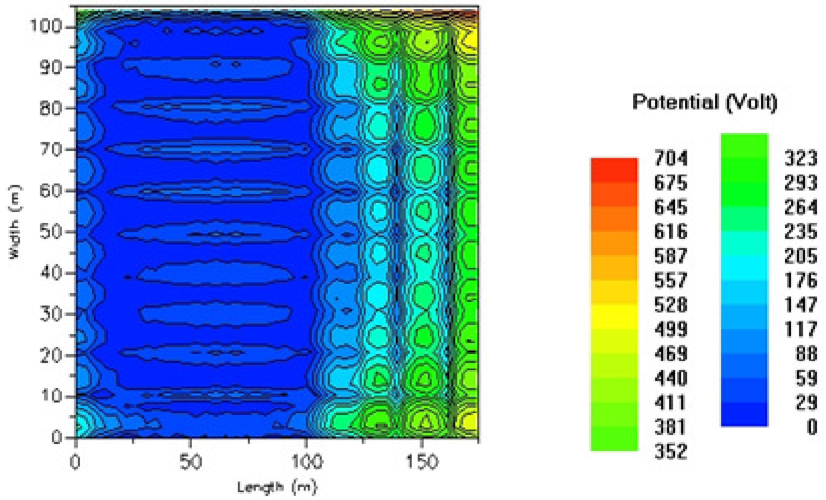

Figure 12. Touch potential equipotential lines for rectangular grid with ground rods

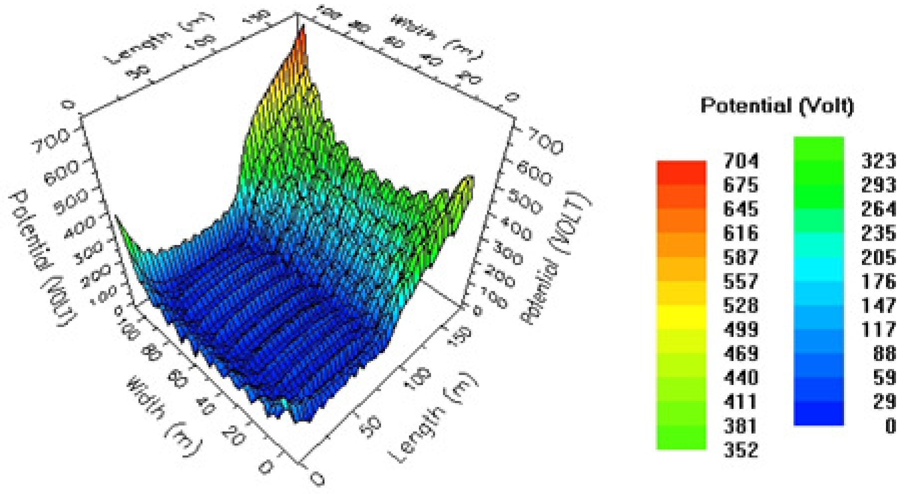

Figure 13. Touch potential 3D Graph for rectangular grid with ground rods

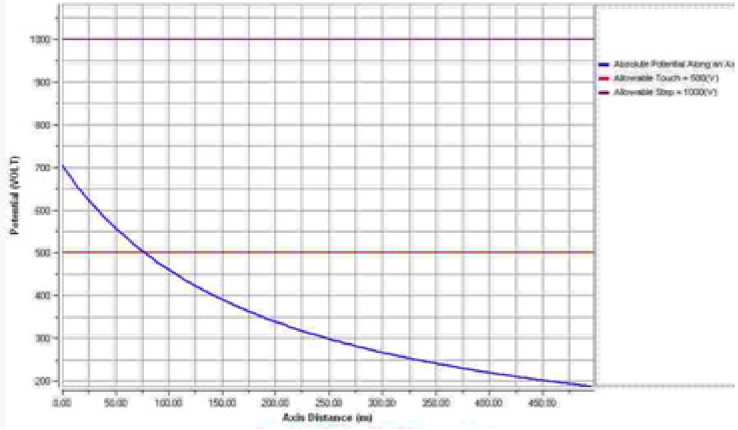

Figure 14. Absolute potential along an axis for rectangular grid with ground rods

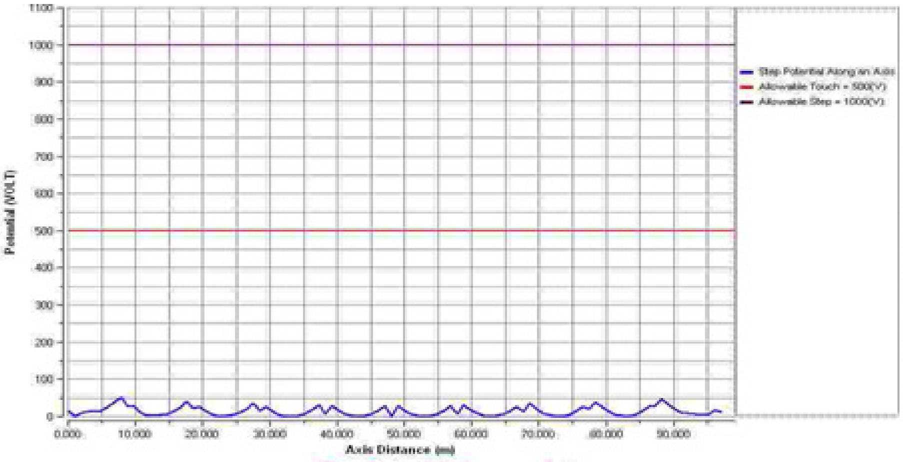

Figure 15. Step potential along an axis for rectangular grid with ground rods

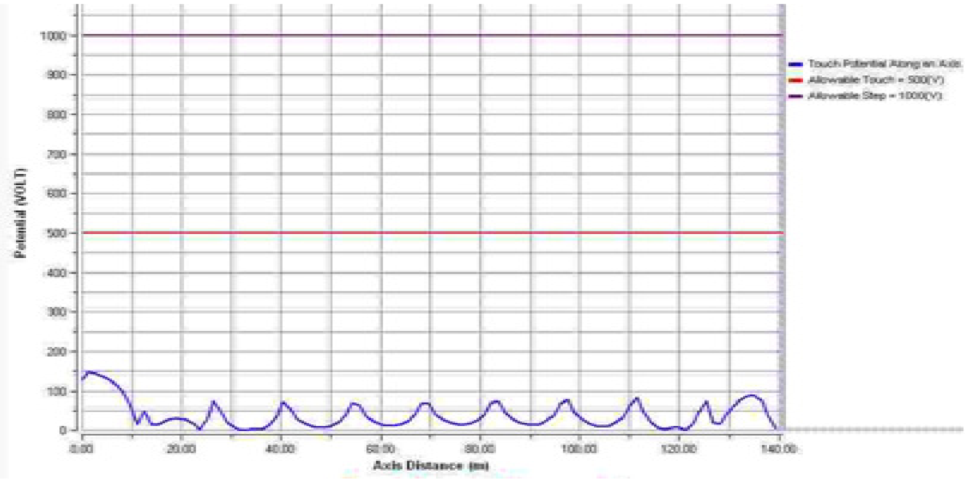

Figure 16. Touch potential along an axis for rectangular grid with ground rods

XI. GROUNDING GRID DESIGN CONSIDERING SEASONAL FACTORS

The Analysis of Grounding grid by taking into account the seasonal changes is done. The different variation in parameters due to seasonal changes is presented in the table 2

Table2. Variation in parameters due to seasonal changes

Case	Resultant model	Surface layer resistivity (□m)	Allowable touch voltage (volt)	Allowable step voltage (volt)	Maximum touch voltage (volt)	Ground potential rise (volt)	Grounding resistance (□)	Safety status
1	Homogenous	15000	3688.02	14085.98	2353.28	9368.28	0.936916	Pass
2	Two Layer	5000	1371.504	4819.922	2612.78	7932.78	0.793305	Fail
3	Two Layer	15000	4184.146	16070.489	7887.33	10311.5	1.03125	fail

A. *Raining season*

Due to the rain the soil gets affected and depending upon the extent of affected layer depth parameter varies. The influenced soil leads to a change of the soil from homogenous soil model into two layer model, with the upper layer soil resistivity as 10□ to 100□ and lower layer soil resistivity remains same as 400□. The grounding grid resistance, maximum touch voltage and step voltage values changes due to the change in resistivity of surface layer material and soil resistivity. In rainy season allowable limits of touch voltage and step voltage decrease, on the other hand maximum touch voltage values increase such that it exceeds allowable touch voltage limit. The influence of the resistivity of the low resistivity soil layer formed in raining season on the grounding resistance is shown in the figure 17, when the thickness of the low resistivity soil layer is small, the grounding resistance will almost be kept unchanged. When the thickness of low resistivity soil layer increases, the grounding resistance decreases linearly with the increase of the low resistivity soil layer.

Table3. Influence of the resistivity of the affected soil layer in raining season

S.No	Resistivity of Affected soil layer (□m)	Grounding resistance (□)				
		ha=.5m	ha=.8m	ha=1.2m	ha=1.6m	ha=2.4
1	10	.96089	.86113	.7759	.7421	.62195
2	25	1.1306	1.04735	.98324	.9336	.857177
3	28	1.14965	1.06812	1.0684	.9595	.886067
4	51	1.24467	1.17196	1.12677	1.0919	1.03691
5	52	1.24755	1.17539	1.1306	1.09611	1.04172
6	55	1.25612	1.18487	1.14167	1.10831	1.05595
7	70	1.29247	1.22617	1.18948	1.1616	1.11749
8	100	1.34526	1.29039	1.26396	1.24426	1.21335

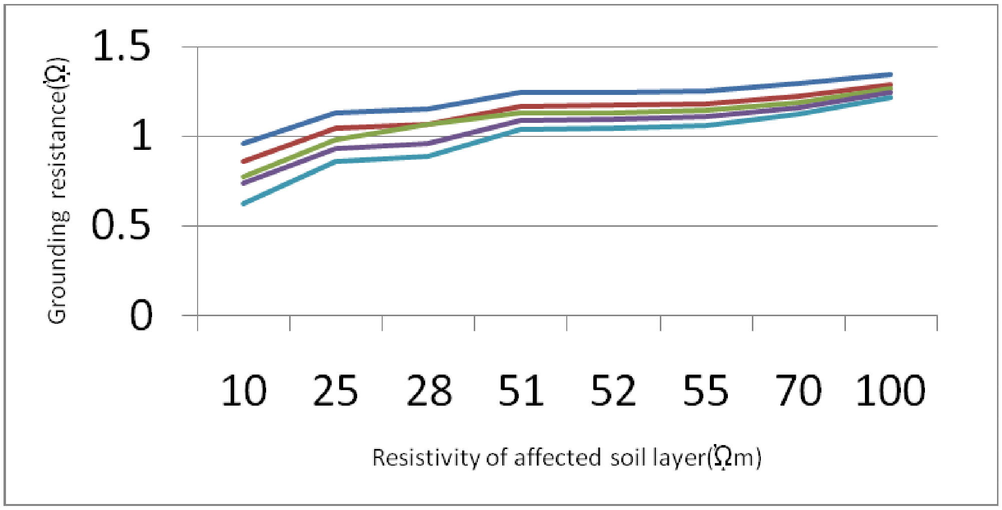

Figure 17. Influence of the resistivity of the affected soil layer in raining season

The influence of the thickness of the low resistivity soil layer formed in raining season on the touch voltage is shown in figure 18. When the thickness of the low resistivity soil layer is smaller than the burial depth, the touch voltage on the grounding surface would increase. When the thickness of the low resistivity soil layer changes from smaller than the burial depth of the grounding system to higher than the burial depth, the touch voltage would decrease rapidly.

Table 4. Influence of the thickness of the affected soil layer in raining season

S.No.	Thickness of low resistivity layer (m)	Touch voltage(volt)
1	.5	619.677
2	.8	517.217
3	1	499.962
4	1.2	488.217
5	1.4	486.272
6	1.6	484.269
7	1.8	482.02
8	2	279.947
9	2.2	477.859

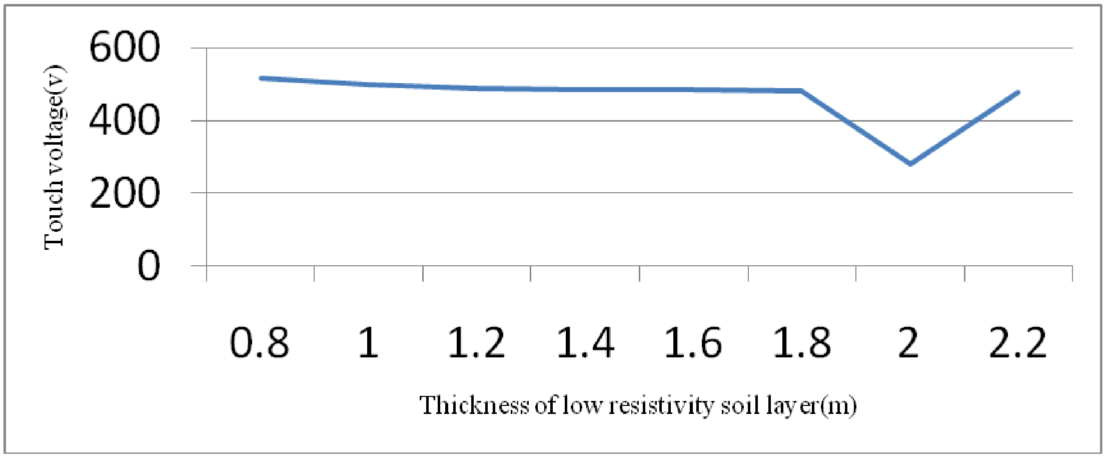

Figure 18. Influence of the thickness of the affected soil layer in raining season

B. Freezing season

In freezing season, a high resistivity surface soil layer is formed, which is called as freezing soil layer. The homogenous soil model can be analyzed from two layer model with upper layer resistivity as in between 200□ to 5000□ and lower layer resistivity as 400□ As compared to raining season the variation in values of different parameters are more in freezing season. The allowable limit of touch voltage and step voltage reduce drastically in freezing season as compared to raining season.

Table5. Influence of the thickness of the freezing soil layer on the touch voltage of the ground surface

S.No	Thickness of freezing soil layer(m)	Touch voltage(volt)		
		ρ_a=200 □m	ρ_a=1200 □m	ρ_a=3000 □m
1	.5	804.426	1288.23	1980.11
2	.8	804.426	2849.64	6201.6
3	1	804.426	3085.39	6892.5
4	1.2	804.426	3254.02	7374.05
5	1.4	804.426	3393.72	7790.4
6	1.6	804.426	3512.5	8138.04
7	1.8	804.426	3617.27	8436.88

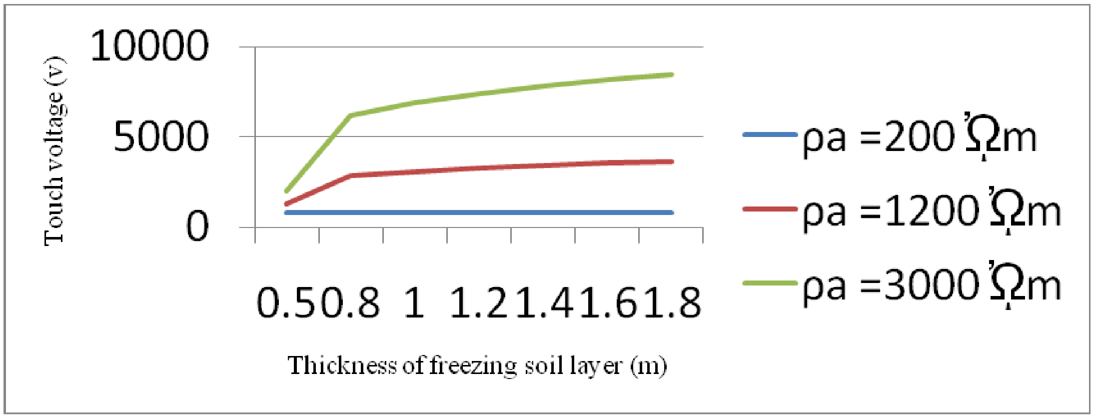

Figure 19. Influence of the thickness of the freezing soil layer on the touch voltage.

XII. CONCLUSION

The safe and reliable earthing system for 132/11 KV Anu substation, Himachal Pradesh, India has been calculated by EDSA software. The main parameters like earthing conductor etc are taken from IEEE 80-2000 standard. The Square and Rectangular grid configuration for the substation has been considered in the designed and corresponding step voltage, touch potential and absolute potential graph are obtained for grounding grid with and without ground rods. The Ground potential rise (GPR) is obtained and analyzed from the grid design report. The measured value for square grid with ground rods is found satisfactory and no danger potential is identified within the substation. The calculated step and touch potential for square grid with ground rods from IEEE equation are found to be lower than the obtained potential of the substation; hence square grid with ground rods is accepted for this particular substation design. The seasonal influence is on the various earthing parameters like touch voltage and ground resistance is also studied

REFERENCES

[1] Institute of Electrical and Electronics Engineers, IEEE Guide for Safety in AC Substation Grounding, IEEE standard 80 – 2000.

[2] Mohamed Nayel, Zhao Jie, He Jin Liang, Cai Zongyuan, Wang Qi, “Study of Step and Touch Voltages in Resistive/Capacitive Ground due to Lighting Stroke”, CEEE 2006, Dalian, 2P1-07, pp 56-60.

[3] Heppe.R.J., “Step Potentials and Body Currents near Grounds in Two Layer Earth”, IEEE Transaction on Power Apparatus and System Voltages, vol.PAS-98, No.1, pp.45-59, Jan. / Feb.1979.

[4] EDSA user manual for EDSA power station 4.0

[5] John D Mc Donald, Electrical power substation engineering, CRC Press, 2006

[6] DAWALIBI, F., and MUKHEDKAR, D. Transferred Earth Potentials in Power Systems, *IEEE Transactions*, Jan 30-Feb 4, 1977, Paper no F 77 196-9, IEEE Power Engineering Society Winter meeting, New York, NY.

[7] Dwarka Prasad, H.C. Sharma, significance of step and touch voltages, International Journal of Soft Computing and Engineering (IJSCE) ISSN: 2231-2307, Volume-1, Issue-5, November 2011