Development of IEEE Complaint Software 'Economical Substation Grounding System Designer' Using MATLAB GUI Development Environment

Kaustubh A. Vyas and J. G. Jamnani

Department of Electrical Engineering
Institute of Technology, Nirma University
Ahmedabad, Gujarat, India
kaustubhavyas@gmail.com, jg.jamnani@nirmauni.ac.in

Abstract: Substations as a whole being an important part of the complete power system, grounding system of substations plays a vital role in overall performance of reliable power system. Grounding system of any substation deserves considerable care and attention at design stage, primarily to ensure electrical safety of persons working within or near substations. Looking to such great significance of grounding system design procedure, software which analyzes performance of ground grids of various shapes as per method described in IEEE standard 80 - 2000 has been developed using MATLAB$^{®}$. Proposed software is able to calculate various performance parameters of grounding system for given input data related to grid geometry, soil and system conditions for all the basic shapes of grounding grid in uniform and two layered soils. Additionally this software can also suggest optimal i.e. most appropriate, safe and cost-effective design of the grounding system under given conditions and safety constraints. This software is deployed as windows standalone application using MATLAB run time compiler. Hence it can run on systems where MATLAB is not installed. In order to test the performance of the software, simple design problems have been solved and the results given by it are compared with those obtained form ETAP – GGS module and after verifying its technical performance it is found to be quite reliable tool in the field of grounding system design.

Keywords: Ground grid; Optimal grounding system design; Safety criteria; Step voltage; Touch voltage; MATLAB

1. Introduction

On its way from generating station to the end consumer, electrical power passes through different kinds of substations. Continuity of electrical power supply depends to a considerable extent upon the successful operation of substation. It is therefore essential to exercise at most care while designing and building a substation. Grounding system plays crucial role in the performance of a substation as it provides place for connecting system neutral points, equipment body and support structures to the earth. It also ensures safety of working personnel within the substation and enables earth fault detection and protection. It provides path for discharging the earth currents from neutrals of equipments, faults, surge arrestors, overhead shielding wires etc. It keeps step and touch potential within tolerable limits. Hence properly designed and installed grounding system ensures reliable performance of electrical substation, safety of persons working within or near substation and limits the ground potential rise GPR within acceptable levels. Substation grounding system being an essential part of the overall electrical system, its design is also of very much importance [1, 2].

Design of grounding system is an area in which there has been extensive study and analysis for last five decades. Several methods for grounding system analysis and design have been proposed. Numbers of computer programs have been developed to calculate safety parameters

of an earthing installation in order to obtain a reliable model of ground grid and predict the hazardous scenarios which could occur under certain situations. Most of these methods are based on professional experience, on semi - empirical works, on experimental data obtained from scale models and laboratory tests or intuitive idea [3 – 6]. IEEE standard 80 – 2000 *'IEEE Guide for safety in AC substation grounding'* [7] is widely accepted document in the field of grounding system design. The same is used as a theoretical base for development of the software mentioned above. This paper mainly describes development and utilization of software Economical Substation Grounding System Designer (ESGSD), which is designed using MATLAB$^{®}$ as mathematical computing tool as well as programming platform [8, 9]. Moreover by using MATLAB compiler run time (MCR), it has been compiled and packed as standalone application. At present it is best suited for educational and training purpose for students and professionals concerned with electrical engineering and especially with substation engineering. However with furthermore development going on it is likely to become professional software for grounding system in nearer future.

To prove technical soundness of the software sample design problems have been solved by ESGSD in uniform soil as well as two layered soil conditions for simple performance analysis as well as optimal design. Results obtained by it are compared with those given by Ground Grid Systems (GGS) module of ETAP – power station 4.7.0. Snap shots showing the analysis results and comparison tables clearly draw attention that ESGSD gives fairly correct results for grounding system design and it is found to be trustworthy tool for design of grounding systems of HV / EHV substations.

2. Safety Criteria for Grounding System Design as per ieee standard 80 – 2000

There are typically five shock situations to which a person working within the substation may be subjected namely, Touch voltage, Step voltage, Mesh voltage, Metal to metal touch voltage and Transferred voltage. Out of these five shock situations, first two are used for derivation of safety criteria for grounding system design. A good grounding system should be able to maintain the actual mesh and step voltages within a substation well below tolerable touch and step voltages respectively. These tolerable safety criteria have been established based on *fibrillation discharge limit* of body current [7]. To attain this safety the equivalent electrical resistance of the grounding system must be low enough to assure that fault currents dissipate mainly through the grounding grid into the earth. Main performance parameters of the grounding system are Grid resistance, Step voltage, Touch voltage and GPR. Hence while designing any substation grounding system the main thing to be taken care of is that *under any circumstances actual step and mesh voltages must not exceed those described as tolerable values* [7].

Figure1 shows touch voltage scenario and Thevenion's equivalent circuit for derivation of touch voltage safety criteria. Here shock current passes through human body from one hand to both feet in parallel. Hence Thevenion's equivalent impedance is half of the resistance of one foot. Touch voltage safety criteria derived form this for people weighing 50 Kg. and 70 Kg. are as follows respectively [7]

$$E\_touch\_50 = (1000 + 1.5\rho_s . C_s) . \frac{0.116}{\sqrt{t_s}} \qquad (1)$$

$$E\_touch\_70 = (1000 + 1.5\rho_s . C_s) . \frac{0.157}{\sqrt{t_s}} \qquad (2)$$

Where

ρ_s = Surface layer resistivity in (Ω . m)
C_S = Surface layer derating factor
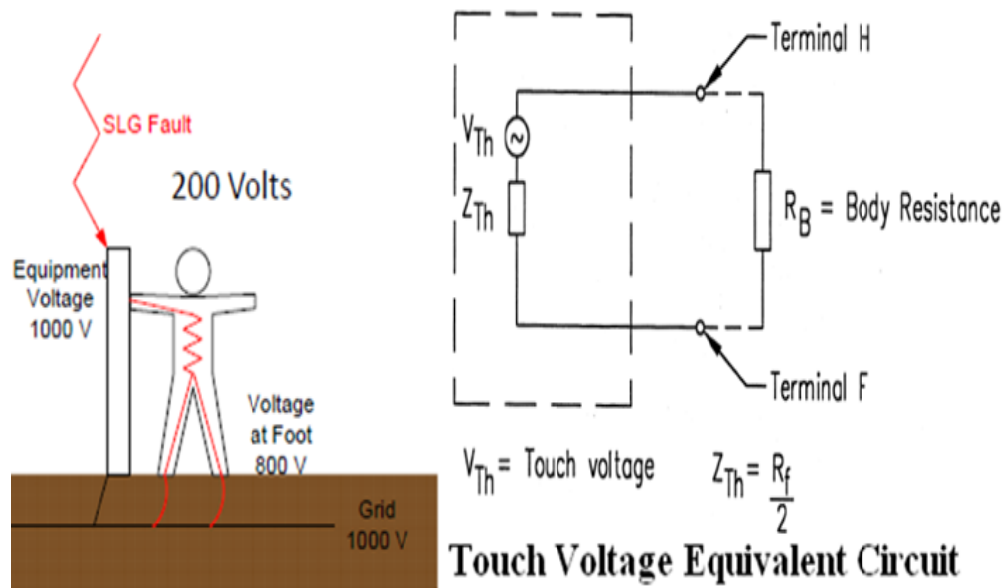T_S = shock duration in (Sec.)

Figure 1. Touch voltage scenario and equivalent circuit

Figure 2. shows step voltage scenario and Thevenion's equivalent circuit for derivation of step voltage safety criteria. Here shock current passes through human body from one foot to another foot, thus both feet resistances being in series. Hence Thevenion's equivalent impedance is twice of the resistance of one foot.
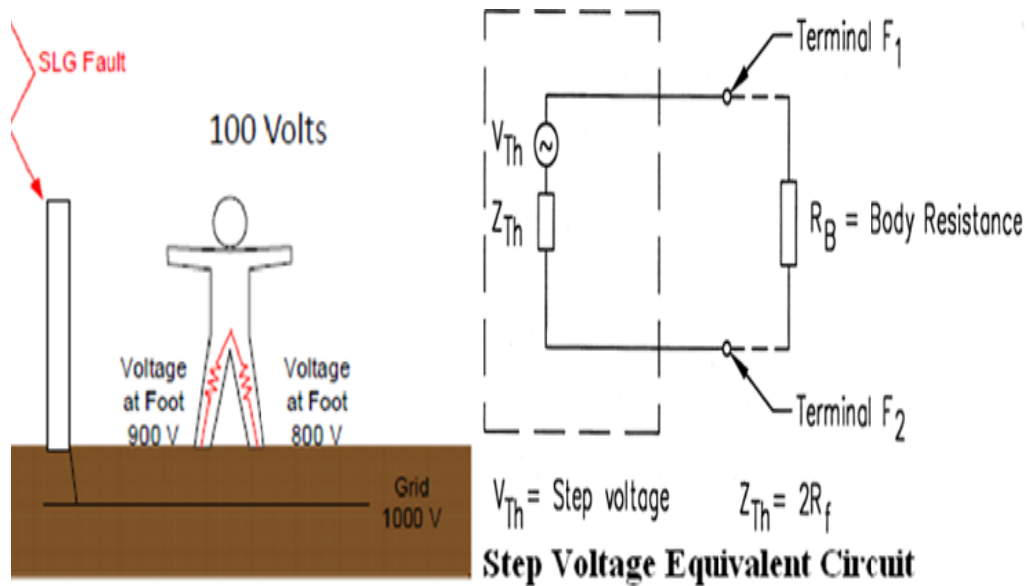

Figure 2. Step voltage scenario and equivalent circuit

Step voltage safety criteria for people weighing 50 Kg. and 70 Kg. are as follows respectively.

$$E\_step\_50 = (1000 + 6\rho_s . C_s) . \frac{0.116}{\sqrt{t_s}}$$
(3)

$$E\_step\_70 = (1000 + 6\rho_s . C_s) . \frac{0.157}{\sqrt{t_s}}$$
(4)

3. Development of Economical Substation Grounding system Designer

IEEE Guide [7] demonstrates guide lines for design of grounding systems for HV / EHV AC substations, considering its performance at power frequencies only. Software Economical Substation Grounding System Designer (ESGSD) has been designed as per guide lines given in the same. Additionally this software provides option for modeling the soil as two layered one which is not given in IEEE guide. ESGSD has been developed using MATLAB – GUI as programming tool and MATLAB as mathematical computing tool [8, 9]. This has been designed using MATLAB version 7.6 R2008a; however it is deployed as standalone application hence it will work even in absence of MATLAB. Various salient features and detailed description of the software can be found from [10].

A. Methods of analysis

This software analyzes performance of any grounding system in following two ways
1. Simple performance analysis of proposed grounding system by taking data related to grid geometry, general system parameters and soil characteristics.
2. Optimal design of substation grounding system for all the five shapes of ground grid namely, Square, Rectangular, Triangular, T shaped and L shaped in uniform as well as two layered soil.

In case of simple performance analysis, the software asks for data related to ground grid geometry, No. of ground rods, data regarding substation soil, generalized data related to power system for safety criteria establishment, conductor size and material etc. Then it calculates tolerable voltages as per safety criteria, actual mesh and step voltages, grounding system resistance (R_g), ground potential rise (GPR) and safety of the proposed grounding system. After calculation results are displayed in a separate window.

In case of optimization, ESGSD suggests the most appropriate, safe and economical i.e. optimal design of grounding system. For the purpose of optimization, two dominating parameters affecting grounding system performance viz. No. of conductors in horizontal ground grid and No. of vertical ground rods, have been considered to be variable. Hence for obtaining optimal design of grounding system, *No. of ground grid conductors are varied* thereby altering separation between them for *fixed grounding system area*. Also *No. of ground rods are varied* to get most appropriate design at minimal cost. *Depth of burial is again assumed constant* and not varied for optimization. Information on effects of various parameters on grounding system performance can be found from [1, 2, 11 -14]

B. Optimization problem formulation

In order to get optimal design, following cost objective function has to be minimal subjected to safety criteria listed below it [15].

Optimization problem:
Minimize the cost of grounding system given by

$$f(N_x, N_y, N_r, L_r) = (N_r \cdot L_r \cdot C_{ri}) + (N_r \cdot C_r) + (C_{ci} \cdot C_c) \cdot (N_x \cdot L_y + L_x \cdot N_y)$$
(5)

Subjected to safety constraints given as follows

$$E_{m\_\alpha} \leq . \, E_{m\_tol} \tag{6}$$

$$E_{s\_act} \leq X . \, E_{s\_tol\_\_} \tag{7}$$

$$0.95. \, D_1 \leq D_2 \leq 1.05 . \, D_1 \tag{8}$$

$$2.5 \leq D \leq 22.5 \tag{9}$$

Where

N_r = No. of vertical ground rods
L_r = Length of each vertical ground rod (m)
C_{ri} = Installation cost of vertical ground rods (` / m)
C_r = Material cost for ground rods (` / rod)
L_C = Total length of conductors in ground grid (m)
C_i = Installation cost for grid conductors (` / m)
C_C = Material cost of conductors (` / m)
E_{m_act} = Actual mesh voltage (Volts)
E_{m_tol} = Tolerable mesh voltage (Volts)
E_{S_act} = Actual step voltage (Volts)
E_{S_tol} = Tolerable step voltage (Volts)
D_1 = Spacing between conductors in X direction (m)
D_2 = Spacing between conductors in Y direction (m)
D = Average separation between any two consecutive conductors in the ground grid(m)
X = Specified percentage of the tolerable value.

These safety criteria state that actual mesh and step voltages must be less than X percent of the corresponding tolerable values, X is dependent on user requirement, spacing between the conductors in horizontal grid should be uniform and almost equal in both directions and spacing between two adjacent conductors should be between 2.5 m to 22.5 m. By satisfying geometrical constraints the design assures that equations given in [7] are applicable to the present grounding system with a fair degree of accuracy and by satisfying safety constraints electrical safety of persons working in the substation site is ensured. Minimization of cost objective function gives economical and yet safe i.e. cost effective design of grounding system. Thus design given by solving above optimization problem is optimal because it reveals minimal cost among all the designs giving similar performance.

Figure 3 shows main page of the software ESGSD. It takes main details related to substation grounding system design such as shape of ground grid and voltage rating of the substation. This page allows access to all other input - output modules. By accessing various other input pages like grid layout, soil model and system data, further details about grounding system design can be entered. Also simple analysis or optimization of the proposed grounding system can be performed by respective options. Report for the designed grounding system can also be generated from here which will be Microsoft word document.

C. Soil model derivation

In case mathematical model of soil in terms of resistivity of soil and layer thickness for two layered soil is not known, ESGSD allows derivation of soil model to be used for calculation purpose from available earth resistivity test (ERT) data. By taking values of probe separation (in m) and measured resistivities (in $\Omega \cdot m$) soil model derivation (SMD) module of ESGSD will facilitate extraction of resistivity and soil layer depth values for uniform or two layered soils and communicate the results to other modules for computational purpose.
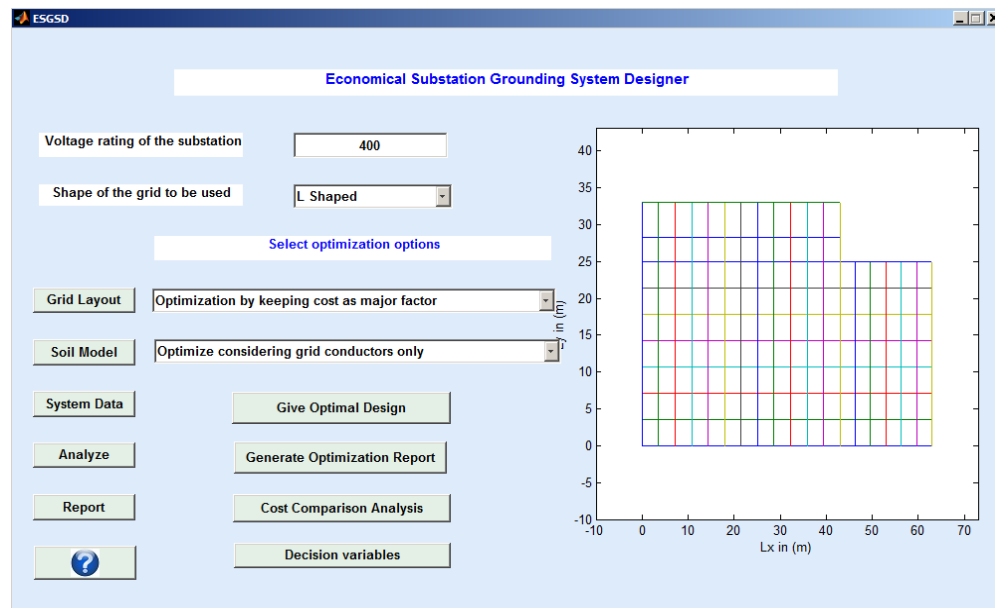
Figure 3. Main page of the software ESGSD

D. Implementation of optimization in ESGSD

Based on user requirements and site specific requirements optimization can be applied in following various ways

1. Optimization by varying No. of ground grid conductors only for fixed grid area, depth of burial of grid and fixed No. of ground rods.
2. Optimization by varying No. of ground rods only for fixed grid area, depth of burial of grid and fixed No. of ground grid conductors
3. Optimization by varying No. of ground grid conductors and ground rods for fixed grid area and depth of burial of grid

Algorithm of working of this software is shown in fig. 4 as shown below.

As seen from the figure 4, the software follows IEEE standard guidelines for designing grounding system and also considers safety constraint laid by it for making design optimal. It can simply analyze any proposed grounding system and additionally, it can give safe and economical i.e. optimal design of grounding system that is compliant with IEEE standard.
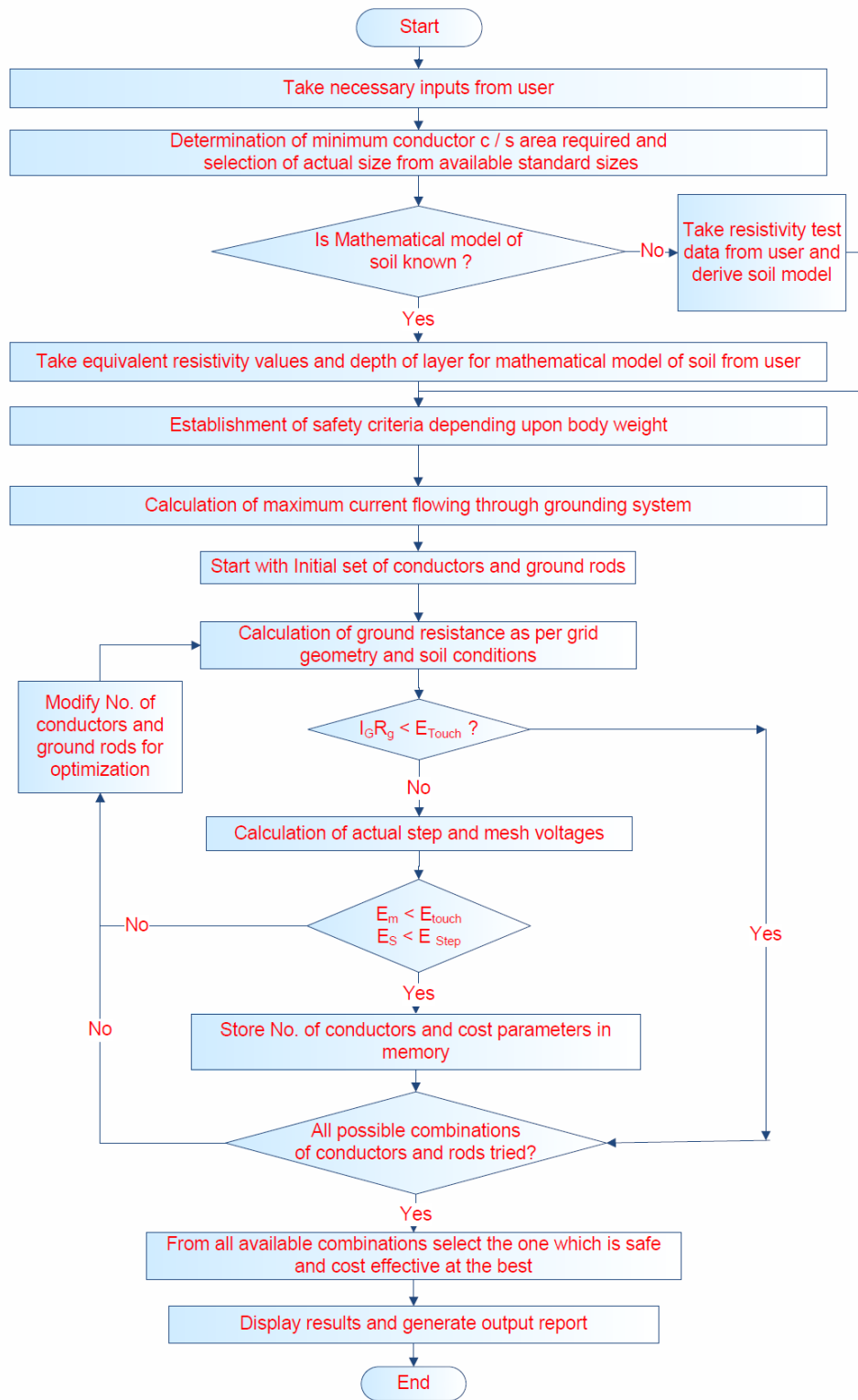
Figure 4. Flowchart describing algorithm of working of ESGSD

4. Performance Evaluation of ESGSD

A. Design of grounding system with ESGSD and verification of results with ETAP – GGS

The software ESGSD has been developed using MATLAB and is based on IEEE – 80 – 2000 guidelines as described before. In order to validate the results given by the software following two problems have been solved by it and the same are also solved with the help of Ground Grid Systems (GGS) module of ETAP – professional software. ESGSD facilitates two types of analysis for grounding system design.

1. Simple performance analysis: Here it only gives output whether the system is safe or not with the proposed grounding system as per data entered by user.
2. Optimization: It works in two ways as explained below.
   - ✓ If the proposed system is already safe then optimization gives the design at minimal cost i.e. monetary saving without sacrificing electrical safety performance.
   - ✓ If the initially proposed system is not safe then optimization makes design safe and that too at least cost.

These points become clear from following two examples.

1. Rectangular shaped grid in uniform soil

In the first design problem, grounding system having rectangular shaped grid supplemented by vertical ground rods and situated in uniform resistivity soil has been analyzed by both the software for simple performance and also optimization has been applied to the original design. Results produced by both the software are compared for checking performance of ESGSD. Following table 1 shows input data required for grounding system design.

Table 1. Input data required for grounding system design

Ground grid parameters	Value	Soil and system data	Value
Grid shape	Rectangular	Fault current split factor (S_f)	0.6
Depth of burial of grid (h)	0.6 m	Shock Duration (t_s)	0.5 sec
Length in X direction (L_x)	80 m	Fault duration (t_f)	1 sec
Length in Y direction (L_Y)	41 m	Current projection factor	1.25
Spacing between conductors (D)	4 m	Surface layer resistivity (ρ_s)	1500 $\Omega \cdot m$
No. of ground rods (N_r)	50	Surface layer thickness (h_s)	0.2 m
Length of ground rod (L_r)	3 m	Soil resistivity (ρ)	50 $\Omega \cdot m$
Ambient temperature (T_a)	50 ºC	Fault current (I_f)	15kA
Cost of grid conductors ($C_c + C_i$)	2100 `/m	Material for grid conductors	Galvanized steel
Cost of ground rods ($C_r + C_{ri}$)	2100 `/m	Material for ground rods	Galvanized steel

After simply analyzing performance of the grounding system described in table 1, ESGSD gives results as shown in following table 2. These results are also compared with those obtained form ETAP.

In the table 2, following notations are used

(E_{s_tol}) = Tolerable step voltage
(E_{m_tol}) = Tolerable mesh voltage
(E_{s_act}) = Actual step voltage
(E_{m_act}) = Actual mesh voltage
Nx_opt = Optimal No. of Conductors in X direction
Ny_opt = Optimal No. of Conductors in Y direction
Nr_opt = Optimal No. of ground rods

Table 2. Results for rectangular shaped grounding system located in uniform soil

Particular	Unit	Before optimization		After optimization	
		Results obtained form		Results obtained form	
		ESGSD	ETAP	ESGSD	ETAP
Resistance (R_g)	Ω	0.408	0.41	0.41	0.41
GPR	Volts	4598.9	4598.9	4618.9	4646.1
(E_{s_tol})	Volts	1378.34	1378.3	1378.34	1378.3
($E_{m\ tol}$)	Volts	467.62	467.6	467.62	467.6
(E_{s_act})	Volts	459.1	459.1	479.6	495.2
(E_{m_act})	Volts	362.6	362.6	396.74	441.9
(E_{s_act})/ (E_{s_tol})	%	33.3	33.3	34.7	35.93
(E_{m_act}) / (E_{m_tol})	%	77.54	77.54	84.84	94.5
Cost of grid	`	36,56,100	36,56,100	35,70,000	34,02,000
Cost of rods	`	3,15,000	3,15,000	1,51,200	25, 200
Total cost	`	39,71,100	39,71,100	37,21,200	34,27,200
Nx_opt	-	-	-	20	20
Ny_opt	-	-	-	11	10
Nr_opt	-	-	-	24	4
Safety		Safe	Safe	Safe	Safe
Saving	-	-	-	2,49,900	5,43,900

As seen from the table, there is close agreement between the results given by both the software. Also proposed grounding system is safe. However actual mesh and step voltages are 77% and 33% of the tolerable values. Hence there is quite a high potential of saving in this design by applying optimization to the existing design as analyzed above. Results of grounding system performance after application of optimization as given by ESGSD and ETAP – GGS are also shown in table 2.

As observed from this table, again ESGSD gives results quite comparable to those given by ETAP – GGS. Optimal No. of ground rods suggested by ESGSD are much higher than those suggested by ETAP. This is in order to keep the actual mesh voltage below 85% of the tolerable value as given in safety constraint; however ETAP goes for actual mesh voltage as much high as 94% of the tolerable value. Next observation is that after application of optimization the system remains safe and that too at lower cost. Hence great saving can be obtained by optimizing the design.

2. Square shaped grid in two layered soil
In the second design problem, grounding system having square shaped grid supplemented by vertical ground rods and situated in two layered soil has been analyzed. Results of both the software are compared for simple performance analysis as well for optimization of the design so that reliability of the results given by ESGSD can be accessed. Following table 3 gives input data and simple proposed design for square grid in two layered soil.

After simply analyzing performance of the grounding system described in table 3, results shown in table 4 are obtained. Looking to the table we observe following two important things.
1. First, ESGSD gives trustworthy results as verified with ETAP – GGS results even for two layered soil and square shaped grid, thereby validating its performance.
2. Next, the above said grounding system is not safe because, actual mesh voltage 666.8 Volts is 30 % more than tolerable mesh voltage 506.7 Volts. Thus revision in design is necessary for making the design safe.

Here comes into picture second aspect of optimization that is making unsafe system safe by application of optimization and that too at least possible cost. In order to make system safe now optimization is applied to the aforesaid grounding system with the help of ESGSD as well as ETAP – GGS. Results are shown in table 4.

Table 3. Input data required for grounding system design

Ground grid parameters	Value	Soil and system data	Value
Grid shape	Square	Fault current split factor (S_f)	0.63
Depth of burial of grid (h)	0.5 m	Shock Duration (t_s)	0.5 sec
Length in X direction (L_x)	65 m	Fault duration (t_f)	1 sec
Length in Y direction (L_Y)	65 m	Current projection factor	1.35
Spacing between conductors (D)	5 m	Surface layer resistivity (ρ_s)	1800 $\Omega \cdot m$
No. of ground rods (N_r)	40	Surface layer thickness (h_s)	0.15 m
Length of ground rod (L_r)	2.5 m	Upper layer resistivity(ρ_1)	16.67 $\Omega \cdot m$
Ambient temperature (T_a)	50 ^{o}C	Lower layer resistivity (ρ)	50 $\Omega \cdot m$
Cost of grid conductors ($C_c + C_i$)	2200 `/m	Thickness of upper layer	1.8 m
Cost of ground rods ($C_r + C_{ri}$)	2000 `/m	Material for grid conductors	Galvanized steel
Fault current (I_f)	35kA	Material for ground rods	Galvanized steel

Table 4. Results for square shaped grounding system located in two layered soil

Particular	Unit	Before optimization		After optimization	
		Results obtained form		Results obtained form	
		ESGSD	ETAP	ESGSD	ETAP
Resistance (R_g)	Ω	0.202	0.22	0.26	0.25
GPR	Volts	6035	6556	7875	7344
(E_{s_tol})	Volts	1534.67	1534.7	1534.67	1534.7
(E_{m_tol})	Volts	506.70	506.7	506.7	506.7
(E_{s_act})	Volts	838.82	837.6	899.54	913.6
(E_{m_act})	Volts	666.8	665.8	480.9	491.8
(E_{s_act})/(E_{s_tol})	%	54.66	54.57	58.61	59.61
(E_{m_act})/ (E_{m_tol})	%	131.59	131.39	94.9	97.19
Cost of grid	`	40,04,000	40,04,000	54,34,000	54,34,000
Cost of rods	`	2,00,000	2,00,000	95, 000	20, 000
Total cost	`	42,04,000	42,04,000	55,29,000	54,54,000
Nx_opt	-	-	-	19	19
Ny_opt	-	-	-	19	19
Nr_opt	-	-	-	19	4
Safety		Not Safe	Not Safe	Safe	Safe
Expenditure	-	-	-	13,25,000	12,50,000

As observed from above table, after application of optimization the grounding system becomes safe as both actual voltages are less than corresponding tolerable values. Of course this involves additional expenditure on grounding system installation and material cost which is about 31% of the cost of original unsafe system. However this should not be constraint

because in order bring actual voltages below the specified maximum voltages, levels more no. of conductors are supposed to be used and after all personnel safety is of major interest than money. Also the design suggested by ESGSD is optimal and the most favorable at least at preliminary analysis stage. This is also verified by corresponding results of ETAP.

3. General observations and discussion
We can summarize complete description given up till now as follows
✓ Newly developed software ESGSD performs quite reliably while evaluating technical performance of any grounding system in uniform as well as two layer modeled soil for all the five grid shapes mentioned above which can also be verified form[16].
✓ Also it gives most favorable design for grounding system of any HV / EHV AC substations considering the safety criteria established by IEEE, furthermore it keeps design optimal i.e. safe and cost – effective .
✓ Optimization does not mean that the design obtained after optimization is only cheap or only safe, rather it considers both factors i.e. technical performance in terms of electrical safety and cost. Optimization gives safe and economical design. Neither the technical performance is underestimated nor is the system made over designed and excessively costly.
✓ Results obtained by ESGSD are validated by professional software ETAP – GGS for all the cases. It proves technical soundness of the novel software thus confirming it as a reliable tool in substation grounding system design as far as preliminary grounding system performance at power frequency is concerned.

5. Conclusion
In this paper initially importance of grounding system is starched at and newly developed software is briefly introduced. Next, safety criterion is explained along with appropriate figures and equations. Then information about development of software together with its salient features is given. Next objective function for optimizing the grounding system design along with the safety and geometrical design constraints is described. Then general design methodology as per IEEE guidelines is discussed with flowchart of program algorithm. Finally performance of newly developed software ESGSD is evaluated by solving two design problems and comparing results with those given by professional software ETAP. Analysis results clearly show technical soundness of the novel software and importance of application of optimization. Finally ESGSD can be considered as an effective design tool at least at preliminary level for designing grounding system of AC substations considering only power frequency performance parameters. It can serve quite useful to design engineers for designing preliminary grounding system as per standards rather than using empirical hand calculation methods based on rough approximation or previous experiences.

References
[1]. Kaustubh A. Vyas and J.G. Jamnani, "Optimal design and development of software for design of substation grounding system", 2nd International Conference on Current Trends in Technology – NUiCONE, Ahmedabad, Gujarat, India, December 2011, pp. 1 – 6.
[2]. Project report available at: https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnxncm 91bmRpbmdzeXN0ZW1kZXNpZ258Z3g6NDY2NWM2NTVlYzljNjk0ZQ
[3]. F. P. Dawalibi and D. Mukhedkar, "Optimum Design of Substation Grounding in a two Layer Earth Structure, Part - 1", IEEE Trans. on PAS, Vol. PAS 94, No. 2, pp. 252-272, 1974.
[4]. J. G. Sverak, "Optimized Grounding Grid Design Using Variable Spacing Technique", IEEE Trans. on PAS, Vol. PAS 95, No. 1, pp. 362-374, 1976.
[5]. J. Nahman, and D. Salamon, "Earthing system modeling by element aggregation" IEE PROCEEDINGS, Vol. 133, Part. C, No. I, pp. 54 – 58, January 1986.

[6]. J. A. Sulivan, "Alternative earthing calculations for grids and rods", *Proc. IEE Gen. Transm. Distrib.*, Vol. 145, pp. 271- 280, May 1998.

[7]. IEEE guide for safety in AC substation grounding, IEEE standard 80, 2000

[8]. Dr. Attia A. El-Fergany, "Design and optimize substation grounding grid based on IEEE Std. 80 - 2000 using GUI and MATLAB codes", International Journal of Engineering Science and Technology, Vol. 3 No. 7, pp. 6033- 6039, July 2011

[9]. http://www.mathworks.in/help/techdoc/creating_guis/bqz6p81.html

[10]. Help file of software available at : https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnxncm91bmRpbmdzeXN0ZW1kZXNpZ258Z3g6Mjg5ODkzYTE0ZGVhNmE0OOQ

[11]. John D Mc Donald, Electrical power substation engineering, CRC Press: 2006

[12]. A. Puttarach, N.Chakpitak, T. Kasirawat and C. Pongsriwat, "Ground layer depth and the effect of GPR", *IEEE PES Conference and Exposition, Johannesburg, South Africa*, July 2007, pp.1 – 5.

[13]. Ahdab Elmorshedy Rabah Amer Sherif Ghoneim, Holger Hirsch, "Surface potential calculation for grounding grids", *First International Power and Energy Conference*, November 2006, pp. 501 – 505.

[14]. Gupta B. R, Power System Analysis and Design: S. Chand & Company Limited, 2008

[15]. Gary Gilbert, "High voltage grounding systems", PhD thesis, University of Waterloo, 2011

[16]. Project report available at: https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnxncm91bmRpbmdzeXN0ZW1kZXNpZ258Z3g6OTQ5MWEyNmE4NzA0NmYz.

Kaustubh A. Vyas was born in Mandvi, Gujarat, India on March 25, 1988. He is currently Assistant Professor in the Department of Electrical Engineering at Kalol Institute and Research Institute, Kalol, Gujarat, India. He obtained his B.E. (Electrical) in 2009 from L. D. Engineering College and M.Tech (Electrical Power Systems) from Institute of Technology, Nirma University, Ahmedabad, Gujarat, India in 2012. His areas of interest include Power System Protection, Power System Stability, Electrical Switchgear, Grounding System Design and development of software useful for educational purpose. He has published 4 papers in National/International conferences/Journals.

J. G. Jamnani was born in Godhra-city, Gujarat, India on December 20, 1971. He is currently Professor and Head in the Department of Electrical Engineering at Gujarat Power Engineering and Research Institute, Mehsana, Gujarat, India. He obtained his B.E. Electrical in 1993, M.Tech. Electrical from the Indian Institute of Technology, Roorkee, in 2002 and Ph.D. in Electrical Engineering from M. S. University, Vadodara. He has over 17 years of teaching experience at both the undergraduate and postgraduate levels and 2 years Industrial experience. His areas of interest include power systems, High voltage Engineering and Electrical machines. He has published more than 22 papers in National/International conferences/Journals and completed many consultancy projects for Industry. He is a life member of ISTE and member of IEEE.