SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V13I10P111

Volume 13 Issue 10, 160-170, October 2026
© 2026 Seventh Sense Research Group®

Original Article

Substation Grounding Grid Design: A Diversified Grid-Geometrical Approach

Avani Mistry[1], Ravindra Kumar Yadav[2], Vineeta Chauhan[3], Kaustubh Vyas[4]

[1,4]*Electrical Department, VGEC Chandkheda, Gujarat - 3802424 India.*
[2] *Electrical Department, KPGU, Vadodara, Gujarat India.*
[3] *Electrical Department, Indus University, Gujarat India.*

[1]*Corresponding Author : avani.electrical09@gmail.com*

Received: 21 August 2026 Revised: 01 October 2026 Accepted: 20 October 2026 Published: 28 October 2026

Abstract *- Substation is the most important element in the electrical power system network. The continuity and reliability of power systems depend on the sound operation of substation. Safety of humans and stability of equipment in the substation are guaranteed by a carefully designed grounding system. The grounding system designed depends on many aspects like geometrical design of the area, soil resistivity, choice of number and material of conductors and ground rods, etc. In this context, the complexity of the geometrical analysis for grounding grid designing is an important feature that may cause errors in the calculation. This paper deals with the simplification of length calculations for calculating the step and touch potentials for the selected grid dimensions, depending on the geometry of the network formed by conductors and rods. This mathematical analysis simplifies the design and thus, in a way, contributes to ensuring the safe limits of the potential developed in the substation, such that human and equipment limits are way inside the limits.*

Keywords *- Substation grounding grid, ETAP, Geometrical grid, Touch and step potential, Ground Potential Rise.*

1. Introduction

Electrical power system is a widespread network consisting of generation, transmission and distribution. It is a complicated, well organised network which helps in maintaining electrical supply continuity and reliability. This widespread network must have a balance between economic and continuity aspects, both balanced to maintain the supply efficiency. Substations are considered the critical elements in this whole network and play an undoubted important role in this well-synchronized system. Switching, regulating and controlling electric power-both at generating and distribution ends and even at the load end- requires substations [1-5].

It is necessary to have designing substation, safe and sound, to maintain the stability of the substation. Designing the substation grounding grid plays an important role in achieving this objective. Grounding system should be safe not only for the human working in and around the substation, but also the equipment safety limits should be guaranteed in any fault in the substation.

Safe grounding system ensures is to direct the flow of current in the ground during abnormal conditions, with safe limits of operation of electrical equipment, and makes the risk of human exposure to deadly shock equal to zero. A good grounding system meets both these limits, human and electrical safety and requires system continuity and stability. One of the important features of this design is human safety, as the effects of fault currents can be deadly, leading to immediate arrest of blood circulation, because of ventricular fibrillation. Human body is sensitive to the effects of current in the range of 0.1A. Current lesser than 1mA can create a tingling sensation in fingers and can be borne by the human body. Currents in the range of 1mA to 6mA result in unpleasant sensations but are let-go currents, and can release the energized object by muscle strength. Currents between 9mA and 25 mA are pain currents, and the release of an energized object is not possible, resulting in muscle damage. Currents from 60mA to 100 mA are fatal currents resulting in ventricular fibrillation, heart damage and respiratory issues in the human body [5].

Thus, the substation grounding grid is the only solution that not only ensures human safety but also maintains the stability of equipment in case of the worst faults possible in substations, ensuring continuity of service. The ground electrode connections form a horizontal grid of buried conductor in soil supported by a number of vertical rods forming a grid. The grid is inserted in soil, making a combinational system of horizontal conductors and vertical ground rods. The shape of the grounding grid is decided according to the area available for a particular substation grid

This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

to be designed. Grid design is a complex mathematical design procedure that ensures that the potential developed in the grid is less than the permissible values. The design procedure is mathematically complex and time-consuming, so various software such as CDEGS, CYMGRD, MATLAB, ESSGD, etc. are used. This paper deals with design simplification for any type of 5 standard shapes suggested by the IEEE 80 standard. The simplification makes it possible to get the mathematical model of the grid right, determine the number of grid conductors and the geometry of the grid, determine the soil resistivities (acceptable values) and ensure the safety of the designed grid [3, 6-9].

The novelty of this work is the development of a simplified grid design approach for a substation grounding grid, which considers the different grid geometrical configurations, the Ground Potential Rise (GPR) and the touch voltage and step voltage. The proposed approach takes into account potential distribution in 5 shape diversified grid, instead of only the low grounding resistance criteria that are considered in traditional methods at the substation. The outcomes are compared with the already established grounding designs based on IEEE Std 80 to show improvement in safety, accuracy and design efficiency. Thus, this modification helps in maintaining mathematical accuracy in design and can also contribute to the simplification of the existing methodology, which drives more accuracy and lesser mathematical errors in the substation grounding grid approach.

2. Concept of Grounding Grid Geometry

The design of a grounding system for a substation is directed towards two main goals: To assure an effective path for the leakage and fault currents to return to earth with a low enough impedance to not exceed equipment operating limits; and to provide a path for leakage and fault currents to return to earth without creating hazardous conditions for electric shock to personnel in and around grounded equipment.

The design procedure, therefore, aims to keep the step and touch voltages within, and close to, the fenced area of the substation, while considering that transferred potentials on external metallic structures can occasionally exceed the substation Ground Potential Rise (GPR) and may need additional protection measures to be taken. The mesh voltage at the corner of the grid is usually the largest touch voltage within a uniformly spaced, symmetrical grid and is therefore used as a reference for safety to be calculated; the calculated mesh or touch voltage is required to be less than the tolerable touch voltage. If the ground grid is regularly spaced and the soil is uniform, the potential distribution is linear such that the voltages of the mesh elements rise from the centre to the corners, and the voltage on the corners meshes will tend to be much higher than the voltages on the interior meshes. The gradient depends on grid size, conductor spacing, conductor depth and diameter, soil resistivity profile and the location and number of ground rods, and numerical studies indicate that the voltage ratio (c - c) across the mesh can be greater than 5 in large, finely-meshed grids.

In the practical design, the touch voltage at the centre of the corner mesh is generally assumed to be as close as possible to the worst-case mesh voltage, though actual peak touch voltages can be slightly off the centre of the mesh at the corners when the rods are located close to the boundary, or when the spacing of the conductors is significantly non-uniform. Verification and subsequent possible modification of the grid layout are carried out until acceptable mesh and stepping voltage limits are reached for the selected shock time and surface-layer.

The IEEE Std 80 - 2013 defines a set of site-dependent parameters that significantly affect the performance of the grounding grid: maximum grid current I_G, duration of fault t_f, duration of shock t_s, bulk soil resistivity ρ, surface-layer resistivity ρ_s and geometry of the grounding grid [6]. This is done by considering the division of fault current between alternate return paths, grid resistance and current decrement factors; and choosing t_f and t_s in the range of 0.25-1.0s, which is the transmission and distribution application range. Methods of measuring soil resistivity, like the Wenner four pin test, directly impact the grid resistance and surface voltage gradients, and can often be represented as a single or multiple-layer model for calculating the mesh and step voltages [10-12]. A high-resistivity surface layer (e.g., gravel) has the greatest effect on body resistance, leading to a reduction in permissible body current and hence surface derating factors for step and touch voltages, while of the geometric parameters, the grounded area, conductor spacing and burial depth have the greatest impact on mesh voltage, with the diameter of the conductors and thickness of the surfacing having comparatively small effects.

The geometry of the grid plays an important role in the whole procedure. The weight balancing the grid design parameters is an economic limitation and assurance of safety. The geometrical shape of the grid design is in accordance with the shape of the area available in which the substation is constructed. The 5 basic shapes available are: square, rectangle, L, T and triangle [1, 13].

The design varies with the shape selected, so a generalised design procedure is necessary to make a design simple and yet ensure safety and economic constraints. For general mathematical calculations, the dimensions of the shapes are assumed as shown in Figure 1 for the 5 shapes that are designed. It is possible to reduce the size of the triangle to be assumed in a broader sense as L and B, which are the dimensions of the rectangles, because of the number of rectangles.

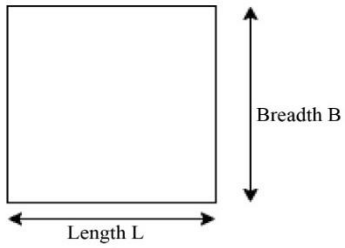
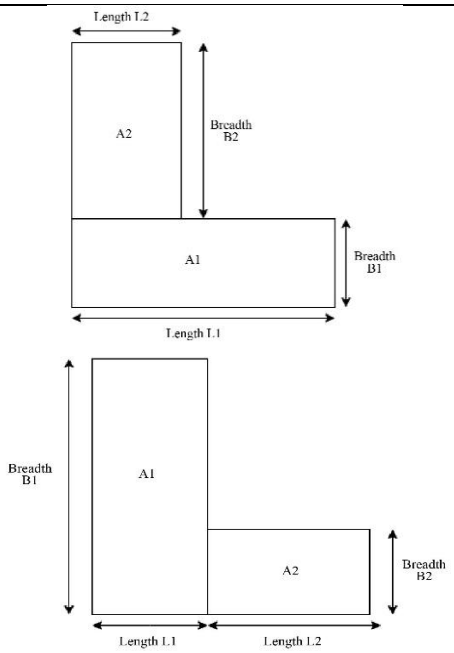
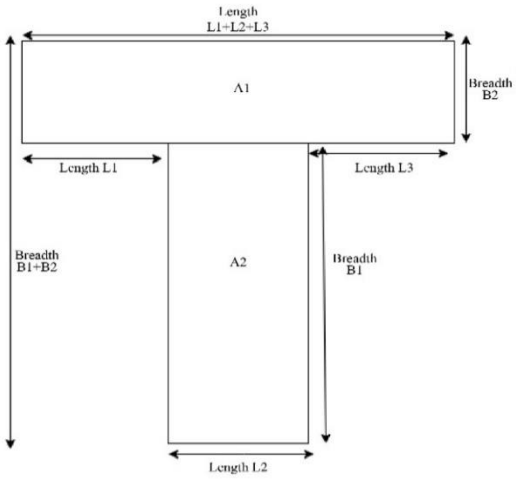
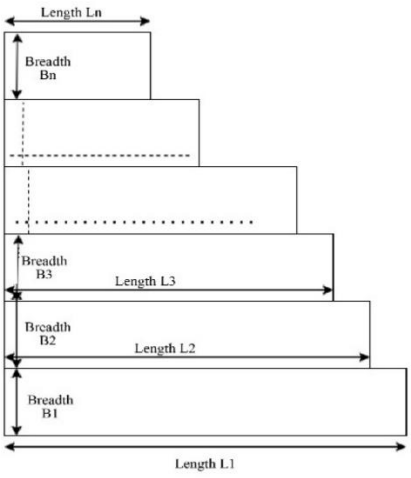
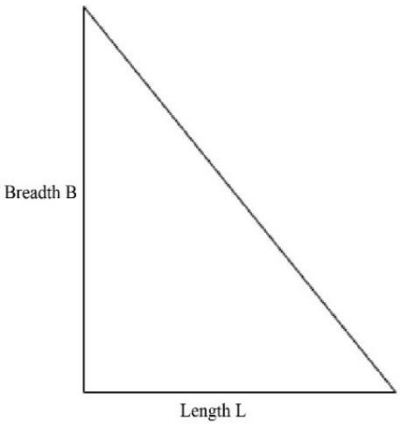
<table>
<tr><th>Shape of the grid</th><th>Details</th><th>Shape of the grid</th><th>Details</th></tr>
<tr><td>Square</td><td rowspan="2">
</td><td rowspan="2">L</td><td rowspan="2">
</td></tr>
<tr><td>Rectangle</td></tr>
<tr><td>T</td><td colspan="3">
</td></tr>
<tr><td>Triangle</td><td>
</td><td colspan="2">
</td></tr>
</table>

Fig. 1 Different shapes for the substation area available

3. Design Methodology for Substation Grounding Grid

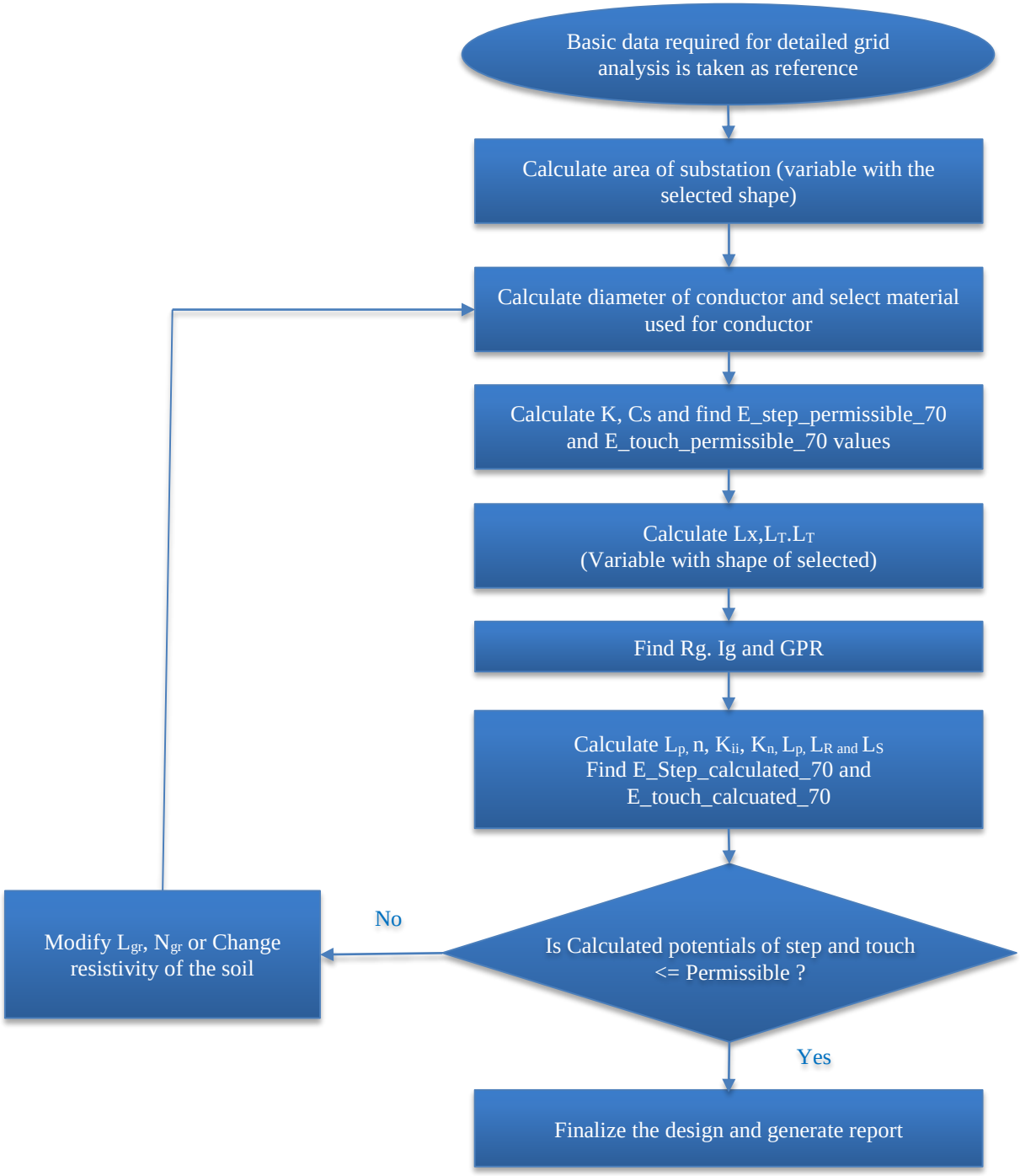


Fig. 2 Decisive flow chart

The proposed design process is a systematic step-by-step design algorithm that starts with the collection of field data specific to the site and ends with a completely verified grounding system for the substation, meeting the safety criteria of Ground Potential Rise (GPR), Mesh Voltage, and step voltage in the worst-case scenario. From property maps and substation layout, the designer first characterises the grounded area and soil resistivity profile, then sizes the conductors in the grid for the maximum prospective ground fault current, fault clearing time and thermal limit of the conductor material, and calculates tolerable touch and step voltages considering the shock duration, body weight and characteristics of the surface layer. Based on this, an initial ground-grid configuration is created, usually consisting of an

outer conductor loop and inner meshes with potential locations of ground rods. Then, the initial grid resistance and grid current are calculated, and a preliminary GPR check is conducted for the tolerable touch voltage, giving an early indication if the layout is already conservative or if further refinement is necessary. Figure 2 is a complete flow chart for determining the grounding grid procedure. The first data is assumed to be the input for the grid design, as seen in Table 1.

Table 1. Common input parameter for grid design

Parameter	Symbol	Value
Fault current	I_f	3.18 kA
Soil resistivity	ρ	400 Ωm
Surface resistivity	ρ_s	2500 Ωm
Maximum temperature	T_m	700 ˚C
Ambient temperature	T_a	40˚C
Thickness of surface layer	h_s	0.102 m
Reactance by resistance ratio	X/R	3.33
Ground grid conductor depth	h	0.5m
Split factor	S_f	0.6
Decrement factor	D_f	1
Material used in conductors	-	30% Cu clad steel wire 2
Duration of fault current	$t_f = t_s = t_c$	0.5 sec
Reference height	h_o	1m

These data are turned into assumed to establish a connection between the proposed design and then obtained from ETAP. Then, according to the shape of the grounding grid selected, the area covering the design is calculated, which will vary according to the shape selected. Then determine the diameter and type of conductor to be used in the design of the grid. Calculations of step and touch permissible potentials are made, which will be threshold values for safe grounding design as shown below [5, 14].

$$E_{step70_permissible} = (1000 + 6C_s * \rho_s)\frac{0.157}{\sqrt{t_s}} \quad (1)$$

$$E_{touch70_permissible} = (1000 + 1.5C_s * \rho_s)\frac{0.157}{\sqrt{t_s}} \quad (2)$$

These potentials should be less than or equal to the allowable values; if not, the grid design should be refined, and the entire potentials recalculated. The grid refinement continues until the permissible values are greater than the obtained values, and then the design is finalized.

4. Proposed Mathematical Model

The grid design requires different length calculations at various steps, and incorporating it with various shapes is a complicated mathematical task; therefore, a simplified methodology, owing to different shapes and lengths, is proposed. There are two main lengths in the calculations, one is the length of conductor L, the length of the grounding rods Lgr, the length in the x direction Lx and the length in the y direction Ly.

For simplicity, two lengths are introduced: one is the effective length of ground rods LT', and the other is the total length of conductors in the grid (LT), which is dependent on the shape adopted and includes the number and length of ground rods. There are 5 different cases, which are mathematically defined in terms of these lengths. For each of these, the mathematical calculation of the length changes. The distance between the two consecutive conductors is given by D meters. The perimetric length is given by L_p, which is used in the calculation of constant n, which is found from n_a,n_b,n_c and n_d.

4.1. Square and Rectangle Shape Area of the Grid

Table 2. Length calculation in square and rectangular grid shape area

Parameter	Symbol	Details
Simplification factor in horizontal direction(m)	X	X=L
Simplification factor in the vertical direction(m)	Y	Y=B
Overall length in X direction of the grid(m)	L_x	$\frac{L}{D} + 1$
Overall length in the Y direction of the grid(m)	L_y	$\frac{B}{D} + 1$
Effective length of ground rods in the grid(m)	L_T'	L_x*Y + L_y*X
Total length of conductors in the grid(m)	L_T	L_T' + (L_{gr}*N_{gr})
Perimetric length	L_p	2(L + B)

The square area is the simplest of all 5 shapes available as per IEEE 80:2013. The Length in the horizontal direction and the length in the vertical direction, effective length and total length are given in Table 2. Here, for simplification X axis length factor and Y-axis length factors are introduced, which are denoted by X and Y, respectively.

4.2. L Shape Area of the Grid

There are two cases that can produce L shape geometrical area, as shown in Figure 1. In case 1, L1>L2 and case 2, L1< or = L2. Since there are two areas, that is, the overall length of the X and Y directions are shown as Lx1, Lx2, Ly1, Ly2, respectively, as shown in Table 3.

Table 3. Length calculation in L shape area

Parameter	Symbol	Details in case 1	Details in case 2
Simplification factor in horizontal direction(m)	X_1,X_2	$X_1=L_1$, $X_2=L_2$	
Simplification factor in the vertical direction(m)	Y_1,Y_2	$Y_1=B_1$, $Y_2=B_2$	
Overall length in X direction of the grid(m)	L_{x1}	$\frac{L_1}{D}+1$	$\frac{L_1}{D}+1$
	L_{x2}	$\frac{L_2}{D}+1$	$\frac{L_2}{D}$
Overall length in the Y direction of the grid(m)	L_{y1}	$\frac{B_1}{D}+1$	$\frac{B_1}{D}+1$
	L_{y2}	$\frac{B_2}{D}$	$\frac{B_2}{D}+1$
Effective length of ground rods in the grid(m)	L_T'	$L_{x1}*Y_1 + L_{y1}*X_1 + L_{x2}*Y_2 + L_{y2}*X_2$	
Total length of conductors in the grid(m)	L_T	$L_T' + (L_{gr}*N_{gr})$	
Perimetric length	L_p	$2(L_1 + 2B_2 + 2B_1)$	

4.3. T Shape Area of the Grid

The T shape is a typical case in grounding grid design, where the design is implemented by two rectangular grounds with areas A1 and A2. The area measurement of the overall X axis is L1+L2+L3, and the area measurement of the overall Y axis is B1+B2. Table 4 simplifies the above simplification.

Table 4. Length calculation in T shape area

Parameter	Symbol	Details in case 1
Simplification factor in horizontal direction(m)	X_1,X_2	$X_1= L_1 + L_2 + L_3$, $X_2=L_2$
Simplification factor in Vertical direction(m)	Y_1,Y_2	$Y_1=B_2$, $Y_2=B_1$
Overall length in X direction of the grid(m)	L_{x1}	$\frac{L_1+L_2+L_3}{D}+1$
	L_{x2}	$\frac{L_2}{D}+1$
Overall length in the Y direction of the grid(m)	L_{y1}	$\frac{B_2}{D}$
	L_{y2}	$\frac{B_1}{D}$
Effective length of ground rods in the grid(m)	L_T'	$L_{x1}*Y_1 + L_{y1}*X_1 + L_{x2}*Y_2 + L_{y2}*X_2$
Total length of conductors in the grid(m)	L_T	$L_T' + (L_{gr}*N_{gr})$
Perimetric length	L_p	$2(L_1 + L_2 + L_3 + B_1 + B_2)$

4.4. Triangle Shape Area of the Grid

Table 5. Length calculation in a triangle-shaped area

Parameter	Symbol	Details in case 1
Simplification factor in horizontal direction(m)	X_1,X_2,X_3…….X_n	$X_1= L_1$, $X_2=L_2$,$X_3=L_3$….$X_n=L_n$
Simplification factor in Vertical direction(m)	Y_1,Y_2	$Y_1= B_1$, $Y_2=B_2$,$Y_3=B_3$….$Y_n=B_n$
Overall length in X direction of the grid(m)	L_{x1}	$\frac{L_1}{D}$
	L_{x2}	$\frac{L_2}{D}$

	L_{xn}	$\frac{L_n}{D}$
Overall length in the Y direction of the grid(m)	L_{y1}	$\frac{B_1}{D}$
	L_{y2}	$\frac{B_2}{D}$-0.5
	L_{yn}	$\frac{B_n}{D}$-0.5
Effective length of ground rods in the grid(m)	L_T'	$L_{x1}*Y_1 + L_{y1}*X_1 + L_{x2}*Y_2 + L_{y2}*X_2 + \ldots + L_{xn}*Y_n + L_{yn}*X_n$
Total length of conductors in the grid(m)	L_T	$L_T' + (L_{gr}*N_{gr})$
Perimetric length	L_p	2(L + B)

The triangle shape of area can be formed by a combination of 'n' rectangles joined to form a uniform length L and Breadth B. It is assumed that the area of substation is a right-angled area. As 'n' area is assumed, the length and breadth are formed accordingly, as shown in Table 5. The constant 'n' is used in calculating the step and touch potentials and is an important criterion in the calculation of the safety criteria of the grounding system. The final expression is further simplified as it is shown in Table 6 and used in the subsequent analysis. Overall factor n= na*nb*nc*nd. In calculation for nd, the dm distance is used, which is the maximum distance between any two points in the grid.

Table 6. Geometric factor 'n'

Factor	Square	Rectangular	L	T	Triangular
n_a	$\frac{2 * L_T'}{L_P}$	$\frac{2 * L_T'}{L_P}$	$\frac{2 * L_T'}{L_P}$	$\frac{2 * L_T'}{L_P}$	$\frac{2 * L_T'}{L_P}$
n_b	1	$\sqrt{\frac{L_P}{4 * \sqrt{A}}}$	$\sqrt{\frac{L_P}{4 * \sqrt{A}}}$	$\sqrt{\frac{L_P}{4 * \sqrt{A}}}$	$\sqrt{\frac{L_P}{4 * \sqrt{A}}}$
n_c	1	1	$\frac{L * Y^{\frac{0.7A}{LY}}}{A}$	$\frac{L * Y^{\frac{0.7A}{LY}}}{A}$	$\frac{L * Y^{\frac{0.7A}{LY}}}{A}$
n_d	1	1	1	$\frac{D_m}{\sqrt{L^2 + Y^2}}$	1

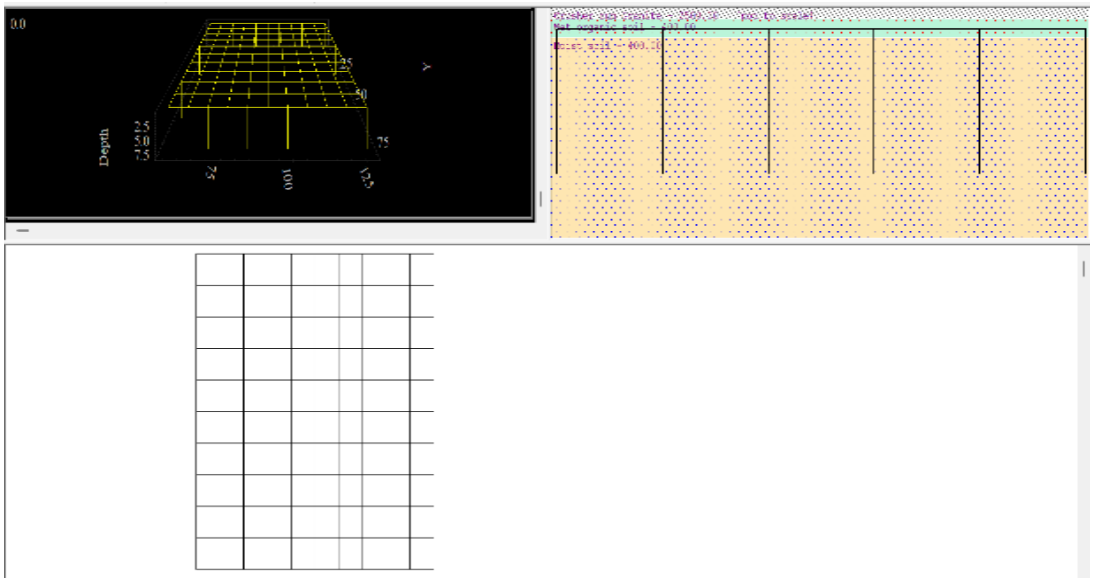
5. Results and Discussion

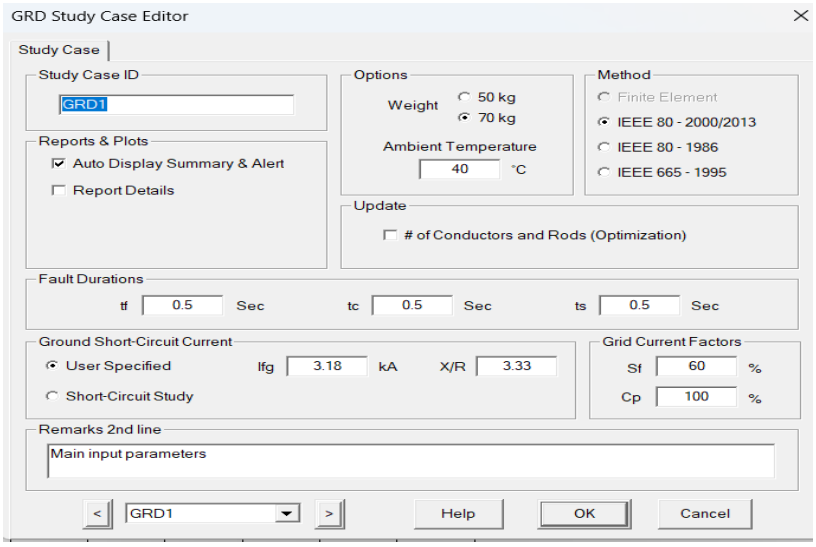
The grounding system design has been developed from the basic ETAP software that includes a Ground Grid System module to analyze and optimize earthing networks. The software can model the geometry of the grid, soil resistivity profile and the layout of the conductors and allows for calculating the grounding performance by calculating step and touch voltage. Moreover, ETAP enables grounding studies using industry standards like IEEE 80 as a secure basis for safety-related substation grounding design. The parameters of the shape selected are as shown in Table 7.

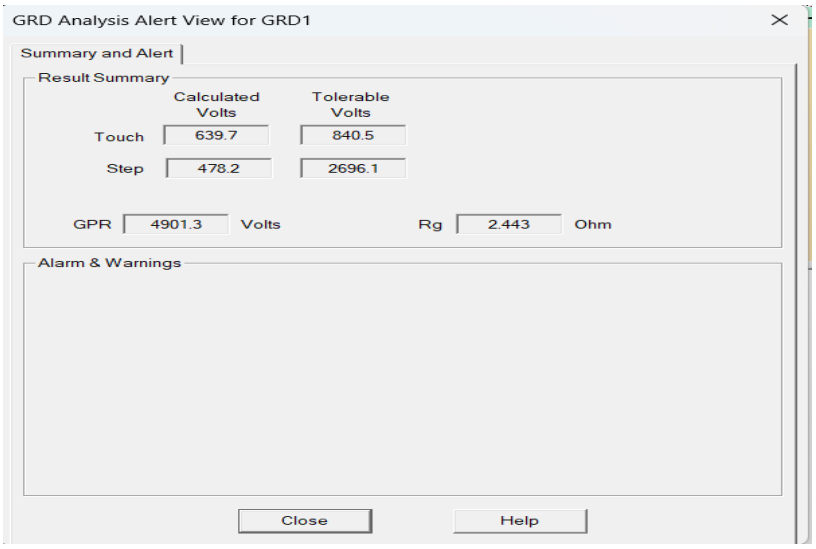
The 5 shape designs are calculated manually with the proposed modifications of length in the design, and the same input parameters are provided to the ETAP software, and the results are compared. Model of substation was developed using ETAP software, and the parameters used to design grounding grid cases are depicted in Figure 3.

Table 7. Input parameters

Grounding grid shape	Area (m^2)	N_{gr}	L_{gr} (m)	Arrangement of rods
Square	70 *70	20	7.5	Placed along the perimeter of the grid
Rectangular	63 * 84	38	10	Concentrating on the periphery, then towards the center
L	105 * 70 (70 * 35 or 35 * 70)	24	7.5	Placed along the perimeter of the grid
T	105 * 35, 70 * 35	21	7.5	Placed along the perimeter of the grid
Triangle	63 * 84	38	10	Placed along the perimeter of the grid


0.0
Depth
2.5
5.0
7.5
25
50
75
100
125


GRD Study Case Editor
Study Case
Study Case ID
GRD1
Options
Weight
50 kg
70 kg
Ambient Temperature
40
°C
Method
Finite Element
IEEE 80 - 2000/2013
IEEE 80 - 1986
IEEE 665 - 1995
Reports & Plots
Auto Display Summary & Alert
Report Details
Update
# of Conductors and Rods (Optimization)
Fault Durations
tf
0.5
Sec
tc
0.5
Sec
ts
0.5
Sec
Ground Short-Circuit Current
User Specified
Ifg
3.18
kA
X/R
3.33
Short-Circuit Study
Grid Current Factors
Sf
60
%
Cp
100
%
Remarks 2nd line
Main input parameters
<
GRD1
>
Help
OK
Cancel


GRD Analysis Alert View for GRD1
Summary and Alert
Result Summary
Calculated Volts
Tolerable Volts
Touch
639.7
840.5
Step
478.2
2696.1
GPR
4901.3
Volts
Rg
2.443
Ohm
Alarm & Warnings
Close
Help

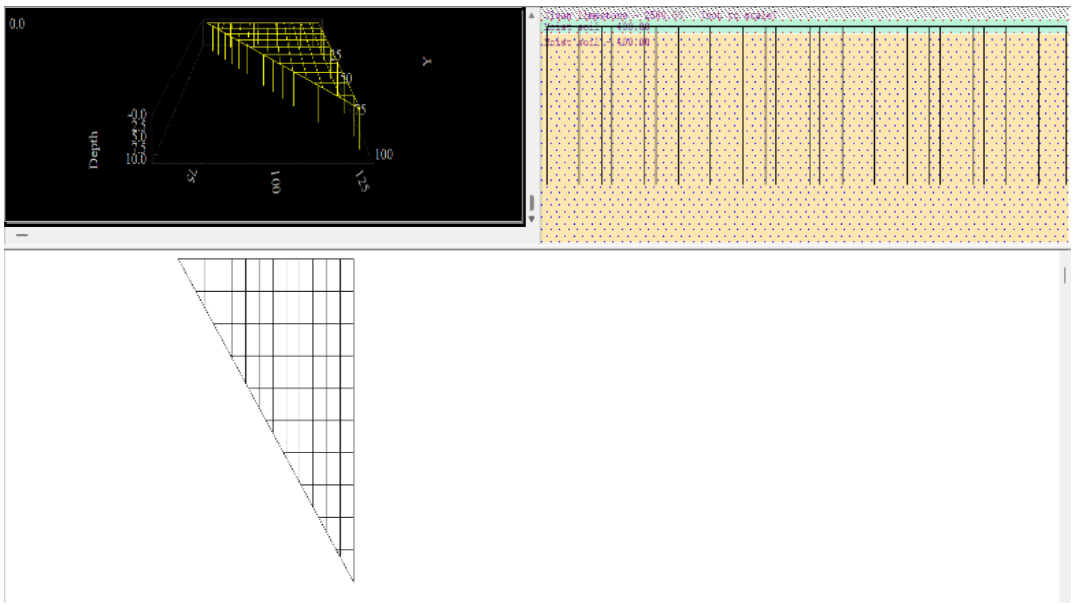


Fig. 3 ETAP software analysis

The touch and step potentials need to be calculated and be less than the allowable range that ensures the grid is safe.

The values of GPR and Rg are also verified mathematically and that by software.

Table 8. Touch potential results

Geometry of the substation grounding area	Touch potential (V)				
	$E_{touch70_obtained}$		$E_{step70_permissible}$		Remarks
	Proposed method	ETAP	Proposed method	ETAP	
Square	766.84	742.1	839.83	840.5	The design is safe, and the results obtained validate with the software.
Rectangle	594.8	593.4	838.2	840.5	
T	753.05	755.2	838.2	840.5	
L	679.31	639.7	839.83	840.5	
Triangle	793.73	799.5	839.83	840.5	

Table 9. Step potential results

Geometry of the substation grounding area	Step potential (V)				
	$E_{step70_obtained}$		$E_{step70_permissible}$		Remarks
	Proposed method	ETAP	Proposed method	ETAP	
Square	549.33	554.9	2692.4	2696.1	The proposed methodology results match with the software readings
Rectangle	449.19	459.2	2686.5	2696.1	
T	563.86	557.5	2686.5	2696.1	
L	479.03	478.2	2693.24	2696.1	
Triangle	627.71	680.2	2693.24	2696.1	

Table 10. GPR and R_g results

Geometry of the substation grounding area	Ground potential rise(V)		
	Proposed method	ETAP	Remarks
Square	5247	5307.4	The GPR values closely match the readings obtained.
Rectangle	4998.96	5037.5	
T	5235.31	5258	
L	4759.63	4901.3	
Triangle	7059.68	7108.9	

Geometry of the substation grounding area	Resistance offered by the grid R_g (Ω)		
	Proposed method	ETAP	Remarks
Square	2.75	2.75	The ground resistance with the proposed methodology match with the software results.
Rectangle	2.62	2.61	
T	2.74	2.72	
L	2.49	2.44	
Triangle	3.7	3.68	

Tables 6-8 gives the comparison of results obtained, which are for a weight of 70kg. The method of modification in mathematical calculation is a simplified method in designing the grids, which reduces confusion in calculating the length and area of shape selected. This simplification makes the chances of error less, and at the same time, the time for grid design using a manual approach is reduced. The suggested grid design method guarantees protection of the equipment and the person.

6. Conclusion

The necessity of length simplification in the calculation of step and touch potentials, which are developed during the design of a substation grounding grid, is explained in the paper. The overall length in horizontal and vertical directions, effective length, perimetric length, and total length provide a vivid idea for the designing purpose. Incorporating the lengths with the geometric grid analysis makes the procedure simple and easy to understand. Simple shapes such as square, rectangle and L-shape are analyzed in the same way as complex shapes such as T-shape and triangle. The 5 different geometric analysis results are verified using the standard software ETAP, and the similarity is about 99%, which is guaranteed by the accuracy of the design procedure, so that the simplified procedure will be used as a reference procedure for starting the grounding grid design of the substation, and the safety of the people involved and the stability of the equipment in the substation will be guaranteed.

Conflicts of Interest

"The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper."

References

[1] S. Nandhini, S. Sankara Kumar, and M. Willjuice Iruthayarajan, "Design of Earthing Grid using ETAP," *2022 6th International Conference on Trends in Electronics and Informatics*, Tirunelveli, India, pp. 392-399, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[2] Pujara Ninad, and Kapasi Husen, "*Design of Economical EHV Substation, B*," Tech Major Project Report, Institute of Technology Nirma University Ahmedabad, 2011. [Google Scholar]

[3] Arwut Puttarach et al., "Optimal Design in Distribution Substation's Grounding System for Decreasing Touch Voltage," *2020 17th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, Phuket, Thailand, pp. 486-489, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[4] Hailong Xu et al., "Analysis of Grounding Index of Substation in High Resistivity Area," *2023 8th Asia Conference on Power and Electrical Engineering*, Tianjin, China, pp. 2689-2694, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[5] "80-2013 - IEEE Guide for Safety in AC Substation Grounding," *IEEE Std 80-2013*, pp. 1-226, 2015. [CrossRef] [Publisher Link]

[6] Asanka S. Rodrigo et al., "Development of a Software Tool for Grounding System Design in Regular and Irregular Shaped Areas," *2023 Moratuwa Engineering Research Conference*, Moratuwa, Sri Lanka, pp. 13-18, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[7] Vuyani M.N. Dladla, Agha F. Nnachi, and Rembuluwani P. Tshubwana, "The Impact of System Fault Level on the Design of a Substation Earthing Grid Simulation using ETAP," *2022 30th Southern African Universities Power Engineering Conference*, Durban, South Africa, pp. 1-6, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[8] Chetan S. Payshetti, Himmat Jadhav, and Shrihari Kulkarani, "Analysis of Grounding Grid of Substation," *2017 International Conference on Circuit, Power and Computing Technologies*, Kollam, India, pp. 1-5, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[9] Fahmida Amin, Mohammad Rasel, and Safkat Islam, "Modeling and Performance Analysis of Grounding System of a Grid Substation," *2021 International Conference on Science and Contemporary Technologies*, Dhaka, Bangladesh, pp. 1-6, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[10] R. Pratama, and W.S. Saputra, "Analysis of Additional Bentonit and Salt for Improving the Resistance of Electrode Rods," *IOP Conference Series: Materials Science and Engineering*, vol. 384, no. 1, pp. 1-10, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[11] Jinliang He et al., "Decreasing Grounding Resistance of Substation by Deep-Ground-Well Method," *IEEE Transactions on Power Delivery*, vol. 20, no. 2, pp. 738-744, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[12] S. Ndhlamblenze, and Tlotlollo Sidwell Hlalele, "Earth Grid Design for 400KV Neiuwehoop Substation using CDEGS Platform," *2020 IEEE PES/IAS PowerAfrica*, Nairobi, Kenya, pp. 1-5, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[13] Surya Hardi et al., "Application Modeling of Substation Grounding Grid Design using Matlab," *2022 6th International Conference on Electrical, Telecommunication and Computer Engineering*, Medan, Indonesia, pp. 38-43, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[14] Navinesshani Permal et al., "The Impact of Substation Grounding Grid Design Parameters in Non-Homogenous Soil to the Grid Safety Threshold Parameters," *IEEE Access*, vol. 9, pp. 37497-37509, 2021. [CrossRef] [Google Scholar] [Publisher Link]