DEVELOPMENT OF GROUNDING SYSTEM ANALYZER – A Simulation Software

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DECLARATION

I hereby certify that the work which is being presented in this thesis entitled, **"Development of Grounding System Analyzer – A Simulation Software"** as a part of curriculum during Master of Engineering in Power Systems, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried under the Guidance of Dr. Parag Nijhawan, Assistant Professor, EIED. It refers others researcher's work which are duly listed in the reference section.The matter contained in this dessertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

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25/7/2017

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

Parag

Date 25/07/17

Dr. Parag Nijhawan
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First of all, I would like to thank almighty God, who gave me opportunity and strength to carryout this work.*"Achievement is finding out what you would be doing, what you have to do. The higher the summit, higher will be the climb."* It has been rightly said that we are build on the shoulders of others but the satisfaction that accompanies the successful completion of any task would be incompletewithout the mention of the people who made it possible.

Gratitude is accorded to all the authorities of Thapar University, Patiala for providing the necessary facilities to complete my M.E thesis work.

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The paucity of words does not compromise to thank my parents, whose blessings have brought me this far in life. I would also like to thank my family, friends and Harjyot Singh Bhogal for their constant support.

(SUKHMANI KAUR)

ABSTRACT

User-friendly simulation software based on empirical formula defined under IEEE Standard 80-1986[24] and IEEE Standard 80-2000[10] is being developed in Visual Studio 2013, which will help in making the process of calculation of various factors in substation grounding grid designing easier.

This thesis is basically compilation of all the single layer soil model designing formulae for easy interpretation of the data from the values calculated by the software.

For designing a grounding grid, calculation of step voltage, ground resistance and mesh voltage can be done with different available methods.

This thesis work also take into account the concept of adding earth rods to the grounding grids. So, user friendly software is being developed which can be used by anyone with little knowledge of grounding.

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Chapter-1

INTRODUCTION

1.1 Objective

The purpose of the thesis is to develop a user-friendly simulation software based on empirical formula defined under IEEE Standard 80-1986[24] and IEEE Standard 80-2000[10], which will help in making the process of calculation of various factors in substation grounding grid designing easier.

To obtain the above purpose following steps are taken:

a) A visual basic program is used for calculations and obtaining results by simple data entry by the user.

b) The methodology that effectively favors addition/elimination of various correction factors that would result in minimizing the errors and making calculations fast.

This thesis is basically compilation of all the single layer soil model designing formulae for easy interpretation of the data from the values calculated by the software.

For designing a grounding grid, calculation of step voltage, ground resistance and mesh voltage can be done with different available methods. But the problem is though many programs are there which give accurate results but they are not available at the field site and mostly require an expert to run it. So, a user friendly software is being developed which can be used by anyone with little knowledge of grounding.

1.2 Procedure

In this process of thesis work, simulation software was made in Visual Basic 2013 software. The user is allowed to input the data into the input window, and then the calculated results are displayed simultaneously in the window only. Later on these results were compared and verified with the manual calculations also.

1.3 Author's Contribution

First of all IEEE Standard 80-1986[24] and IEEE Standard 80-2000[10] were studied[10] and then compared[11]. The advantages and disadvantages of both the standards were found out and noted down. The most appropriate formulas were then used to develop the simulation software in

Visual Studio 2013.Different cases of geometry of the grounding grid were considered like square, rectangle, triangle, T-shape, L-shape grounding grid. The developed software provides the choice window for calculation by both IEEE Standard 80-1986 and IEEE Standard 80-2000[10]. All the calculations are being done for a single layer soil model, two layer soil model software development is being kept in future scope. Software calculates parameters like grounding resistance, step voltage and mesh voltage. A new case of grounding rods have also been added to study its effect on the design of the grid and change it brought to the final value of grounding grid resistance.

1.4 Organization of Thesis

The thesis is organized in a way to give introduction to the designing of grounding grid arrangements and the simulation software.

Chapter 1 has thus far given a brief introduction to the need for grounding system, purpose of this thesis work and the simulation software.

Chapter 2 covers the literature part studied to carry out the thesis work which formed the basis of this thesis work.

Chapter 3 gives an overview to the IEEE Standard 80[10], discusses the empirical formula of IEEE Standard 80-1986[24] and IEEE Standard 80-2000[10]. This chapter also discusses the changes brought up in IEEE Standard 80-1986 to IEEE Standard 80-2000[11]. The seasonal effect on the working of grounding grid [3], the effect of adding earth rods in the grounding grid[10] is also discussed. Glimpse of the simulation software is also shown in this chapter.

Chapter 4 discusses the results by comparing the theoretically calculated values with the software calculated values.

Chapter 5 gives the conclusion and the future scope of this thesis work.

CHAPTER-2

LITERATURE SURVEY

2.1 Introduction

The simulation software is based on IEEE Standard 80[10]. For the development of the software many research papers and journals were read and studied thoroughly so as to get a deep insight view to the IEEE Standard 80. This literature survey gives a brief summary of the expressions already available for the calculation of ground resistance, mesh and step voltages and other designing parameters of the grounding grid arrangements of AC substation.

2.2 Literature Survey

This section gives an overview about the research papers studied one by one.

Kumar *et al* [1] considered the Grounding System Design for small hydropower station. Guide aimed at protecting people and electrical equipment sans fault currents having potential to produce voltages in the earth. Major parameters to be considered during designing one are fault current magnitude and duration & soil resistivity. Guide considered Wenner’s four pin method for soil resistivity measurement, IEEE standard 80-2000, MATLAB software and horizontal and vertical conductors for designing the grounding system. Main observation was the high resistivity (ideally to be lower than 1ohm) . And methods to control this resistance are:

1. Tiding both grids by multiple conductors.
2. Tiding auxiliary material to grounding grid.
3. Tiding earth material to penstock.

Shah *et al* [2] Design for earthing system for HV/EHV AC Substation. Author focused on keeping the scope for future expansion while designing the current earthing system. Designing was carried out for a 400 KV HV/EHV substation earthing system. Mild steel electrodes and conductors were used in the design. Main focus was given on keeping step and touch voltage within tolerable limits and also on the transfer of GPR (ground potential rise).

Mondal *et al* [3] research paper’s area of concern was designing and analysing the earthing system considering seasonal factors. Earthing system was designed keeping in mind the factors of lightning and earth faults. Author considered IEEE 80-2000 standard and used EDSA software for computational purposes. Main area of study was in freezing and rainy seasons. Square and rectangular configurations for earthing grid were considered and square grid with ground rods gave safe and satisfactory results. Parameters studied were:

1. Step voltage and touch potential
2. Absolute potential
3. GPR (ground potential rise)
4. Soil resistivity (which varied with seasons)

Prasad and Sharma [4] author explained the significance of step and touch voltage while designing an earthing system and also for designing gas insulated switch gear (GIS) and air insulated switchgear (AIS) for indoor substation. Study was done for lightening or a short circuited grounding system. Author said that step and touch voltages can be dangerous as they can give electric shocks, hence it should be one of the most important factors to be considered while designing earthing system for high voltage substations. Also that the touch voltage shocks can be prevented by inexpensive insulating layers. Changing soil resistivity with season can also affect the tolerable limits of step and touch voltages.

Thapar *et al* [5] Guide established the simplified formulas for calculating footing resistance (resistance of ground just beneath foot) in substations. Footing resistance is one of the major factors affecting the step and touch voltage for a person. Footing resistance can be improved by laying a thick layer of crushed rocks and insulating sheets as and when required. Existing methods considering foot as a conducting disc on crushed rock layer can give erroneous results because of the missed factors e.g. Mutual ground resistance between two feet, dirt in crevices (which get washed with water hence decreases the resistivity of the layer).Hence they derived formulas and equations which gave reliable results.

Thapar *et al* [6] author discussed the intertying of grounding grids and its impact on various parameters. Intertying can be unintentional (through overhead wires etc.) or intentional (connected by bare grounding conductors buried in soil). Intertie effects ground resistance of two grids, GPR (ground potential rise) & also voltage profile along the length of intertie. Earlier two layer model of soil was used but it was quite lengthy & the soil resistivity keeps on changing along the length of intertie. Moreover the exact result is not required. Hence the guide proposes simple and easy approach which gives approximate results. Also a computer program was developed by the author for answering all the questions raised as of the intertie. It was observed that the approximate results were equally good as given by the accurate computer method.

Chow and Solema [7] formulated method to calculate substation grounding grid resistance. Author said basic objective of a grounding system is to dissipate current to earth without heating and to keep step and touch voltage within tolerable limits. Earlier works for calculating the resistance were proposed by Dwight and Schwartz formula but were quite complex and tedious. Author in this paper published a simple formula which is a function of conductor size, mesh size etc. formula is based on theoretical manipulation of the numerical moment method and of the current image.

He and Zeng [8] in their paper derived a relation between seasonal variation and safety of the grounding system of a substation. Main focus was given on the varying soil resistivity along with varying atmospheric conditions. Earlier to consider the varying soil resistivity simply a seasonal factor was multiplied which was not effective as there were many other factors which cause the variation. Hence a systematic analysis was done by the guide in this paper and few observations found are recorded as follows:

1. Rainy season: Low ground resistance, small step voltage but high touch voltage
2. Freezing season: As the thickness of freezing layer gets more than the burial depth ground resistance increases by 1.7 to 3 times(can be controlled by adding vertical electrodes)

Thapar *et al* [9] Simplified equations for mesh and step voltages in an AC Substation. Major parameters considered for deriving these equations were:

1. Ground resistance

2. Mesh and step voltage

3. Shape of substation area

Earlier the finite element analysis method was used to calculate resistance, current and voltage regarding earthing system was used, author gave the simplified equations which does not require a whole lot of data but give approximate accurate results. Method proposed by author is quite simple and is less expensive. Also the IEEE standards were modified so that they can be applied to shapes (of substation) other than square or rectangular. Error for non-square shapes also improved in these simplified equations.

Keil *et al* [10] prepared IEEE Standard 80-2000, IEEE Guide for Safety in AC Substation Grounding [1].This guide was mainly concerned with outdoor ac substations. The conventional substations and gas-insulated substations were included. Distribution, transmission, and generating plant stations were also included. With required safety measures, the methods described were also proved to be applicable to indoor parts of above mentioned substations, and to indoor substations. DC substations were not included.Guide was aimed to lay down safety measures for grounding practices in AC substation design.The purposes of this guide were to establish the safe limits of potential differences, the basis for design, which can exist in a power station during the fault in between two points which can have contact with the human body. It was also aimed at developing methods for understanding and framing solution for typical gradient problems.

Ma [11] The seasonal effects on grounding were considered in the calculation of grounding resistance. The analysis of gounding grid design calculations were done without considering and after considering the seasonal factors. The methodlogy adopted was of IEEE Standard 80-2000.

Sulaimani [12] designed a project according to the reqirements of the invester and IEEE standard 80-2000 of earthing system. Specific resistance was calculated using the measured values of soil resistivity. The earthing system was designed in such a way that the allowable touch and step voltages limits are not exceeded.The calculations were done using the' CDEG Multi-Ground TM SES' software.

Chen *et al* [13] This paper reviewed the diagonosis of corrosion of grounding grids.It analysed and discussed pros and cons of three different method for analysis of corrosion.These three methods were based on

1. Electricity network
2. Electromagnetic theory
3. Electrochemical theory

It also introduced a new method with its future exploration and advantages called ultrasonic guided wave method.

Thapar *et al* [14] Author talked about evaluating ground resistance of grounding grid of shapes other than square. Earlier work in this field was proposed by:

1. Laurent, Nieman & Sverak for circular plate.

2. Schwarz for rectangular plate

3. Finite element analysis, computer program

In this paper author proposed a formula for calculating Grounding resistance of grounding grid of any shape. And the formula is found out to be accurate & comparable to computised results. This formula is not applicable to:

1. Long vertical rods.

2. Vshape, Ushape cardioid etc.

Kumar and Seedhar [15] Grounding grid for high resistivity limited area substation in hilly region. Performance of a grounding grid depends mainly upon:

1. Determination of Grounding Resistance.

2. Earth surface potential distribution.

Earlier IEEE Standard 80 empirical formula was used but had a number of limitations like it was only for square shape and homogeneous soil. Other methods of calculating same were technique based on average potential method for non-homogenous soil but not for combined grid. Problems in hilly region were high grounding resistance because of low moisture as of hilly rocks and limited ground area. Author in this paper carried out experimental analysis and developed a computer program. Observations found were:

1. Satellite electrode in neighboring lower resistivity soil can lower ground resistance and also step and touch voltage.

2. Ground resistance decrease with increase in depth of a tie wire

Sverak [16] author in this paper carried out a simplified analysis of electrical gradients above a grounding grid and checked the viability of present IEEE method. Earlier to calculate the electrical gradient formulas given by IEEE or a computer work by Gross et al. was used. Equations for corner mesh voltage give a very low result for large grids with many meshes. Step voltage factor produces excessive high step voltages. It was also found that when meshes increases, current densities of individual conductors differ hence a single calculation of corner mesh voltage hence this equation of IEEE had some limitations.

Nahman and Salamon [17] analystical expressions for the resistance of grounding grid in non-uniform soils. No. of formulas for horizontal grid in uniform soil were present but a very few for non-uniform two layer soil. Example Laurent formula for two layer soil horizontal grid. This paper check viability of given formulas and tried to improve some ground resistance formulas. This paper recorded:

1. Schwarz's resistance formula for two layer soil satisfies computer results.

2. Two new empirical formula.

Heppe [18] gave expression to step potentials and body currents near grounds in two layer earth. Author proposed that if the designer focuses only on step voltage rather than body currents, designs proved out to be dangerous and costly. Different layers of soil generate conditions, producing maximum step voltage not being equal to conditions which produces maximum body currents. Author in this paper proposed that body current in two layer soil is equal to four times as in homogenous soil. Also that the variation in soil conductivity in horizontal direction increases the step voltage hence a safety factor need to be included in considerations. Author also observed that a person dragging a metal over the ground experienced a larger current. Moreover two layer model give more realistic data than the assumption of a homogenous earth.

Seedhar and Thapar [19] finite expression for computation of potential in two layer soil. Two layer earth models was found out to be adequate. Expression of potential obtained by method of images of Laplace equations. In this paper guide forwarded empirical expression developed for point current source. It is a simple formula consisting of only a few terms. Error when compared to expression from infinite series, difference found out to be 0.04%. hence can save a lot of computational effort.

Dalziel and Messoglia [20] author explained the concept of let go current and voltages. Let go current can be defined as a current little lesser than the maximum tolerable current. Concept of safe voltages is also important though causes shock as in a circuit only voltage can be measured with some accuracy. During very high voltage contact resistance breaks down easily hence no special role of contact resistance here but considerable in low voltage circuits. Hence probability of getting a shock should be considered and preventive measures need to be incorporated. Safety measures such as safety code, operating instructions etc.

Ferris *et al* [21] Author in this paper focused on describing the effect of electric shock on human heart. Any currents that prevent voluntary control of the skeletal muscles are dangerous. Asphyxial death would result and the time required if in seconds hence the opportunity of saving a person can easily be missed. Death under such conditions is brought about by ventricular fibrillation, which is a disruption of normal heart action. Hence this paper included determining the minimum current that would initiate ventricular fibrillation. The average threshold current for a body weight of 70 kilograms is 0.26 ampere

Prasad and Sharma [22] did the analysis of parameters affecting the design of grounding grid design.It was found parameters like diameter of conductor,depth of burial of grid,soil resistivity,numbers of conductors play an important role in grid designing,so need to be calculated and measured carefully.It was also found that the ground potential rise is affected by grid resistance.

Freschi *et al* [23] developed a semi analytical method which consisted of analystical approach with solution for study of grids with complex geometry and also to study the effects on stratified soils. Model was developed in MATLAB software which determined the basic parameters of grounding systems like ground potential, resistance and others. The model was based on two assumptions:-

1. Grid conductor’s radii are smaller than their lengths

2. Wire mesh is equipotential surface.

Verification of the proposed algorithm was also done and justified with the results.

Sverak *et al* [24] In this guide work was concentrated on grids which are of shapes approaching a square or a rectangle. Simplified equations for making calculations of the ground resistance, and mesh and step voltages for such grids were developed. But not all grids can be approximated by a square or rectangle, and for the design of such grids, the use of the existing expressions led to erroneous results.

Gouda *et al* [25] studied the effect of equal and unequal spacing between the conductors of the grounding grid on ground potential rise. The GPR and earth surface potential rise. The GPR and earth surface potential were calculated using infinite series potential method considering equal and unequal spacing for selection of different arrangements,voltage profiles were designed in three dimensional.

Ramalho *et al* [26] proposed a sensor based wireless network data acquisition system which measures GPR and current into the ground at frequent intervals at different positions of the grid and then transfers the data to coordinator connected to computer, the system is evaluated with respect to transmission and instrumentation modules.

Ghoneim *et al* [27] presented a new strategy for minimization of design cost and voltages of grid arrangements of dingle and two layer soil. They compared the quality factors of initial dimensions with new generation of grid dimension. Many factors like thickness of top layer, number of conductors, GPR, Rg were considered while proposing the strategy.

Yen hua *et al* [28] studied the effect of leakage current and displacement current in the soil while fault is occurring and then established a 3D mathematical model for an 88kV GIS S/S. Then the transient wave injection method, factors like depth of burial of conductor resistivity of soil were analyzed. The surface potential increased with soil resistivity. By surface pot charge, fault can be detected.

Silva *et al* [29] aimed at reducing the number of conductors and material required for grounding grid without compromising the security. Optimization was done considering the geometry of system. Genetic Algorithm was also discussed for optimization purpose.

Yardanova *et al* [30] developed a simulation for grounding considering the impulse produced in soil due to lightning current flowing in grid. Maximum possible touch voltage are determined. This paper studied the relation between touch voltage and impulse effect in soil.

Viscaro *et al* [31] experimented and simulated the results there after from the grounding grids subjected to currents relevant to lightning strokes (first and subsequent strokes). Different cases were considered of grids of different dimensions in

- Low resistivity soil
- Moderate resistivity soil
- High resistivity soil

Parameters like GPR, impulse coefficient and impedence were determined. New expression of impulse impedence relation with low frequency resistance was derived.

Piers *et al* [32] study deals with the horizontal conductor placement at different angle, and its effect on voltage (step, touch, surface) and resistance. A method proposed by Heppe is used for mathematical modeling. This method considers homogenous and two layer soil.

Yu *et al* [33] diagnosed faults in ground grids using electromagnetic method. In this paper, break point diagnosis was done taking into account the underground pipes. It was found that faults can be located accurately by studying resistivity distribution characteristics. It was found that underground pipe at different depths and of different material have a great impact on fault analysis.

Alpio *et al* [34] tested a grounding grid fed with lightning current forming an em model for determination of transient distribution of potentials. It was found that electrically connected components of the grid experience loop currents due to em effect which causes malfunctioning, failure of the grid. It was also found that the impulse loop current can reach to high value even in low resistivity base soil.

Garip and Bal [35] developed a new grounding grid system which had

1. Humidity sensor to keep check on climate change

2. Electrodes – to decrease resistance of grid further

3. Watering system – established underground.

All these three components work in a synchronized way to keep the resistance low.

CHAPTER-3

INTRODUCTION TO IEEE STANDARD 80

3.1 Overview

The grounding arrangement of an AC substation [10],[24] has the following main work to do:

1) During either normal or any adverse fault case, the current is transferred to the ground/earth in such a way that the limits of operation or the rating limits of the equipment employed are not crossed and the continuity of the service is not crossed.
2) To make sure that the personnel working in the area of operation is not endangered of the electric shock.

The ground return circuit is a circuit in which the earth or a similar conductive arrangement is used to allow the circulation of the current from the source or to the source. The ground forms the continuity medium between the circuit and the equipment to the ground or with some other arrangement of circuit/equipment which serves as the grounding ground. This grounding arrangement is mainly used to maintain the potential of the apparatus or the system at nearly the potential of the earth and also to provide the return circuit for fault currents. In case of faults in the AC substation the ground gets saturated with currents leaking out to the ground from the earthing grids and the earth electrode arrangement buried into the ground below the surface[24],[16].

The AC substation grounding grid arrangement is a system of horizontal and vertical, interlinked bare earth.Conductors, placed at some meters distance, are buried in the earth surface at a depth ranging from 0.25 to 2.5 m , this provides a common earthing arrangement to all the equipment and the substation on whole.

All the grounding arrangements provide resistance to fault currents upto a certain value only. The grounding resistance i.e. resistance being offered by the grounding arrangement should be as low as possible especially in case of a substation. The value of the grounding resistance should be around 1Ω for large substations and in case of distribution substations this should be within the range of 1Ω to 5 Ω [10],[24].

During the normal conditions the equipment connected to the grounding grid operates at nearly zero potential, but during fault conditions the part of fault current flowing into the earth through the grounding arrangement make the potential of the ground to rise to a certain level with respect to the remote ground portion. This developed potential difference is known as Ground Potential Rise (GPR) which depends upon the value of the fault current and the grounding resistance of the grounding arrangement grid.

There are two more design parameters that are influenced by the ground rise potential and the grounding resistance. These are mesh voltage and the step voltage of the substation grounding grid.

The Grid of the grounding arrangement is divided into number of sections called meshes by the conductors of the grid. The potential above the grounding grid (GPR) and on surface of ground is not same at all the points, the difference in these two at a particular point is called the touch voltage. The touch voltage is usually measured at a point where personnel is standing in contact with the ground arrangement. The mesh voltage is defined as the maximum value of touch voltage in the substation. When the feet of the person are one meter apart, and his no other body part is in touch or in contact with the grounding grid, then at time the difference in the surface potential experienced by the personnel is called the step voltage[9].

The human body is represented as a non-inductive resistance within the range of 500 **Ω**-5000 **Ω** ,but is usually taken as 1000**Ω**; for dc, and ac power frequencies of 50- 60Hz range.

The duration to which human body can tolerate an electric shock usually depends upon [10]:

1. RMS value of the current (in amperes)
2. Duration of the current flow in the body(in seconds)
3. Empirical constant related to electric shock tolerated by a specific human population.

This all is given by the formula

$$I_s = \sqrt{}(A_s/t_s) \qquad (1)$$

Crossing the critical limit of tolerating electric shock can prove to be fatal. This critical limit depends on many factors including the body weight of the person. It usually varies from person to person. On being exposed to electric shock, person can die, or it can lead to unconsciousness, burning of muscles, fibrillation of heart or nerve blockage of the respiratory system. The magnitude of current that can prove to be fatal ranges from 60 mA to 100 mA[26].

For a person with 50 kg as body weight the critical value of the current is given by:-

$$I_s = 0.116/\sqrt{t_s} \qquad (2)$$

Similarly for a 70kg human, the value of current is given by:-

$$I_s = 0.157/\sqrt{t_s} \tag{3}$$

The above two equations are for time duration of 0.03-0.3 sec, not valid for long durations.

Ferris, *et al* [26] gave the idea of value of shock current value to be of 100 mA in case duration is not known. It has also suggested values of shock current to be of the range of 500 mA for the shock duration to be less than one heartbeat and of 50 mA for shock duration of more than one heartbeat duration. Therefore all these values should be kept in mind while designing the grounding grid. The shock currents limits of the grid should be kept below the mentioned values.

While defining the limits of mesh voltage and step voltage, the resistance of human body is taken to be 1000Ω.

There is usually a layer of crushed pieces of rock on the soil to provide high resistivity below the feet of person working in the substation. Footing resistance is defined as resistance of ground below the feet of the personnel working in the substation[5]. For deriving the expression the mutual resistance between the two feet of the person working in substation is neglected ,the depth of the crushed rock layer is assumed to be very large and thus, value of footing resistance is taken to be $3\rho_r$,where ρ_r is taken as resistivity of the crushed pieces of rocks. Here in the expression the feet of the person are assumed to a conducting disc of 8 cm radius. The two feet of the person are taken to be in parallel in accident circuits for mesh voltage and in case of step voltage they are taken to be in series. Thus therefore in case of mesh voltage it is taken to be $1.5\rho_r$ and for step voltage its $6\rho_r$.The flow of the current through the person's body working in the substation is reduced by the crushed rock layer on the surface of the substation which increases the resistance between surface and the feet of the person.

There is a great impact of the rock layer [10] on the value of the fault current flowing from ground up to the body of the person. The value of fault current depends upon

1. Thickness of the crushed rock layer
2. The relative resistivity of the crushed rock layer and the lower soil
3. Resistance of the foot of the person

There are two factors: absorbing the critical amount of shock energy by a person before the clearance of fault and system gets re-energised. Therefore safety of a person depends on prevention of these two factors[23].

For accidental circuits the voltage should not exceed the following defined limits.

For touch voltage-

$$E_{touch} = (R_s + 0.5R_f)I_s \quad (4)$$

With $R_s = 1000\Omega$ and $R_f = 3\rho_r$, the above equation for a 50kg body weight can be written as

$$E_{touch(50)} = \left(1000 + 1.5 \times C_s\left(h_{s,}k\right)\rho_r\right)0.116/\sqrt{t_s} \quad (5)$$

For step voltage-

$$R_{step} = (R_s + 0.5R_f)I_s \quad (6)$$

For With $R_s = 1000\Omega$ and $R_f = 3\rho_r$, the above equation for a 50kg body weight can be written as

$$R_{Step(50)} = \left(1000 + 6 \times C_s\left(h_{s,}k\right)\rho_r\right)0.116/\sqrt{t_s} \quad (7)$$

The factor C_s [11] is added to compensate the change in resistivity due to addition of rock layer on the surface of soil of substation. This factor C_s is also known as derating factor. The resistivity of the crushed rock layer is different from the soil in the substation area. When there is no upper rocky layer the value of C_s is taken to be unity as the soil is uniform.

The calculated values of E_{step} should not be more than the maximum allowable value of E_{touch}, similarly calculated value of E_{touch} should not exceed the maximum value of $E_{step.}$

ρ_r is the resistivity of the soil And t_s is taken to be the time duration of the shock.

For designing a grounding grid, calculation of step voltage, ground resistance and mesh voltage can be done with different available methods. But the problem is though many programs are there which give accurate results but they are not available at the field site and mostly require an expert to run it.

The factors on which the designing of the grid in general depends are:-

1. Maximum fault current
2. Fault duration

For substation grounding grid, R_g, V_m and V_s depends upon following factors:-

1. Soil resistivity
2. Area of grounding system
3. Conductor spacing
4. Depth of burial of grounding grid
5. Shape of the grid
6. Ground electrodes used or not

3.2 IEEE Standard 80-1986[24]

Earlier resistance expression of a circular plate was used to determine the ground resistance offered by a simple square grid buried under homogeneous soil (i.e. uniform resistivity).Expression is as under [24]-

$$\boldsymbol{R_g} = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} \tag{8}$$

Where,

R_g = ground resistance of the grounding grid arrangement of the substation in Ω.

ρ =resistivity of the homogeneous soil in Ωm.

A=area of the grounding grid in m^2

To add the upper limit to the above expression, Laurent and Neimann [24] gave a factor ρ/L_t to be added. Hence the expression came out to be

$$\boldsymbol{R_g} = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} + \frac{\rho}{L_t} \tag{9}$$

Where

L_t =total length of conductors used in grid (in metres)

ρ/L_t , this factor symbolizes that resistance of the plate (solid) is always less than resistance of the grounding grid arrangement of similar shape.

From the above expression it can be concluded that as the total length of conductor increases the difference between the resistance of plate and that of grid reduces. This difference may approach zero if the total length of conductor increases infinitely.

The above expression is valid for the grids at depth of 0.25 metre or less in homogeneous soil.

For grids buried in between depth of 0.25 metres to 2.5 metres (at maximum), Sevark introduced the following formula [16],[24]:-

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

…...(10)

Where,

R_g = ground resistance in Ω

ρ = resistivity of the homogeneous soil in Ωm

L_t = total length of conductors used in the grid (in metres)

A = area of the grid (in m^2)

h =depth of burial of the grid (in metres)

This above equation was adopted under the IEEE standard 80-1986.

The expression of Step voltage and mesh voltage given under IEEE standard 80-1986 [24] are as following:-

$$V_m = \rho K_{sm} K_g \, {}^{I_g}\!/_{L_t}$$

…..(11)

$$V_s = \rho K_{ss} K_g \, {}^{I_g}\!/_{L_t}$$

……(12)

Where,

K_g is the correction factor for grid geometry,

$$K_g = 0.656 + 0{,}172n$$

K_{sm} is the spacing factor for Mesh Voltage,

$$K_{sm} = \frac{1}{2\pi}\left[ln\left(\frac{D^2}{16hd} + \frac{(D+2h)^2}{8Dd} - \frac{h}{4d}\right) + \frac{K_w}{K_{hc}} ln\left(\frac{8}{\pi(2n-1)}\right)\right]$$

K_{ss} is the spacing factor for Step Voltage

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

K_{hc} is the correction factor for the depth of burial of the grid conductors,

$$K_{hc} = \sqrt{(1+h)}$$

K_w is the corrective weighing factors which help in adjusting inner grid conductor effects on the corner mesh

$$K_w = \frac{1}{(2n)^{2/n}}$$

These correction factors are for compensation of the fact that the actual dimensions of the grounding grid are not same to the model grid which takes into the fact of number of parallel conductors in the grid.

$n =$ Total number of conductors in the grids

Here,$n \leq 25$

$n = \sqrt{}(n_a n_b)$ For mesh voltage calculations,

$n = n_a\ or\ n_b (whichever\ is\ greater)$ For step voltage calculations.

$d =$ Diameter of the grid conductor (in metres)

Here,$d < 0.25h$,

$D =$ Spacing between the parallel conductors of the grid (in metres)

Here, $D \geq 2.5\ m$

I_g = Maximum Grid Current in m-A.

Maximum allowable error in the calculations is 20%.

3.3 IEEE Standard 80-2000[10]

Formulae proposed by Sevark[16],[24] were improved by Thapar *et al* [9],[14]by adding some numerical factors to the expression of grounding resistance, and optimizing the coefficients in the formulae of Step voltage and mesh voltage. These were also applicable to the complex geometry overcoming the limitation of Sevark’s formula[24] of being applicable only to square and rectangular grids.

These modified expressions by Thapar *et al* [9],[14] were accepted as IEEE Standard 80-2000[10].Formulae are as follows:-

$$R_g = \rho \left[\frac{1}{L_t} + \frac{1}{\sqrt{(20A)}} \left(1 + \frac{1}{1 + h\sqrt{\frac{20}{A}}} \right) \right] \times 1.52 \left[2\, l_n \left(L_p \sqrt{\frac{2}{A}} - 1 \right) \right] \frac{\sqrt{A}}{L_p}$$

……(13)

Where,

R_g =Grounding resistance in Ω,

ρ = resistivity of the soil (homogeneous) in Ωm,

L_t = Total length of the grid conductors in metres,

A = area of the grid in m^2,

h =depth of burial of grid in metres;

Here, $0.2\, m \leq h \leq 3\, m$.

L_p = peripheral length of the grid in metres

Further change in expression in Step and Mesh Voltage [10] is as follows:-

$$V_m = \rho K_{sm} K_g \, {}^{I_g}\!/_{L_t}$$

$$V_s = \rho K_{ss} K_g \, {}^{I_g}\!/_{L_t}$$

Where,

$$K_{sm} = \frac{1}{2\pi}\left[ln\left(\frac{D^2}{16hd} + \frac{(D+2h)^2}{8Dd} - \frac{h}{4d}\right) + \frac{K_w}{K_{hc}} ln\left(\frac{8}{\pi(2n-1)}\right)\right]$$

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

$$K_{hc} = \sqrt{(1+h)}$$

$$K_w = \frac{1}{(2n)^{2/n}}$$

n remains same for mesh voltage as well as step voltage.

$$K_g = 0.644 + 0.148n$$

$$n = pqrs$$

……(14)

Where

$$p = \frac{2L_t}{L_p}$$

$$q = \left[\frac{L_p}{4\sqrt{A}}\right]^{1/2}$$

$$r = \left[\frac{L_x L_y}{A}\right]$$

$$s = \frac{Dm}{\left({L_x}^2 + {L_y}^2\right)^{1/2}}$$

Notations are as follows:-

L_x= maximum length of grid in *x* direction (in metres)

L_y= maximum length of grid in *y* direction (in metres)

D_m= maximum distance between any two points of the grid (in metres)

Limits as follows:-

$d \leq 0.25h$

$4m \leq D \leq 10m$

$n \geq 30$

Maximum allowable error is 20% within limits.

3.4 Changes in IEEE Standard 80-1986 to IEEE Standard 80-2000[11]

To provide guidelines and measures for safe practices of the AC substation Grounding systems, IEEE Standard 80 was developed. Earlier many editions came in 1961, 1976 and then in 1986. The most widely adopted edition was of 1986.But now new publication of this standard in 2000 brought in further changes in the standard of 1986 edition. This IEEE standard 80-2000[10] is now widely being used by engineers and designing professionals for the grounding grid design and analysis purpose.

Now let us discuss changes brought up in empirical formulae of 2000 version of IEEE Standard 80 with respect to 1986[24] version one by one.

3.4.1The Touch and Step Voltage

The expressions of touch voltage and step voltage are already discussed in section 3.1 with equations (5) and (7) respectively. The expressions are as follows for a 50kg person n with human body resistance as 1000Ω.

$$E_{touch(50)} = \left(1000 + 1.5 \times C_s\left(h_{s,}k\right)\rho_r\right)0.116/\sqrt{t_s}$$

$$R_{Step(50)} = \left(1000 + 6 \times C_s\left(h_{s,}k\right)\rho_r\right)0.116/\sqrt{t_s}$$

Where, C_s is the surface derating factor. It was found that there was no direct change in the expression of the touch and the step voltage but different approach was adopted in calculation of the surface derating factor and in decrement factor for the DC offset current.

3.4.2 The Surface Derating Factor, C_s

The change in approach of calculation of these factors highly influenced the change in design parameter calculation in IEEE standard 80 as compared to 1986 edition. This factor was included in to bring in the effect of the surface layer in the evaluation of footing resistance. The surface layer usually considered was crushed rock layer of high resistivity. It was also found that more accurate approach was adopted in evaluation of the derating factor in 2000 edition as compared to 1986 edition.

In 2000 publication the expression of C_s is a series expression with each term integrated around a surface whereas the 1986 expression was a simple expression.

When the conducting plate is on the surface of the ground, footing resistance may be given as:-

$$R_f = \frac{\rho}{4c}$$

….(15)

Where ρ is the resistivity of the soil on which conducting plate is there measured in Ωm.

Also c is the radius of the conducting plate, which is usually taken to be 0.08 m. when a surface layer exists on the top of the soil which resistivity ρ_r, the expression changes as follows-

$$R_f = \left(\frac{\rho_r}{4c}\right) C_s$$

…..(16)

Where C_s is the function of thickness of the surface layer and reflection coefficient between the resistivity of surface layer and that of the native layer of the soil. The reflection coefficient is given by the formula, $K = (\rho - \rho_r)/(\rho + \rho_r)$.

According to IEEE Standard 80, 1986 version-

$$C_s = \frac{1}{0.96}\left[1 + 2\sum_{n=1}^{\infty} \frac{K^n}{(1 + (2nh_s/c)^2)^{1/2}}\right]$$

…..(17)

Where, h_s is thickness of the surface layer.

And according to IEEE Standard 80-2000 [10]is given by-

$$C_s = 1 + \frac{8}{\pi c^2}\sum_{n=1}^{\infty} K^n \int_0^c r.\sin^{-1}\left(\frac{2c}{R_a + R_b}\right) dr$$

…..(18)

Where,

$$R_a = ((r+c)^2 - (2nh_s)^2)^{1/2}$$

$$R_b = ((r+c)^2 + (2nh_s)^2)^{1/2}$$

It is found that with increase in derating factor of the surface layer there was a considerable increase in the step voltage and touch voltage also. It is also concluded that on the basis of IEEE Standard 80-1986[24], the lower tolerable step voltage and touch voltage implies to conservative design of the grounding grid system. On the other hand higher values of the voltage in the IEEE Standard 80-2000[10] imply easier design of the grounding grid system.

3.4.3 Decrement factor, D$_s$

A typographical error was found in the expression of the decrement factor expression of 1986 version. Hence there is difference in the expressions of decrement factor of both (1986 and 2000) the versions of IEEE Standard 80 but no intended change was found. Hence IEEE Standard 80-2000[10] version corrected this typographical error.

3.4.4 Uniform Soil Assumption in 1986 version.

In Standard 80-2000[10] there is inclusion of new table with information about typical surface material resistivity, a full detail of procedure of the uniform soil assumption, inclusion of two soil model and brief introduction of multilayer soil model which was absent in standard 80-1986[24].

According to IEEE Standard 80-2000[10], the uniform soil resistivity is given by

$$\rho_{av1} = \frac{\rho_{a_1} + \rho_{a_2} + \cdots + \rho_{a_n}}{n}$$

…..(19)

$$\rho_{av2} = \frac{\rho_{a_{min}} + \rho_{a_{max}}}{2}$$

…..(20)

Where, $\rho_{a_1}, \rho_{a_2}, \dots, \rho_{a_n}$ are the measured resistivities at different places using four-point method;

n is the total number of measurements; and $\rho_{a_{min}}$ and $\rho_{a_{max}}$ are the minimum and the maximum measured values of the soil resistivity.

Flaws in assuming uniform resistivity of the soil are stated as follows-

i. Uniform soil rarely exists.
ii. Average resistivities are considered in both the formulae in relation to the real resistivity instead of spacing between the electrodes/conductors.
iii. The shallow soil resistivities have more influence on small grids whereas the deep soil resistivities have more effect on large grids.
iv. Measurements at small spacing of the electrode reflect the soil resistivity as the surface whereas at large spacing reflects soil resistivity at depth.

Multilayer soil model is also has a mention in IEEE Standard 80-2000[10].

3.4.5 Arrangement of the fences of the Substation.

IEEE Standard 80-2000[10] deals with grounding of substation fences in much greater detail than in IEEE Standard 80-1986[24].Cases discussed are (1) fence on grid perimeter,(2)outside grounding area but close by,(3) outside ground area and far by,(4)within grounding area.

3.5 Schwarz's Equations-To study the effect of earth rods on grounding resistance of the Grid[10].

Grid resistance can also be calculated using Schwarz's equations framed for grid buried in uniform soil which is valid for multi-grid system. Here we will be considering expressions for grid resistance with earth electrodes.

$$R_g = \frac{R_a + R_b - R_p^2}{R_a + R_b - 2R_p}$$

….(21)

Where, R_g is the total ground resistance of the Grid in Ω.

R_1 represents Ground resistance of the grid without the rods,

$$R_a = \frac{\rho}{\pi L_c}\left[ln\left(\frac{2L_c}{a'}\right) + \frac{K_1\, L_c}{\sqrt{A}} - K_2\right]$$

…(22)

Here,

ρ = Resistivity of the soil inΩ-m

Lc = total length of conductor (m)

$a' = \sqrt{a.2h}$ for conductor at depth h (m)

a'= a, for conductor on earth surface (m)

2a= diameter for conductor (m)

A= area covered by conductor in m^2

K_1 and K_2 are the correction factors determined from the graph.

Similarly, R_2 represents Ground resistance of the grid with earth rods inserted,

$$R_b = \frac{\rho}{2\pi n_r L_r}\left[ln\left(\frac{4L_r}{b}\right) - 1 + \frac{2K_1 L_r}{\sqrt{A}}\left(\sqrt{n_r} - 1\right)^2\right]$$

…(23)

Here,

Lr = length of each rod(m)

2b = diameter of rod(m)

n_r =number of rods in area A

And, R_m represents mutual resistance, given by the formula

$$R_p = \frac{\rho}{\pi L_c}\left[ln\left(\frac{2L_c}{L_r}\right) + \frac{K_1 L_c}{\sqrt{A}} - K_2 + 1\right]$$

….(24)

There is limitation in computation of grounding Resistance using these equations as the factors K_1 and K_2 are determine using the graphs. So for our software purpose we considered only two of the following cases:

For computation of K_1 , cases are as follows-

1) h =0; i.e grid is placed on the surface

$$y = -0.04x + 1.41$$

2) h = $\frac{\sqrt{A}}{10}$

$$y = -0.05x + 1.20$$

3) $h = \sqrt{A}/6$

$$y = -0.05 + 1.13$$

For computation of K_2, cases are as follows-

1) h =0

$$y = 0.15x + 5.50$$

2) $h = \sqrt{A}/10$

$$y = 0.10x + 4.68$$

3) $h = \sqrt{A}/6$

$$y = -0.05 + 4.40$$

Reasons for adding earthing electrodes[10],[22]-

1. Peripheral parts of the earth electrode give out a large amount of current into the earth per unit of length. That is why peripheral vertical rods and at time peripheral horizontal conductors are being added.in this case vertical rods are great at lowering the resistance offered by the grounding grid and hence are very effective.
2. The ground surface potentials are lowered by the ground electrodes which are horizontal conductors. Hence they decrease the touch and step voltage. If we lower the distance between horizontal earthing electrodes, then the voltages-step and mesh voltages gets lowered at:
   i. at the soil surface
   ii. Between the conductors.

3.6 Seasonal effect on the Grounding Grid arrangements[3],[8]

Seasonal factors do have a considerable effect on the resistance offered by the grounding grid. Here in this section we will be discussing two factors: Rainy season and Freezing season.

i. Rainy Season

Due to the rain the affected soil's depth parameter changes. The affected soil leads to change of uniform resistivity soil model to a two layer soil model. The resistivity of the upper layer of the soil varies from 10 Ω-m to 100 Ω-m and resistivity of the lower layer comes about to be 400 Ω-m. The resistance of the grid, step voltage touch voltage all vary with change in soil resistivity and the resistivity of the surface. During rainy season as the moisture content increases the limits of allowable values of touch voltage and step voltage decreases whereas maximum limits of these voltages increases in such a way that it exceeds the allowable limit of the voltage. With increase in thickness of the low resistivity upper layer of soil the value of ground resistance decreases. These both hold a linear relationship. With decrease in thickness of low resistivity soil on comparison with the depth of burial of the conductors of the grid the values of grounding surface potential increases. When the thickness of the upper low resistive layer changes from less than burial depth to more than the depth of burial there is a rapid decrease in the value of the voltage.

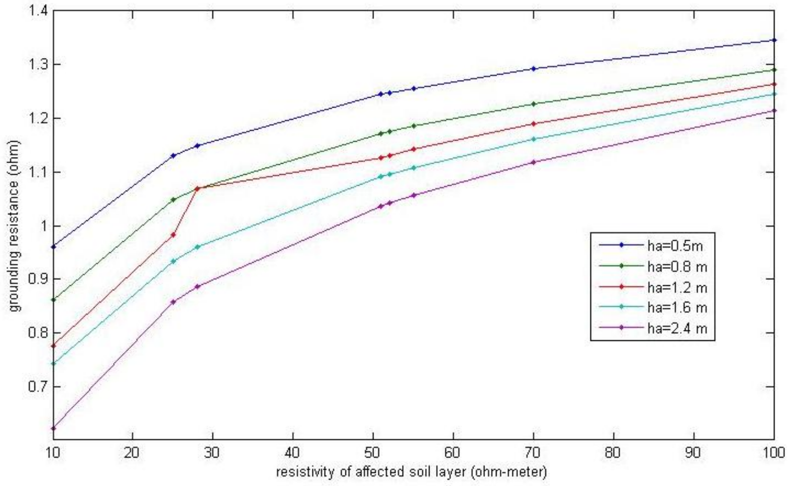


Figure 3.1: Influence of resistivity of the rain affected soil layer [3]

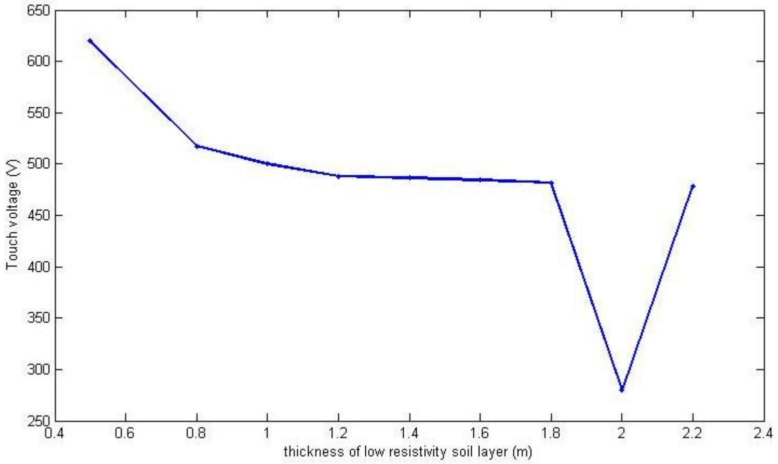


Figure 3.2: Influence of thickness of rain affected soil layer [3]

ii. Freezing Season

A high resistivity layer of soil is formed on the surface during the freezing season. This layer of soil is called freezing soil layer. This can be examined by viewing the homogeneous soil as a two layer soil model. The resistivity of the upper layer of the soil ranges from 200 Ω-m to 5000 Ω-m and the resistivity of the lower layer is 400 Ω-m. If we compare the parameter variation, there is more variation in freezing season in contrast to the raining season.The limits of allowable levels of the touch voltage and step voltage decreases rapidly in freezing season in contrast to rainy season.

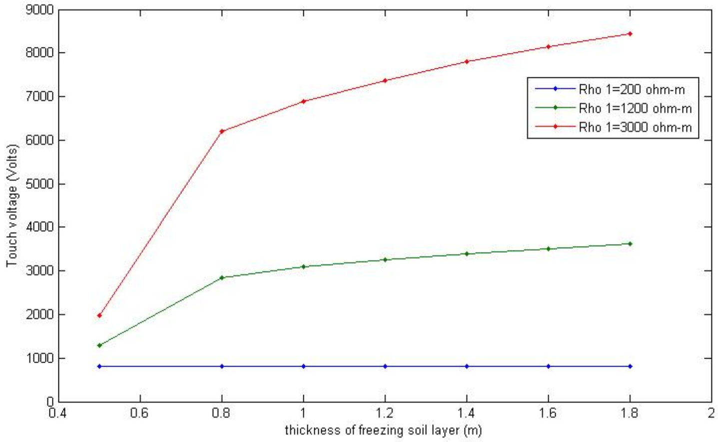


Figure 3.3: Influence of thickness of freezed soil layer on touch voltage [3]

3.7 Introduction to the Software

The Simulation Software is being made in Visual Studio 2013. Visual Studio is used usually to make computer based programs for Windows, many web sites, online applications etc. Visual Studio uses development services such as Windows Forms, Windows Presentation Foundation etc. Here in our software we have used windows forms for the calculation purposes.

One of the major aspects of Simulation Software is substation grounding system design. The calculation of the resistance offered by the grounding grid, and that of the mesh and step voltages on the surface and the effect of adding earth electrode on the grounding resistance is also included. The values of the parameters to be entered as the input data or to be calculated should be within the permissible limits, taking into the account the safety measures of the substation grounding system designing.

Expressions from both IEEE Standard 80-1986 and IEEE Standard 80-2000 are used in computation from the simulation software. Mainly three parameters are being calculated for the designing process; that are grounding resistance, step voltage and mesh voltage.

The simulation software developed provide a medium to calculate various parameters like ground resistance , step voltage , mesh voltage etc. for designing of grounding grid system of AC substation systems.

At present calculation base for homogeneous soil ground has been designed using empirical formulae of substation grounding resistance of both IEEE standard 80-1986 and IEEE standard 80-2000.

3.7.1 Glimpse of the Simulation Software

Simulation Software herein is designed for calculation of grounding grid design parameters that are-

1. Grounding Resistance
2. Step voltage
3. Mesh voltage

In the beginning the first window will allow the user to choose the version of IEEE Standard 80, desired for the calculation purpose, and then the shape of grid will be asked :which shape of grid he/she want to design like –

1. Square grid
2. Rectangular grid
3. Triangular grid
4. T-shaped grid
5. L-shaped grid

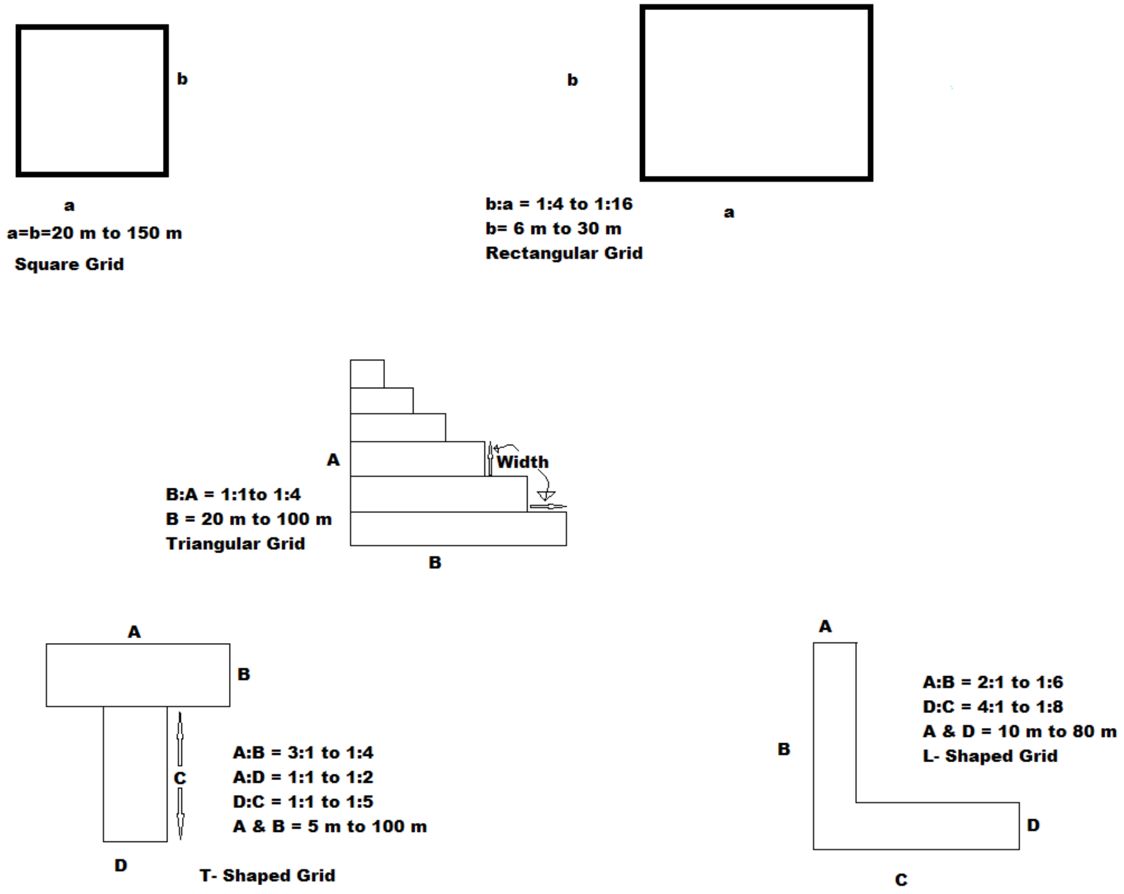
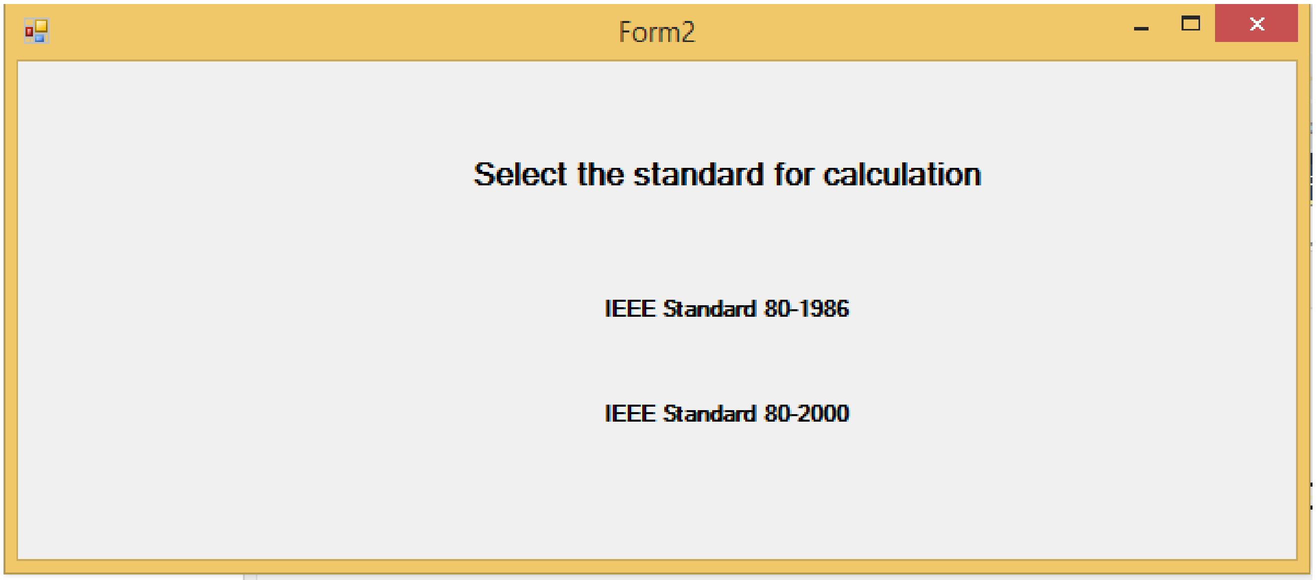


Figure 3.4: Different shapes of grounding grids [10]

The choice of the shape of the grid depends upon the area available for establishing the grounding grid system.

A choice of calculation of addition of earthing electrodes is also given, as if to include it while calculating the grounding resistance or not.



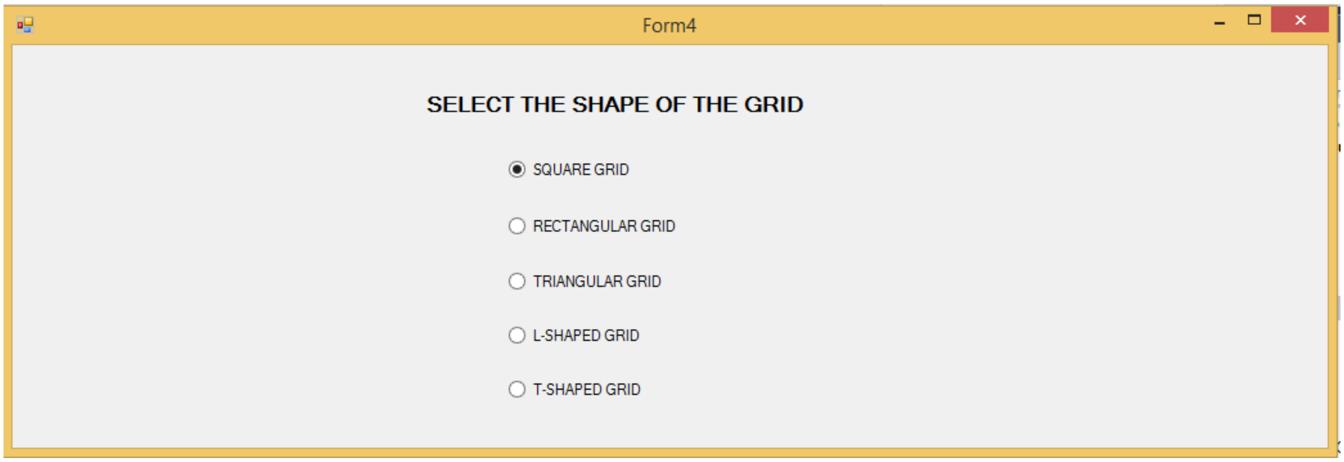
Form2

Select the standard for calculation

IEEE Standard 80-1986

IEEE Standard 80-2000

Figure 3.5: Window with choice of version of IEEE Standard 80



Form4

SELECT THE SHAPE OF THE GRID

● SQUARE GRID
○ RECTANGULAR GRID
○ TRIANGULAR GRID
○ L-SHAPED GRID
○ T-SHAPED GRID

Figure 3.6: Window with display of choices of different shapes of grounding grids

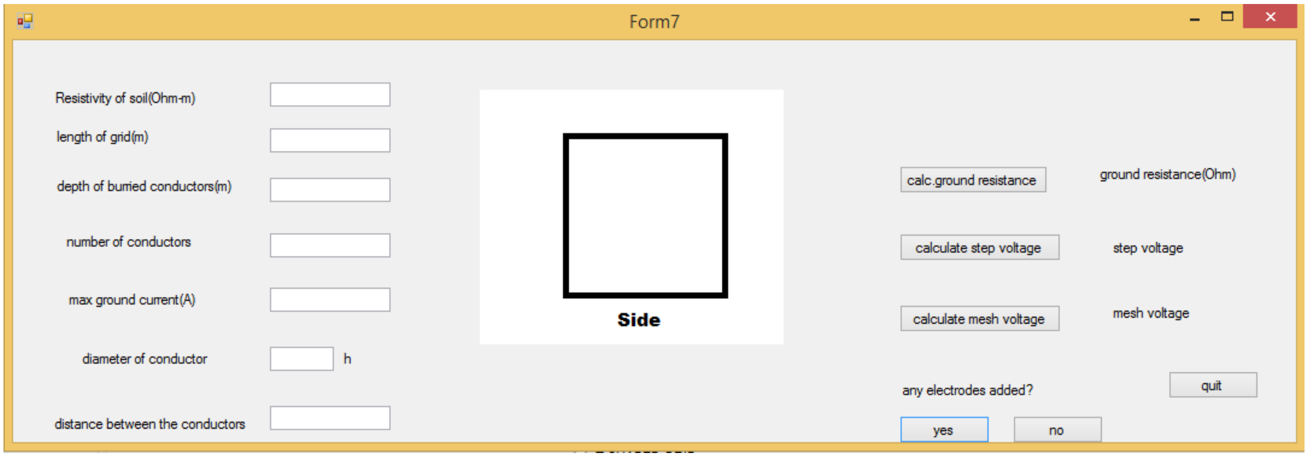


Figure 3.7: Window displaying the main site for data entry and calculation of designing parameters

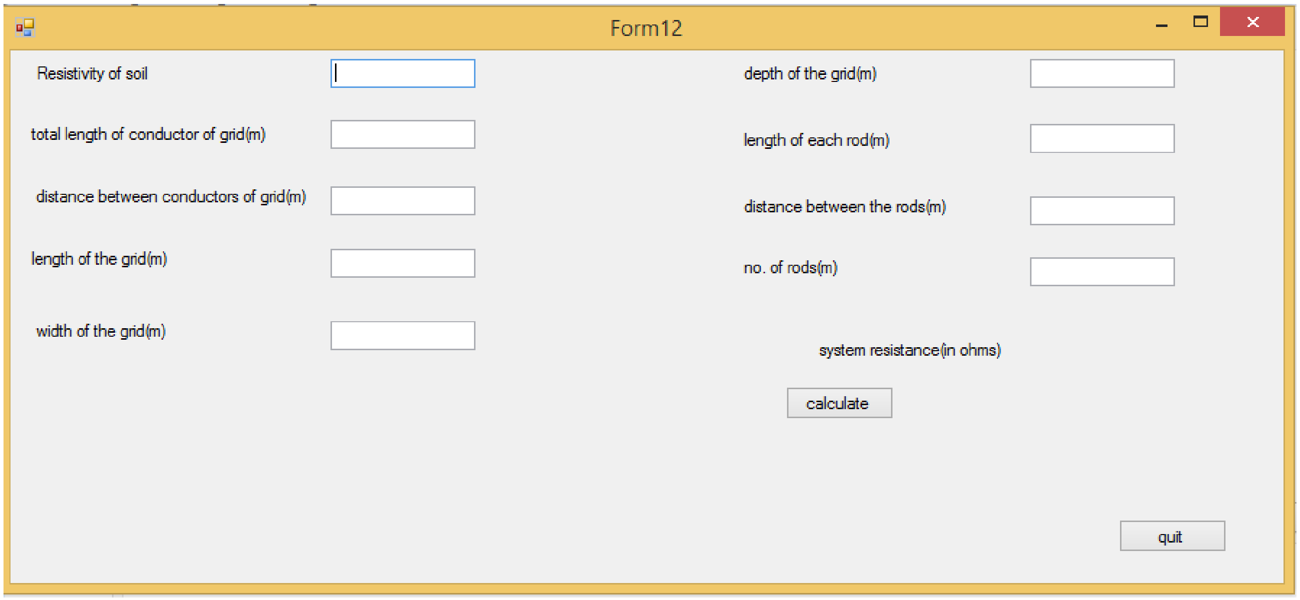


Figure 3.8: Window displaying window for calculation of grounding resistance with addition of earth rods

CHAPTER-4

RESULTS AND DISCUSSION

4.1 Introduction

Here in this section different cases of calculations of grounding grid design parameters are discussed. The calculated results from the software with the results obtained from manual calculations were compared.

The cases to be discussed are –

1. Calculation using IEEE Standard 80-1986 formulae for square or nearly square grids
2. Calculation using IEEE Standard 80-2000 formulae for grids of various shapes
3. Grounding Resistance Calculation considering the earth electrode and discussing the effect of adding earth electrode

4.2 Calculation using IEEE Standard 80-1986 formulae

4.2.1 Square Grid

Statement- Calculate the grounding resistance of a square grid with

Side of grid = 20 m,

Number of conductors along one side of the grid = 5,

Resistivity of soil = 2200 Ω-m

Depth of burial of the grid conductors, h = 1.5 m

Maximum Current through the grid =200 m-A

Diameter of the grid conductor= d = 0.2 h

Distance between the conductors = D =5 m

4.2.1.1 Ground Resistance Calculation

Solution- From the given data:-

$L_t = 20 \times 10 = 200m$

$A = 20 \times 20 = 200m^2$

Therefore, Grounding grid resistance can be calculated using the formula in equation (10) [10],

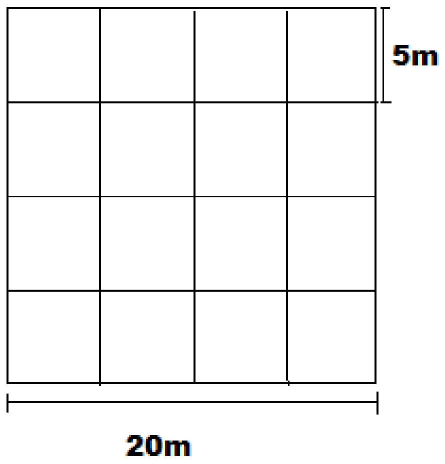
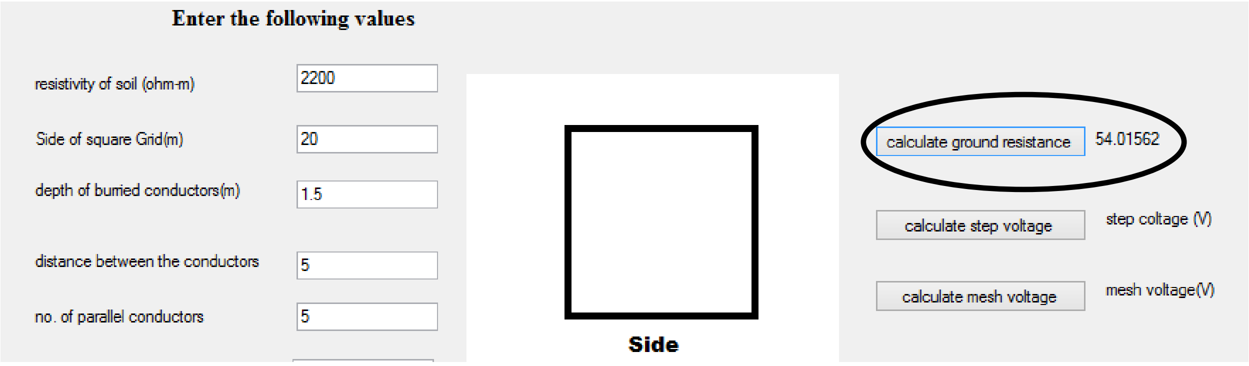


Figure 4.1: Rough sketch for position of grid conductors in square grid

$$R_g = 2200\left[\frac{1}{200} + \frac{1}{\sqrt{20 \times 400}}\left(1 + \frac{1}{1 + 1.5\sqrt{\frac{20}{400}}}\right)\right]$$

Hence on solving, $R_g = 54.01\ \Omega$

Similarly on calculating the same on software we got 54.01562 Ω.



Enter the following values

resistivity of soil (ohm-m) 2200
Side of square Grid(m) 20
depth of buried conductors(m) 1.5
distance between the conductors 5
no. of parallel conductors 5

calculate ground resistance 54.01562

Figure 4.2: Screenshot showing calculated value of ground resistance of square grid (IEEE Standard 80-1986)

4.2.1.2 Step and Mesh Voltage Calculation

Solution - From the above data, using equation (11) and (12)

$L_t = 20 \times 10 = 200m$

$A = 20 \times 20 = 200m^2$

According to IEEE Standard 80-1986 [10]-

$K_g = 1.516$

$K_w = \frac{1}{(2 \times 5)^{\frac{2}{5}}} = 0.398$

$K_{hc} = \sqrt{1 + 1.5} = 1.581$

Now,

$K_{ss} = \frac{1}{\pi}\left[\frac{1}{3} + \frac{1}{6.5} + \frac{1}{5}(1 - 0.5^3)\right]$

$K_{ss} = 0.2107$

Next,

$$K_{sm} = \frac{1}{2\pi}\left[ln\left(\frac{25}{16 \times 1.5 \times 0.2 \times 1.5} + \frac{(5+3)^2}{8 \times 5 \times 0.2 \times 1.5} - \frac{1.5}{4 \times 0.2 \times 1.5}\right) + \frac{0.398}{1.581} ln\left(\frac{8}{\pi(9)}\right)\right]$$

Hence $K_{sm} = 0.271$

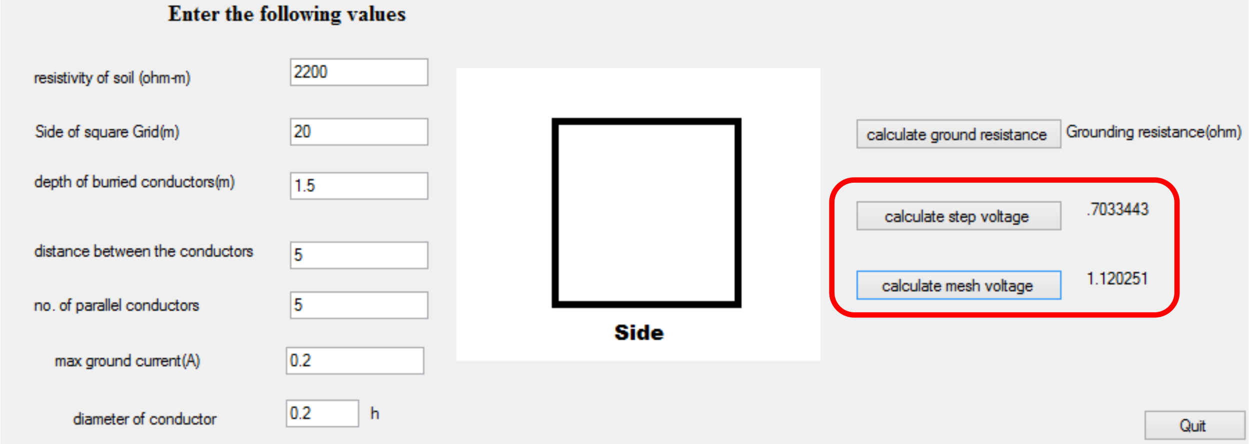
Therefore, Mesh Voltage is as follows

$V_m = 2200 \times 0.271 \times 1.516 \times {}^{200 \times 10^{-3}}/_{200} = 0.903V$

Similarly, for Step Voltage

$V_s = 2200 \times 0.2107 \times 1.516 \times {}^{200 \times 10^{-3}}/_{200} = 0.702V$

From the software the calculated values of step and mesh voltage come out to be 0.7033 V and 1.120251 V respectively.



resistivity of soil (ohm-m) 2200
Side of square Grid(m) 20
depth of burried conductors(m) 1.5
distance between the conductors 5
no. of parallel conductors 5
max ground current(A) 0.2
diameter of conductor 0.2 h
calculate step voltage .7033443
calculate mesh voltage 1.120251

Figure 4.3: Window displaying the calculated result for step and mesh voltage of square grid (IEEE Standard 80-1986)

Table 4.1: Comparison of calculated results theoretically and from software (square grid-IEEE Standard 80-1986)

	Theoretically Calculated Value	Software Calculated Value
Grounding Resistance of Grid	54.01 Ω	54.01Ω
Step Voltage	0.702 V	0.7033 V
Mesh Voltage	0.903 V	1.1202 V

4.2.2 Nearly Square Grid

Statement: Length of the grid = 25 m

Width of the grid = 20 m

Resistivity of the soil = 3000 Ω-m

Depth of burial of the conductor = 1.6 m

No. of conductors on length side= 6, and on width side = 5 m

Distance between the parallel conductors = 5 m

Diameter of the grid conductor = 0.23 h

Grid current (maximum) = 200 mA

4.2.2.1 Ground Resistance Calculation

<u>Solution</u>: From the given data:-

$A = (20 \times 25) = 500m^2$

$L_t = (25 \times 5) + (20 \times 6) = 245\ m$

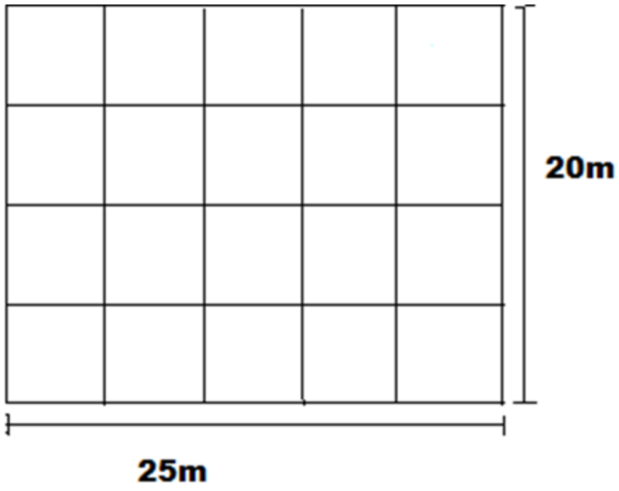


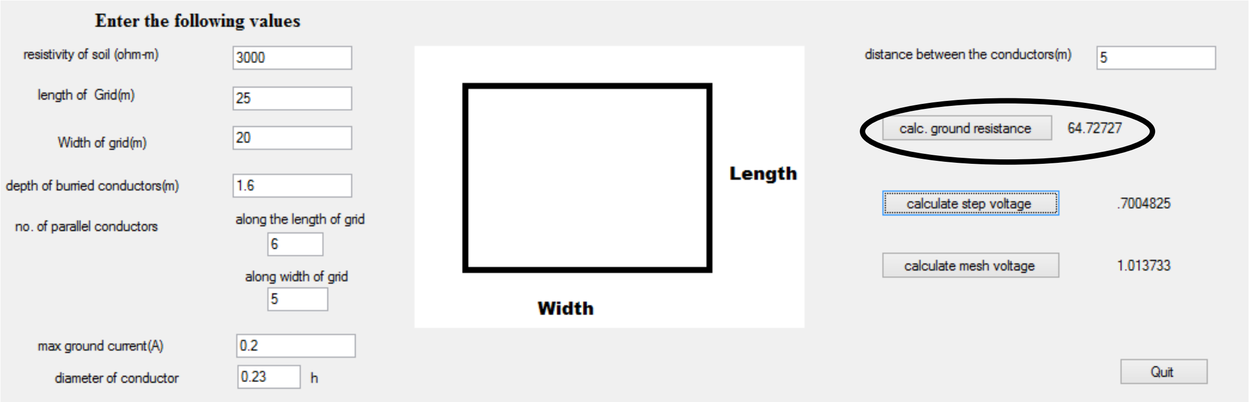
Figure 4.4: Rough layout of the rectangular grid showing the conductors

Hence using the equation (10) [10], we get

$$R_g = 3000\left[\frac{1}{245} + \frac{1}{\sqrt{(20X500)}}\left(1 + \frac{1}{1 + 1.6\sqrt{\frac{20}{500}}}\right)\right]$$

$$R_g = 64.93\Omega$$

From the software the calculated value comes out be 64.7277 **Ω**.



Enter the following values

resistivity of soil (ohm-m) 3000
length of Grid(m) 25
Width of grid(m) 20
depth of burried conductors(m) 1.6
no. of parallel conductors
along the length of grid 6
along width of grid 5
max ground current(A) 0.2
diameter of conductor 0.23 h
distance between the conductors(m) 5
calc. ground resistance 64.72727
calculate step voltage .7004825
calculate mesh voltage 1.013733

Figure 4.5: Showing the calculated value of ground resistance for nearly square grid (IEEE Standard 80-1986)

4.2.2.2 Step and Mesh Voltage Calculation

<u>Solution</u>: Using the empirical Formulas (11) and (12)[10] we get,

Mesh Voltage

$$K_g = 0.656 + 0.172 \times 5.47 = 1.597$$

$$K_{hc} = \sqrt{(1 + 1.6)} = 1.612$$

$$K_w = \frac{1}{(2 \times 5.47)^{2/5.47}} = 0.4169$$

$$n = \sqrt{6 \times 5} = 5.47$$

Hence,

$$K_{sm} = \frac{1}{2\pi}\left[ln\left(\frac{5^2}{16 \times 1.6 \times 0.368} + \frac{(5 + 2 \times 1.6)^2}{8 \times 5 \times 0.368} - \frac{1.6}{4 \times 0.368}\right) + \frac{0.4169}{1.612}\,ln\left(\frac{8}{\pi(2 \times 1.597 - 1)}\right)\right] = 0.232$$

Therefore,

$$V_m = 3000 \times 1.597 \times 0.232\,{}^{0.2}\!/_{245} = 0.991V$$

Now Step Voltage,

$$n = 6$$

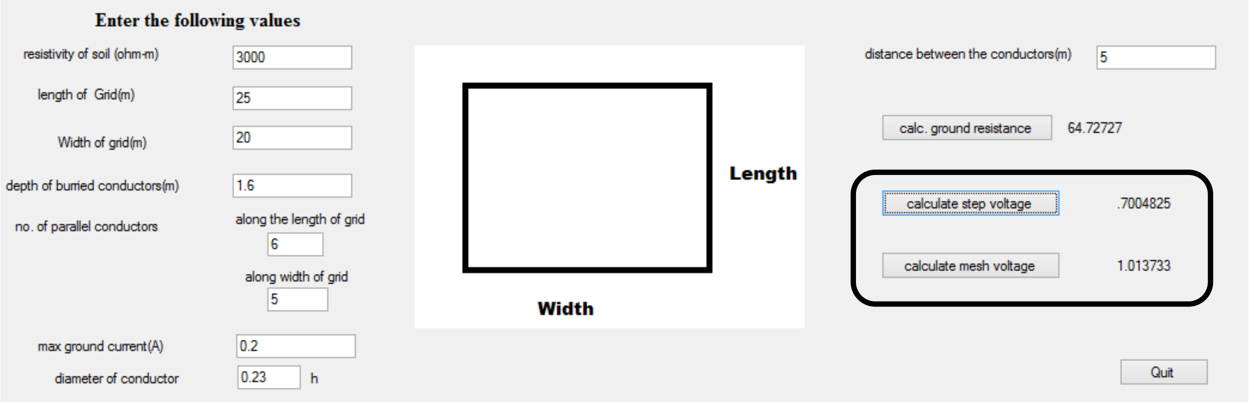
Hence,

$$K_{ss} = \frac{1}{\pi}\left[\frac{1}{2 \times 1.6} + \frac{1}{5 + 1.6} + \frac{1}{5}(1 - 0.5^{6-2})\right] = 0.2056$$

Therefore,

$$V_s = 3000 \times 0.2056 \times 1.597\ ^{0.2}/_{245} = 0.689V$$

From the software calculated values of Step and Mesh voltage come out to be 0.7004 V and 1.013 V respectively.



Enter the following values

resistivity of soil (ohm-m): 3000

length of Grid(m): 25

Width of grid(m): 20

depth of buried conductors(m): 1.6

no. of parallel conductors

along the length of grid: 6

along width of grid: 5

max ground current(A): 0.2

diameter of conductor: 0.23 h

distance between the conductors(m): 5

calc. ground resistance: 64.72727

calculate step voltage: .7004825

calculate mesh voltage: 1.013733

Figure 4.6: Results for Step and Mesh Voltage Calculation of nearly square grid (IEEE Standard 80-1986)

Table 4.2: Comparison of calculated results theoretically and from software (rectangular grid-IEEE Standard 80-1986)

	<u>Theoretically Calculated Value</u>	<u>Software Calculated Value</u>
Grounding Resistance of Grid	64.93 Ω	64.727Ω
Step Voltage	0.689 V	0.7004 V
Mesh Voltage	0.991 V	1.0137 V

4.3 Calculation using IEEE Standard 80-2000 empirical Formulae.

4.3.1 Square Grid

Statement- Calculate the grounding resistance of a square grid with

Side of grid = 20 m,

Number of conductors along one side of the grid = 5,

Resistivity of soil = 2200 Ω-m

Depth of burial of the grid conductors, h = 1.5 m

Maximum Current through the grid =200 m-A

Diameter of the grid conductor= d = 0.2 h

Distance between the conductors = D =5 m

4.3.1.1 Ground Resistance Calculation

Solution- From the given data:-

$L_t = 20 \times 10 = 200m$

$A = 20 \times 20 = 200m^2$

$L_p = 80\ m$

Therefore, Grounding Resistance of the Grid can be calculated using the formula in equation(13) [10],

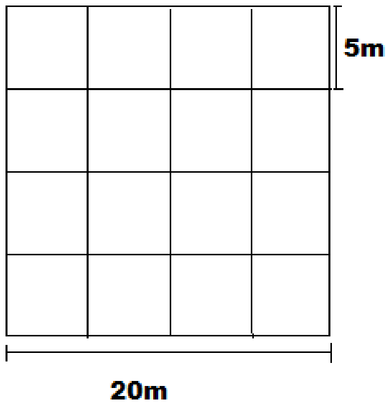
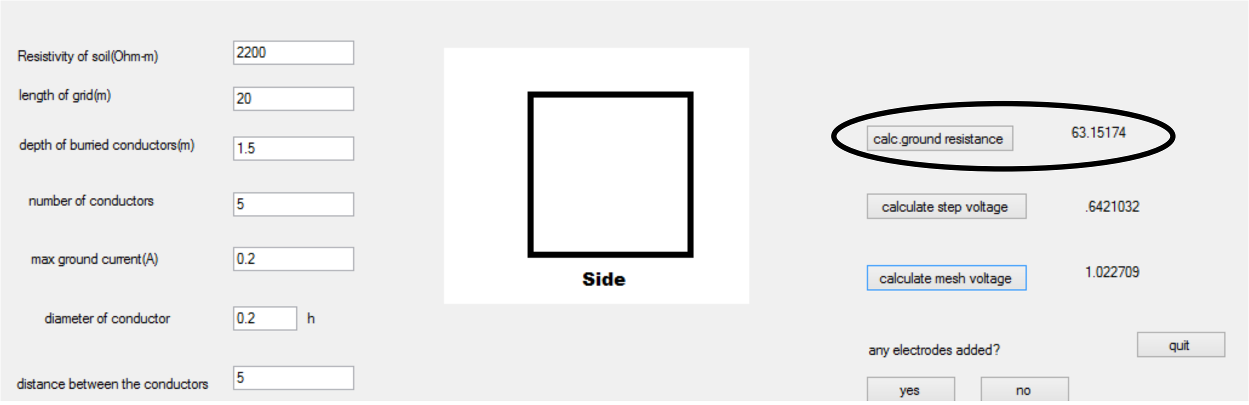


Figure 4.7: Rough sketch for mesh of conductors of given square grid

$$R_g = 2200\left[\frac{1}{200} + \frac{1}{\sqrt{(20\times 400)}}\left(1 + \frac{1}{1 + 1.5\sqrt{\frac{20}{400}}}\right)\right] \times 1.52\left[2l_n\left(200\sqrt{\frac{2}{400}} - 1\right)\right]\frac{\sqrt{A}}{80}$$

$$= 62.98\Omega$$


Resistivity of soil(Ohm-m) 2200
length of grid(m) 20
depth of buried conductors(m) 1.5
number of conductors 5
max ground current(A) 0.2
diameter of conductor 0.2 h
distance between the conductors 5

calc.ground resistance 63.15174
calculate step voltage .6421032
calculate mesh voltage 1.022709

Figure 4.8: Calculated value of ground resistance for square grid (IEEE Standard 80-2000)

From the Software value comes out to be 63.15174 Ω, which is nearer to the above calculated value.

4.3.1.2 Step and Mesh Voltage Calculation

From the set of equation (11), (12) and (14) [10]

$$D_m = 28.28m$$

$$n = 5$$

Where $p = \frac{2\times 200}{80} = 5$

$q = \left[\frac{80}{4\sqrt{400}}\right]^{1/2} = 1$

$r = 1$

$s = 1$

$K_g = 0.644 + 0.148\, n = 1.384$

$K_w = \frac{1}{(2n)^{\frac{2}{n}}} = \frac{1}{(2\times 5)^{\frac{2}{5}}} = 0.398$

$K_{hc} = \sqrt{1+h} = \sqrt{1+1.5} = 1.581$

Now,

$K_{ss} = \frac{1}{\pi}\left[\frac{1}{3} + \frac{1}{6.5} + \frac{1}{5}(1 - 0.5^3)\right]$

$K_{ss} = 0.2107$

Next,

$$K_{sm} = \frac{1}{2\pi}\left[ln\left(\frac{25}{16 \times 1.5 \times 0.2 \times 1.5} + \frac{(5+3)^2}{8 \times 5 \times 0.2 \times 1.5} - \frac{1.5}{4 \times 0.2 \times 1.5}\right) + \frac{0.398}{1.581}\, ln\left(\frac{8}{\pi(9)}\right)\right]$$

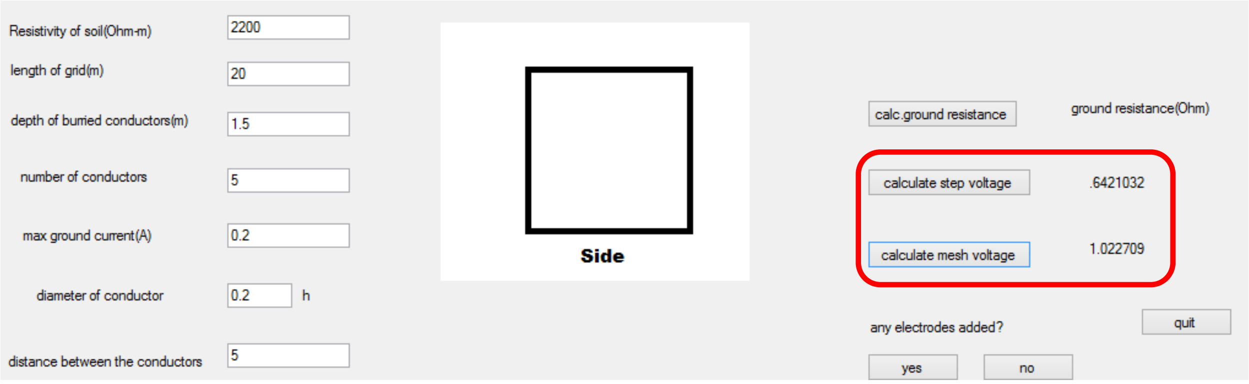
Hence $K_{sm} = 0.271$

Therefore, Mesh Voltage is as follows

$V_m = 2200 \times 0.271 \times 1.384 \times {}^{200 \times 10^{-3}}/_{200} = 0.824V$

Similarly, for Step Voltage

$V_s = 2200 \times 0.2107 \times 1.384 \times {}^{200 \times 10^{-3}}/_{200} = 0.6408V$



Resistivity of soil(Ohm-m) 2200
length of grid(m) 20
depth of buried conductors(m) 1.5
number of conductors 5
max ground current(A) 0.2
diameter of conductor 0.2 h
distance between the conductors 5
ground resistance(Ohm)
calculate step voltage .6421032
calculate mesh voltage 1.022709

Figure 4.9: Calculated result of step and mesh voltage for square grid (IEEE Standard 80-2000)

From the software the calculated values for Step and Mesh Voltage comes out to be 0.6421 V and 1.022 V respectively.

Table 4.3: Comparison of calculated results theoretically and from software (square grid-IEEE Standard 80-2000)

	Theoretically Calculated Value	Software Calculated Value
Grounding Resistance of Grid	62.98 Ω	63.15 Ω
Step Voltage	0.6408 V	0.6421 V
Mesh Voltage	0.8240 V	1.0227 V

4.3.2 Rectangular Grid

Statement- Length of the grid = 25 m

Width of the grid = 20 m

Resistivity of the soil = 3000 Ω-m

Depth of burial of the conductor = 1.6 m

No. of conductors on length side= 6, and on width side = 5 m

Distance between the parallel conductors = 5 m

4.3.2.1 Ground Resistance Calculation

Solution: From the given data:-

$A = (20 \times 25) = 500m^2$

$L_t = (25 \times 5) + (20 \times 6) = 245\ m$

$L_p = (20 + 20) + (25 + 25) = 90\ m$

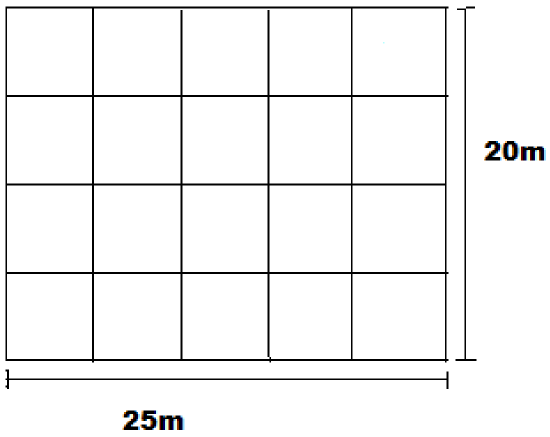


Figure 4.10: Rough layout of the rectangular grid showing the conductors

Hence using the formula as in equation (13) for calculation of grid resistance [10],

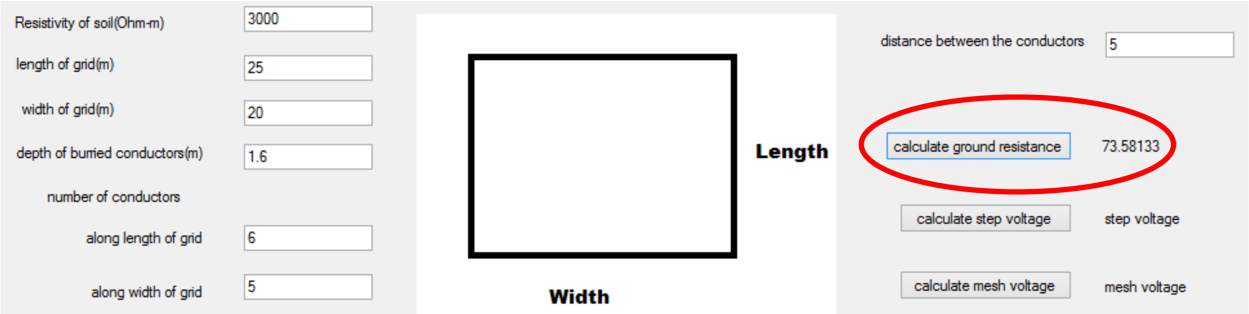
$$R_g = \rho \left[\frac{1}{L_t} + \frac{1}{\sqrt{(20A)}} \left(1 + \frac{1}{1 + h\sqrt{\frac{20}{A}}} \right) \right] \times 1.52 \left[2l_n \left(L_p \sqrt{\frac{2}{A}} - 1 \right) \right] \frac{\sqrt{A}}{L_p}$$

$$R_g = 3000 \left[\frac{1}{245} + \frac{1}{\sqrt{(20 \times 500)}} \left(1 + \frac{1}{1 + 1.6\sqrt{\frac{20}{500}}} \right) \right] \times 1.52 \left[2l_n \left(90 \sqrt{\frac{2}{500}} - 1 \right) \right] \frac{\sqrt{500}}{90}$$

On Solving we get,

$$R_g = 73.6\ \Omega$$

Similarly the result of software is 73.58133 Ω



Resistivity of soil(Ohm-m) 3000
length of grid(m) 25
width of grid(m) 20
depth of burried conductors(m) 1.6
number of conductors
along length of grid 6
along width of grid 5
distance between the conductors 5
calculate ground resistance 73.58133
calculate step voltage step voltage
calculate mesh voltage mesh voltage

Figure 4.11: Window showing calculated result of ground resistance for rectangular grid (IEEE Standard 80-2000)

4.3.2.2 Step and Mesh Voltage calculation

Solution: Using the empirical Formulas (11), (12) and (14) [10] we get,

$n = 5.44$

Where $p = \frac{2\times 245}{90} = 5.44$

$q = 1$

$r = 1$

$s = 1$

Mesh Voltage

$$K_g = 0.644 + 0.148 \times 5.44 = 1.44921$$

$$K_{hc} = \sqrt{(1 + 1.6)} = 1.612$$

$$K_w = \frac{1}{(2 \times 5.47)^{2/5.44}} = 0.4169$$

Hence,

$$K_{sm} = \frac{1}{2\pi}\left[ln\left(\frac{5^2}{16 \times 1.6 \times 0.368} + \frac{(5 + 2 \times 1.6)^2}{8 \times 5 \times 0.368} - \frac{1.6}{4 \times 0.368}\right) + \frac{0.4169}{1.612} ln\left(\frac{8}{\pi(2 \times 1.597 - 1)}\right)\right] = 0.232$$

Therefore,

$$V_m = 3000 \times 1.44 \times 0.232\,{}^{0.2}\!/_{245} = 0.981V$$

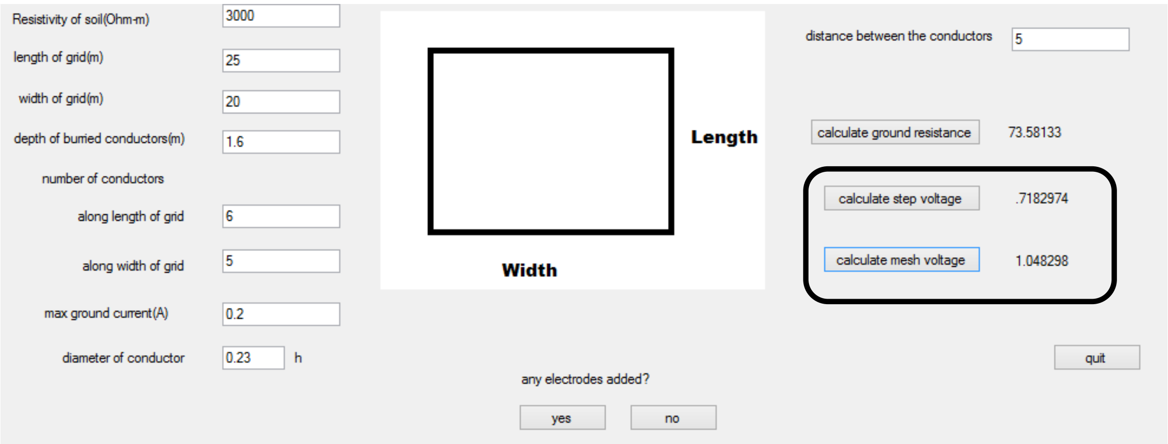
Now Step Voltage,

$$K_{ss} = \frac{1}{\pi}\left[\frac{1}{2 \times 1.6} + \frac{1}{5 + 1.6} + \frac{1}{5}\left(1 - 0.5^{6-2}\right)\right] = 0.2056$$

Therefore,

$$V_s = 3000 \times 0.2056 \times 1.44\,{}^{0.2}\!/_{245} = 0.72505V$$

From the software results for Step and Mesh Voltage comes out to be 0.71829 V and 1.04829 V respectively.



Resistivity of soil(Ohm-m) 3000

length of grid(m) 25

width of grid(m) 20

depth of burried conductors(m) 1.6

number of conductors

along length of grid 6

along width of grid 5

max ground current(A) 0.2

diameter of conductor 0.23 h

distance between the conductors 5

calculate ground resistance 73.58133

calculate step voltage .7182974

calculate mesh voltage 1.048298

Figure 4.12: Calculated results for step and mesh voltage for rectangular grid (IEEE Standard 80-2000)

Table 4.4: Comparison of calculated results theoretically and from software (Rectangular grid-IEEE Standard 80-2000)

	<u>Theoretically Calculated Value</u>	<u>Software Calculated Value</u>
Grounding Resistance of Grid	73.6 Ω	73.5813 Ω
Step Voltage	0.72505 V	0.71829 V
Mesh Voltage	0.981 V	1.04829 V

4.3.3 Triangular Grid

Data- Resistivity of soil = 2200 Ω-m

Depth of burial of grid conductors = 1.5 m

Side of the triangle (isosceles triangle here) = 20 m

Distance between the conductors = 5 m

Maximum Grid Current = 0.2 A

Diameter of the Grid conductor = 0.2 h

4.3.3.1 Ground Resistance Calculation

Solution- From the above data, using equation (13)

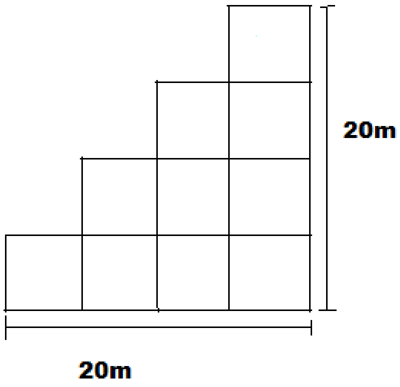


Figure 4.13: Rough idea about placement of the grid conductors in triangular shape

$L_t = 80 + 15 + 10 + 5 + 15 + 10 + 5 = 140\ m$

$L_p = 80m$

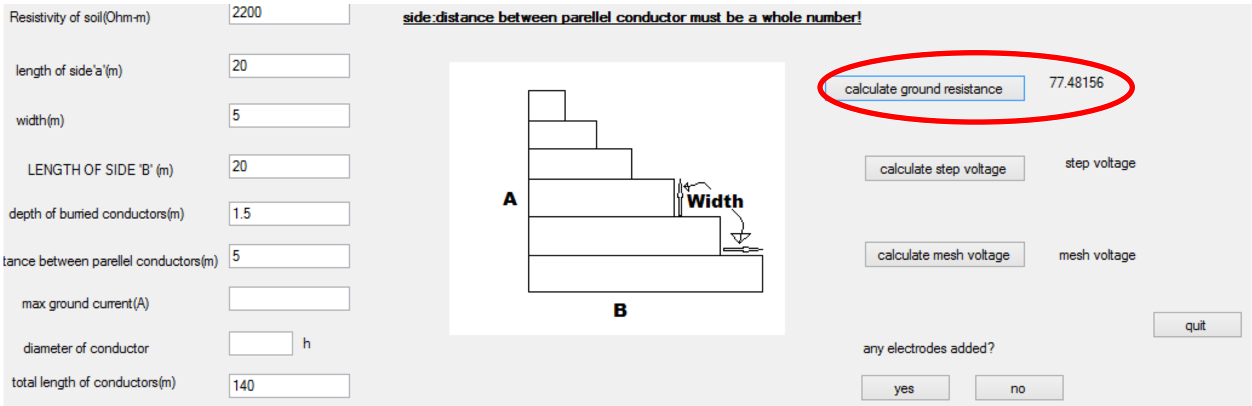
$A = [20 \times 5 + 15 \times 5 + 10 \times 5 + 5 \times 5] = 250m^2$

Therefore equation (13) [10] for calculating grounding resistance we get

$$R_g = 2200\left[\frac{1}{140} + \frac{1}{\sqrt{(20 \times 250)}}\left(1 + \frac{1}{1 + 1.5\sqrt{\frac{20}{250}}}\right)\right] \times 1.52\left[2l_n\left(80\sqrt{\frac{2}{250}} - 1\right)\right]\frac{\sqrt{250}}{80}$$

On solving we get

$$R_g = 77.3835\Omega$$



Resistivity of soil(Ohm-m) 2200
length of side'a'(m) 20
width(m) 5
LENGTH OF SIDE 'B' (m) 20
depth of burried conductors(m) 1.5
tance between parellel conductors(m) 5
max ground current(A)
diameter of conductor h
total length of conductors(m) 140

side:distance between parellel conductor must be a whole number!

calculate ground resistance 77.48156

Figure 4.14: Window showing the calculated value of ground resistance for triangular grid (IEEE Standard 80-2000)

From the software the calculated value comes out to be 77.48156Ω which is close to the above calculated value.

4.3.3.2 Step voltage and Mesh voltage Calculation

Using the Formulae in Section (10), (11) and (14) [10]

$$p = 2 \times \frac{140}{80} = 3.5$$

$$q = \sqrt{80/4 \times \sqrt{250}} = 1.124$$

$$r = \left[\frac{20 \times 20}{250}\right]^{\frac{0.7 \times 250}{20 \times 20}} = 1.228$$

$$s = 1$$

Hence $n = 4.83095$

$K_{hc} = \sqrt{1+1.5}$ =1.5811

$$K_g = 0.644 + 0.148 \times 4.8309 = 1.35898$$

$$K_w = 0.391017$$

$$K_{ss} = \frac{1}{\pi}\left[\frac{1}{3} + \frac{1}{6.5} + \frac{1}{5}(1 - 0.5^{4.830957-2})\right] = 0.209789$$

$$K_{sm} = \frac{1}{2\pi}\left[ln\left(\frac{25}{16} + \frac{(5+3)^2}{8 \times 5 \times 0.3} - \frac{1.5}{4 \times 0.3}\right) + \frac{0.391017}{1.5811} ln\left(\frac{8}{\pi(8.6619)}\right)\right] = 0.2736$$

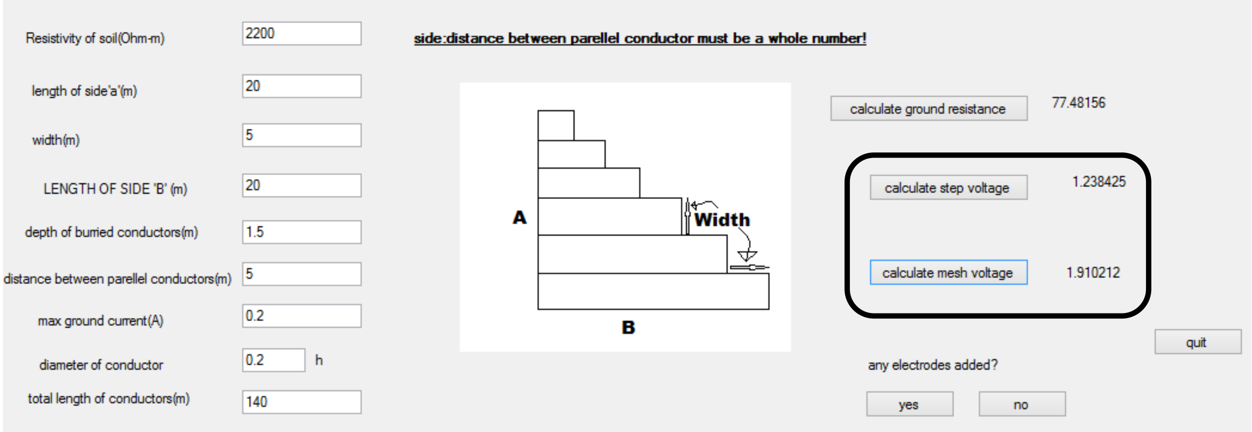
Therefore,

$$V_m = 2200 \times 0.2736 \times 1.35898 \times \frac{0.2}{140} = 1.8985V$$

Similarly,

$$V_s = 2200 \times 0.2097 \times 1.3598 \times \frac{0.2}{140} = 1.1902V$$

From the Software Calculated values of step and mesh voltage comes out to be 1.2384 V and 1.9102 V respectively.



Resistivity of soil(Ohm-m) 2200
length of side'a'(m) 20
width(m) 5
LENGTH OF SIDE 'B' (m) 20
depth of burried conductors(m) 1.5
distance between parellel conductors(m) 5
max ground current(A) 0.2
diameter of conductor 0.2 h
total length of conductors(m) 140

side:distance between parellel conductor must be a whole number!

calculate ground resistance 77.48156
calculate step voltage 1.238425
calculate mesh voltage 1.910212

Figure 4.15: Calculated result for step and mesh voltages for a triangular grid (IEEE Standard 80-2000)

Table 4.5: Comparison of calculated results theoretically and from software (triangular grid-IEEE Standard 80-2000)

	Theoretically Calculated Value	Software Calculated Value
Grounding Resistance of Grid	77.3835 Ω	77.48156 Ω
Step Voltage	1.1902 V	1.2384 V
Mesh Voltage	1.8985 V	1.9102 V

4.3.4 L-shaped Grid

Data- resistivity of the soil = 1800 Ω-m

Depth of burial of conductors = 1.3 m

Diameter of the grid Conductors = 0.2 h

Maximum current in the grid = 0.15 A

Distance between the grid conductors = 4 m

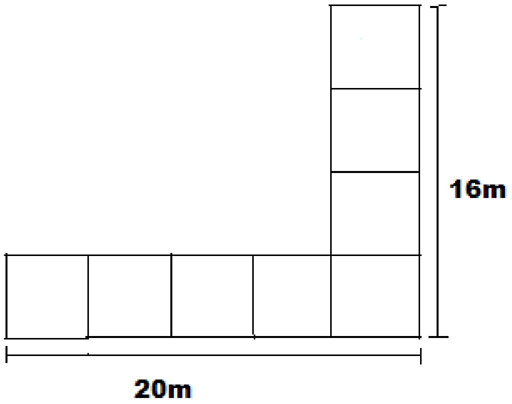


Figure 4.16: Rough Layout of the given L-shaped grid conductors

4.3.4.1 Ground Resistance Calculation

$$L_t = 100\ m$$

$$A = (20 \times 4) + (12 \times 4) = 128\, m^2$$

$$L_p = 20 + 16 + 12 + 16 + 8 = 72m$$

Therefore, calculating Ground Resistance using the formula given by equation (13) [10]-

$$R_g = 1800 \left[\frac{1}{100} + \frac{1}{\sqrt{(20 \times 128)}} \left(1 + \frac{1}{1 + 1.3\sqrt{\frac{20}{128}}} \right) \right] \times 1.52 \left[2l_n \left(72\sqrt{\frac{2}{128}} - 1 \right) \right] \frac{\sqrt{128}}{72}$$

$$= 75.504\ \Omega$$

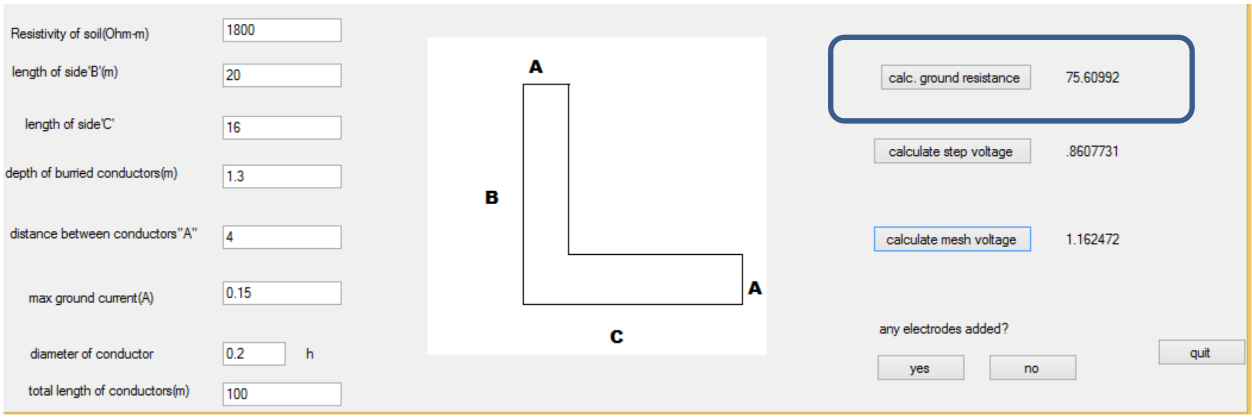

Resistivity of soil(Ohm-m) 1800
length of side'B'(m) 20
length of side'C' 16
depth of burried conductors(m) 1.3
distance between conductors"A" 4
max ground current(A) 0.15
diameter of conductor 0.2 h
total length of conductors(m) 100
calc. ground resistance 75.60992
calculate step voltage .8607731
calculate mesh voltage 1.162472
any electrodes added?

Figure 4.17: Calculated value of ground resistance for L-shaped grid (IEEE Standard 80-2000)

The calculated value comes out to be 75.6099 Ω from the software which is nearer to the above calculated value.

4.3.4.2 Step and Mesh Voltage Calculation

Using the Formulae in equation (11), (12) and (14) [10]

$$p = 2 \times \frac{100}{72} = 2.77$$

$$q = \sqrt{72/4 \times \sqrt{128}} = 1.2613$$

$$r = \left[\frac{16 \times 20}{128}\right]^{\frac{0.7 \times 128}{20 \times 16}} = 1.2924 \quad ; s = 1$$

Hence $n = 4.5153$

$$K_{hc} = 1.516$$

$$K_g = 0.644 + 0.148 \times 4.5153 = 1.3122$$

$$K_w = 0.3772$$

$$K_{ss} = \frac{1}{\pi}\left[\frac{1}{5.3} + \frac{1}{2.6} + \frac{1}{4}\left(1 - 0.5^{2.5153-2}\right)\right] = 0.248$$

$$K_{sm} = \frac{1}{2\pi}\left[ln\left(\frac{16}{16 \times 1.3 \times 0.26} + \frac{(4+2.6)^2}{8 \times 4 \times 0.26} - \frac{1.3}{4 \times 0.26}\right) + \frac{0.3772}{1.5165} ln\left(\frac{8}{\pi(8.0306)}\right)\right]$$
$$= 0.2629$$

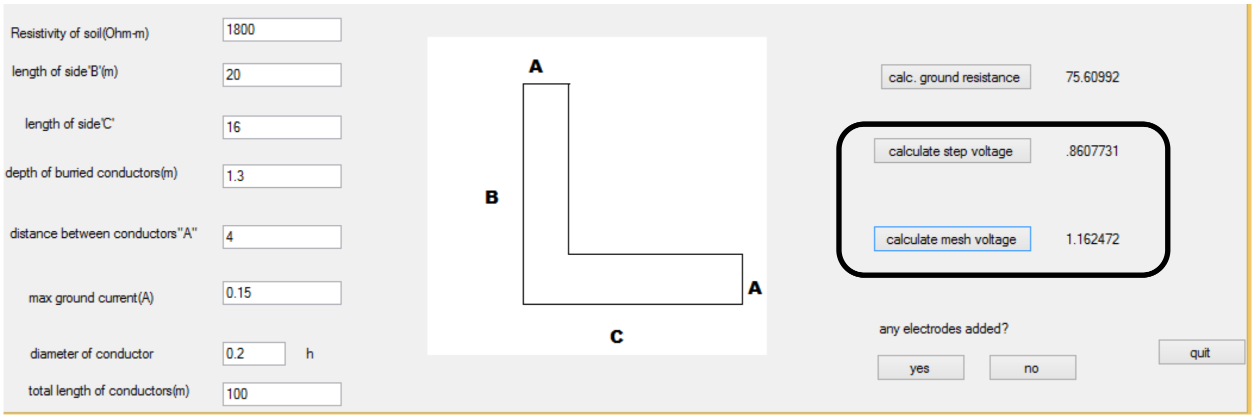
Therefore,

$$V_m = 1800 \times 0.2629 \times 1.3122 \times 0.15/100 = 1.1852V$$

Similarly,

$$V_s = 1800 \times 0.248 \times 1.3122 \times \frac{0.15}{100} = 0.8611V$$

Also, calculated values from the software of step and mesh voltage comes out to be 0.86077 V and 1.162472 V.



Resistivity of soil(Ohm-m) 1800
length of side'B'(m) 20
length of side'C' 16
depth of burried conductors(m) 1.3
distance between conductors"A" 4
max ground current(A) 0.15
diameter of conductor 0.2 h
total length of conductors(m) 100

calc. ground resistance 75.60992
calculate step voltage .8607731
calculate mesh voltage 1.162472

any electrodes added?

Figure 4.18: Calculated result for the value of step and mesh voltages For a L-shaped grid (IEEE Standard 80-2000)

Table 4.6: Comparison of calculated results theoretically and from software (L-shaped grid-IEEE Standard 80-2000)

	Theoretically Calculated Value	Software Calculated Value
Grounding Resistance of Grid	75.504 Ω	75.60992 Ω
Step Voltage	0.8611 V	0.8607 V
Mesh Voltage	1.1852 V	1.162472 V

4.3.5 T-Shaped Grid

Data- Resistivity of the soil = 2000Ω

Depth of burial of Grid Conductors =1.4 m

Diameter of the Grid Conductors = 0.23 h

Maximum grid current = 150 mA

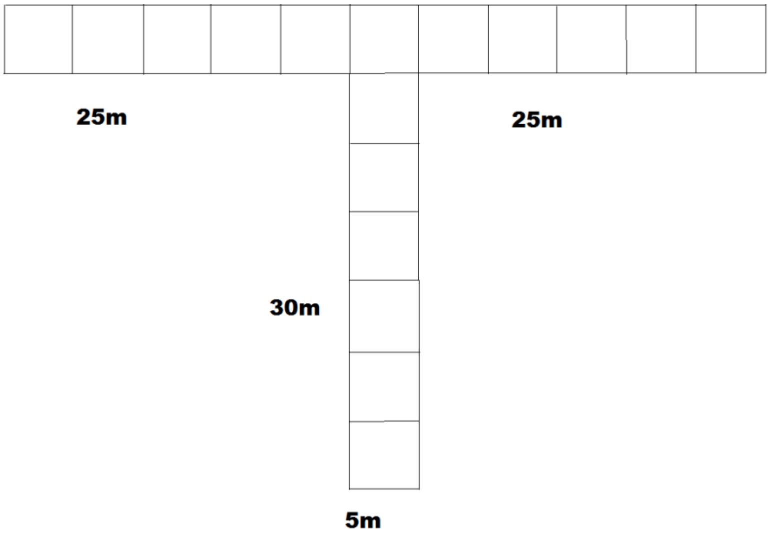


Figure 4.19: Rough sketch of T shape grid conductors

4.3.5.1 Ground Resistance Calculation

From the Data and using equation (13) [10]

$$A = (5 \times 55) + (5 \times 30) = 425m^2$$

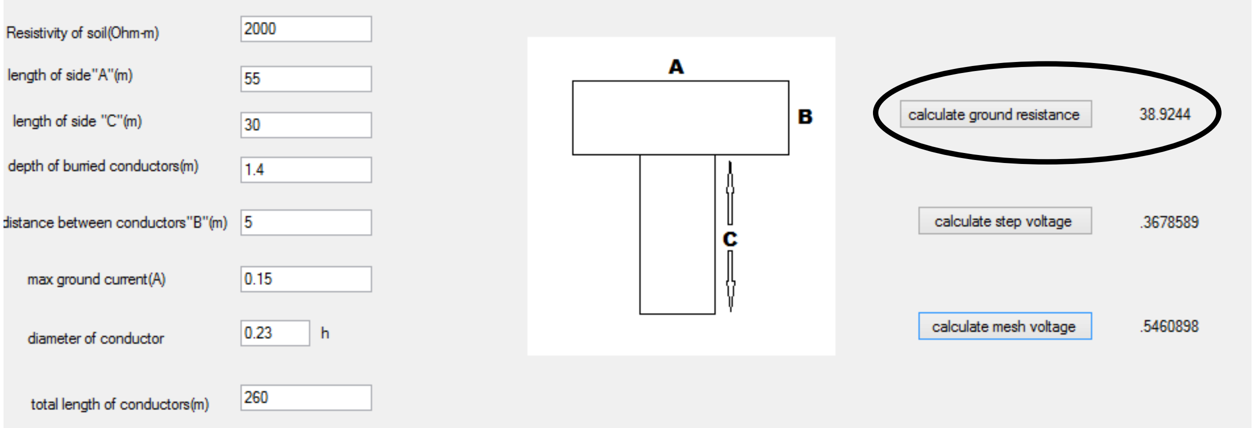
$$L_t = 260m$$

$$L_p = 180m$$

$$R_g = 2000\left[1/260 + \frac{1}{\sqrt{(20 \times 425)}}\left(1 + \frac{1}{1 + 1.4\sqrt{\frac{20}{425}}}\right)\right] \times 1.52\left[2l_n\left(180\sqrt{\frac{2}{425}} - 1\right)\right]\frac{\sqrt{425}}{180}$$

$$= 38.9238\Omega$$

From software calculated value is 38.9244Ω which is similar to the above calculated value.



Resistivity of soil(Ohm-m) 2000

length of side"A"(m) 55

length of side "C"(m) 30

depth of burried conductors(m) 1.4

distance between conductors"B"(m) 5

max ground current(A) 0.15

diameter of conductor 0.23 h

total length of conductors(m) 260

calculate ground resistance 38.9244

calculate step voltage .3678589

calculate mesh voltage .5460898

Figure 4.20: Calculated result of grounding resistance for T shaped grid (IEEE Standard 80-2000)

4.3.5.2 Step and Mesh Voltage Calculation

Using equations (11), (12) and (14) [10]

$$p = 2 \times \frac{260}{180} = 2.88\,;\, q = \sqrt{\frac{180}{4\sqrt{425}}} = 1.4774$$

$$r = [(55 \times 35)/425]^{\frac{0.7 \times 425}{35 \times 55}} = 1.26295\ ;\ s = \frac{55.22}{\sqrt{55^2 + 35^2}} = 0.847$$

Hence, $n = 4.5642$

$$K_g = 0.644 + 0.148 \times 4.5642 = 1.3195$$

$$K_{hc} = 1.54919$$

$$K_w = 0.37945$$

Now,

$$K_{sm} = \frac{1}{2\pi}\left[ln\left(\frac{5^2}{16 \times 1.4 \times 1.4 \times 0.23} + \frac{(5 + 2 \times 0.23)^2}{8 \times 5 \times 0.23 \times 1.4} - \frac{1.4}{4 \times 0.23 \times 1.4}\right) + \frac{0.37945}{1.54919} ln\left(\frac{8}{\pi(2 \times 4.5642 - 1)}\right)\right] = 0.26676$$

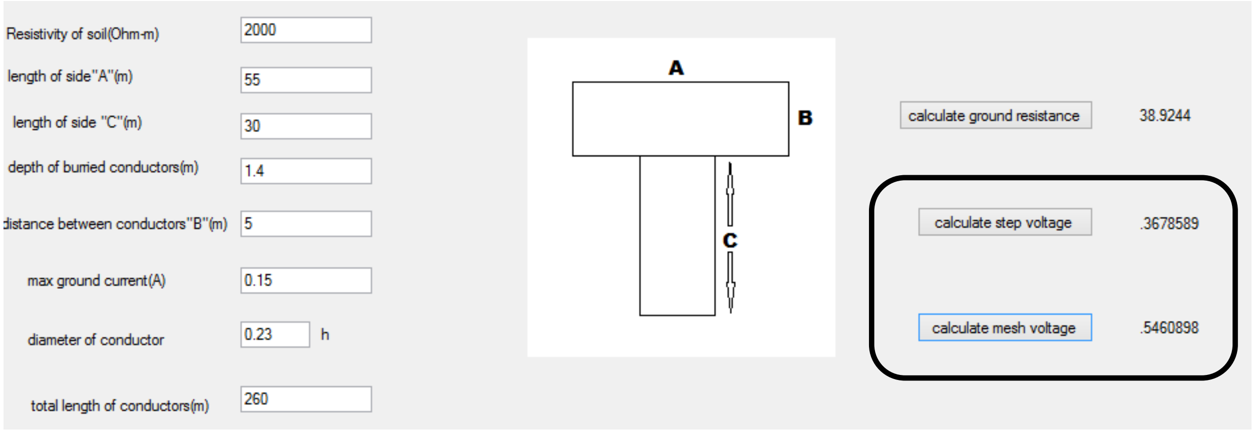
Similarly

$$K_{ss} = \frac{1}{\pi}\left[\frac{1}{2 \times 1.4} + \frac{1}{5 + 1.4} + \frac{1}{5(1 - 0.5^{4.5642-2})}\right] = 0.21642$$

$$V_m = 2000 \times 0.26676 \times 1.319\ {}^{0.15}\!/_{260} = 0.554V$$

$$V_s = 2000 \times 0.21642 \times 1.319\ {}^{0.15}\!/_{260} = 0.321V$$

From software the calculated results for step and mesh voltage come out to be 0.367 V and 0.54608 V respectively.



Resistivity of soil(Ohm-m) 2000
length of side"A"(m) 55
length of side "C"(m) 30
depth of burried conductors(m) 1.4
distance between conductors"B"(m) 5
max ground current(A) 0.15
diameter of conductor 0.23
total length of conductors(m) 260

38.9244
.3678589
.5460898

Figure 4.21: Calculated values of step and mesh voltage for T-shaped grid (IEEE Standard 80-2000)

Table 4.7: Comparison of calculated results theoretically and from software (T-shaped grid-IEEE Standard 80-2000)

	Theoretically Calculated Value	Software Calculated Value
Grounding Resistance of Grid	38.9238 Ω	38.9244 Ω
Step Voltage	0.321 V	0.3678 V
Mesh Voltage	0.554 V	0.54608 V

4.4 Grounding Resistance Calculation considering the earth rod and discussing the effect of adding earth rod.

Here we will be employing Schwarz's Equations. The limitation of these equations is that they give accurate results only for square and rectangular grids with maximum of length to width ratio 8:1 only.

4.4.1 Square Grid

Data- Resistivity of the soil =2200Ωm

Side of square= 20 m

Depth of burial of grid conductors = 2 m

Total length of conductors = 200 m

Distance between the conductors = 5 m

Length of ground rod = 4 m

Radius of the rod = 0.05 m

Number of ground rods = 6

Calculation – Using the equation (22), (23) and (24) [10]

$$A = 20 \times 20 = 400\ m^2$$

$$K_1 = -0.05 + 1.2 = 1.15$$

$$K_2 = 0.1 + 4.68 = 4.78$$

$$R_a = \frac{2200}{\pi \times 200}\left[ln\left(\frac{2 \times 200}{3.872}\right) + \frac{1.15 \times 200}{20} - 4.78\right] = 39.786\Omega$$

Next

$$R_b = \frac{2200}{2\pi \times 6 \times 4}\left[ln\left(\frac{4 \times 4}{0.05}\right) - 1 + \frac{2 \times 1.15 \times 4}{20}\left(\sqrt{6} - 1\right)^2\right] = 83.70469\ \Omega$$

Mutual resistance,

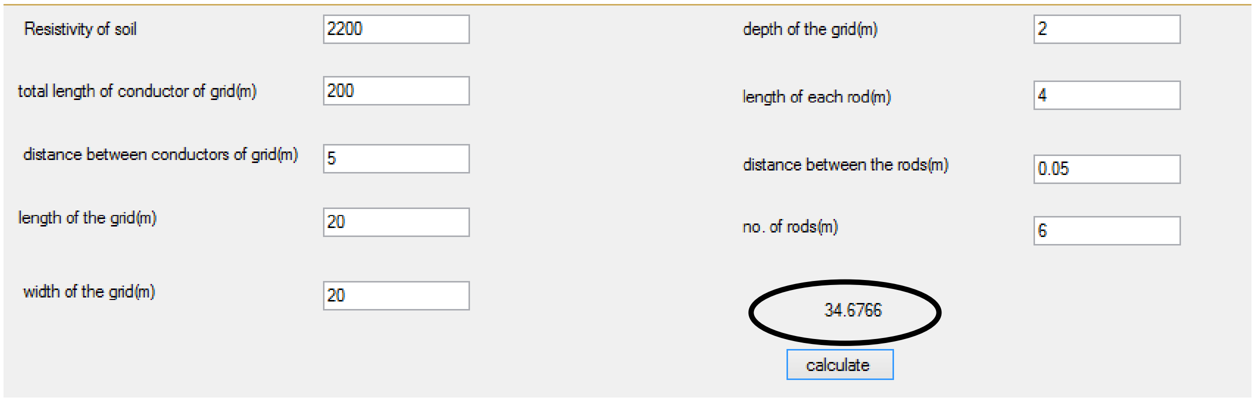
$$R_p = \frac{2200}{\pi \times 200}\left[ln\left(\frac{2 \times 200}{4}\right) + \frac{1.15 \times 200}{20} - 4.78 + 1\right] = 43.17669\Omega$$

Hence now the total resistance offered by the grid with earth rods is given by-

$$R_g = \frac{39.786 \times 83.70469 - (43.176)^2}{39.786 + 83.70469 - 2 \times 43.176} = 36.47656\ \Omega$$

Hence the calculated value from the above procedure of the grounding resistance = 34.47656 Ω

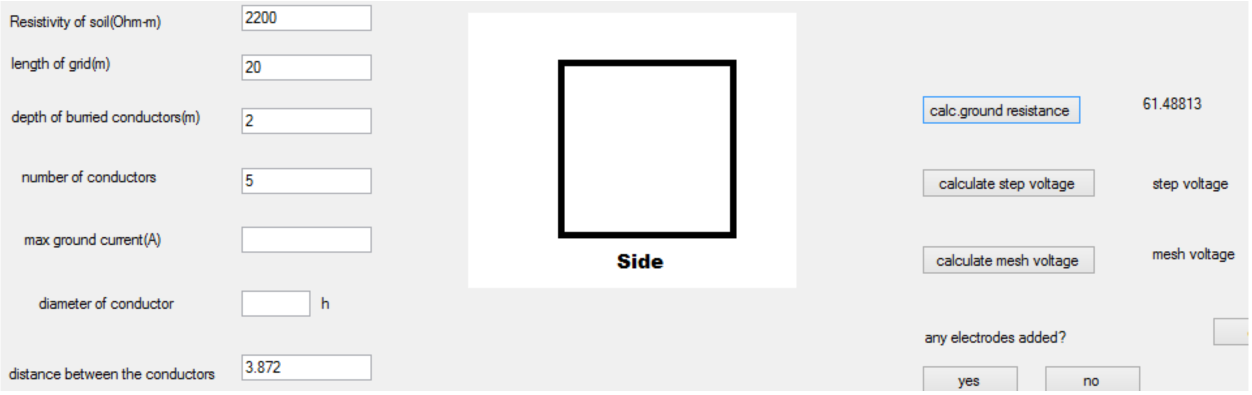
Let us now see the calculated value from the software of the resistance offered by the grid (with earth rods).Here it comes out to be 34.6766 Ω which is near to the manual calculated value.



Resistivity of soil	2200	depth of the grid(m)	2
total length of conductor of grid(m)	200	length of each rod(m)	4
distance between conductors of grid(m)	5	distance between the rods(m)	0.05
length of the grid(m)	20	no. of rods(m)	6
width of the grid(m)	20		34.6766

Figure 4.22: Result of calculated value of ground resistance with 6 earth rods

Comparing the above value with the value obtained without any earth rods,



Resistivity of soil(Ohm-m) 2200
length of grid(m) 20
depth of burried conductors(m) 2
number of conductors 5
max ground current(A)
diameter of conductor h
distance between the conductors 3.872
calc.ground resistance 61.48813

Figure 4.23: Value of ground resistance of a square grid without considering any earth rod

Hence we conclude that ground resistance value gets lowered when earth rods are used in the grid.

Let us now consider different cases by changing no. of earth rods.

Table 4.8: Influence of adding earth rods to the ground resistance of a square grid

Number of Earth Rods	Value of Ground Resistance(Ω)
4	64.66
5	46.45
6	34.676
7	26.4977

From the above observations we can plot a graph to study the variation of no. of earthing rods.

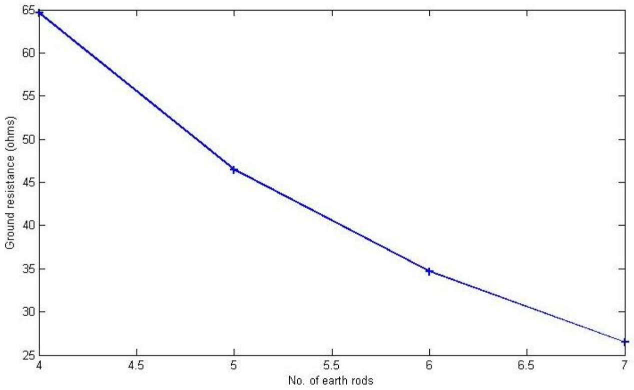


Figure 4.24: Influence of number of earth rods on ground resistance for square shaped grid

The above plot explains that with the increase in no. of earth rods the grounding resistance decreases hence improving the working of the grounding grid.

4.4.2 Rectangular Grid

Data-Resistivity of the soil = 1100 Ω-m

Length of the Grid=25 m

Width of the grid = 20 m

Depth of burial of grid conductors = 2.236 m

Spacing between the grid conductors = 5 m

Length of earth rod = 4 m

Radius of the rod = 0.05 m

Number of earth rods = 6

Solution- From the above data

$A = 20 \times 25 = 500m^2$

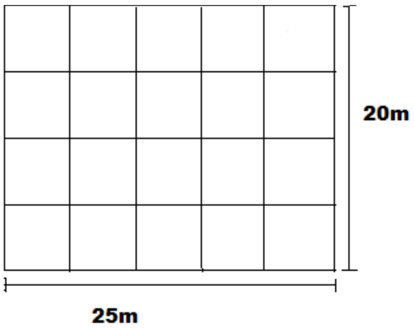


Figure 4.25: Rough layout of the rectangular grid showing the conductors

Hence $\sqrt{A}$ =$10\sqrt{5}m$

$a' = \sqrt{5 \times 2 \times 2.236} = 4.7286\ m$

$x = \frac{length}{width} = \frac{25}{20} = 1.25$

$$K_1 = -0.05 \times 1.25 + .20 = 1.1375$$

$$K_2 = 0.10 \times 1.25 + 4.68 = 6.055$$

$$R_a = \frac{1100}{\pi\times245}\left[ln\left(\frac{2\times245}{4.7286}\right)+\frac{1.1375\times245}{10\sqrt{5}}-6.055\right] = 15.7987\Omega$$

Next

$$R_b = \frac{1100}{2\pi\times6\times4}\left[ln\left(\frac{4\times4}{0.05}\right)-1+\frac{2\times1.1375\times4}{10\sqrt{5}}\left(\sqrt{6}-1\right)^2\right] = 41.0409\ \Omega$$

Mutual resistance,

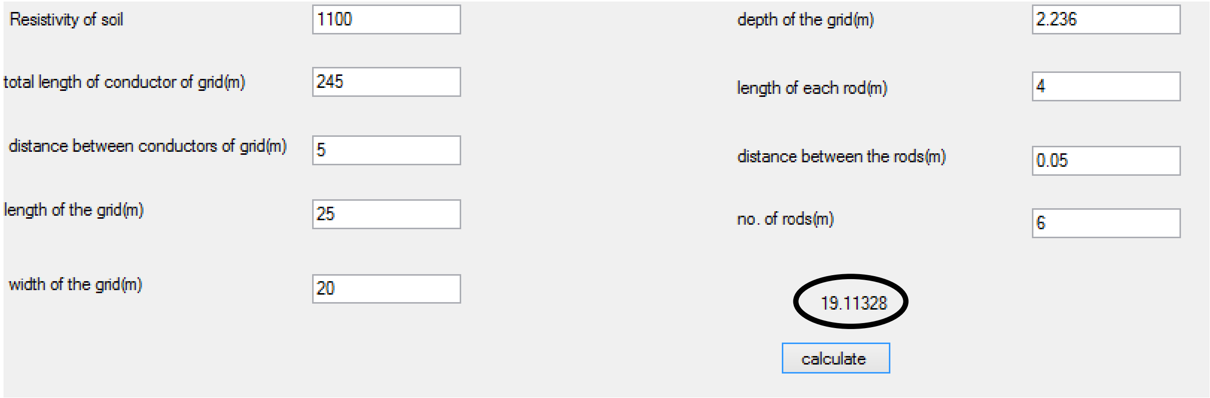
$$R_p = \frac{1100}{\pi\times245}\left[ln\left(\frac{2\times245}{4}\right)+\frac{1.375\times245}{10\sqrt{5}}-6.055+1\right] = 17.46785\Omega$$

Hence now the total resistance offered by the grid with earth rods is given by-

$$R_g = \frac{15.7987\times41.0409-(17.46785)^2}{15.7987+41.0409-2\times17.46785} = 18.67150522\ \Omega$$

Hence the calculated value from the above procedure of the grounding resistance = 15.67Ω

Let us now see the calculated value from the software of the resistance offered by the grid (with earth rods).Here it comes out to be 19.113 Ω which is near to the manual calculated value.

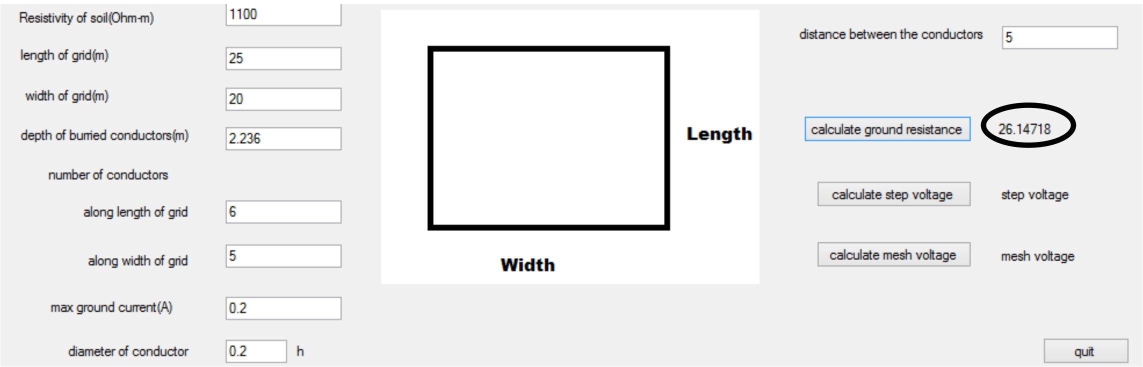


Resistivity of soil	1100	depth of the grid(m)	2.236
total length of conductor of grid(m)	245	length of each rod(m)	4
distance between conductors of grid(m)	5	distance between the rods(m)	0.05
length of the grid(m)	25	no. of rods(m)	6
width of the grid(m)	20		

19.11328

Figure 4.26: Window showing the calculated value of ground resistance with 6 earth rods

Now let us compare the result with the grounding resistance (without earth rod)



Resistivity of soil(Ohm-m) 1100
length of grid(m) 25
width of grid(m) 20
depth of burried conductors(m) 2.236
number of conductors
along length of grid 6
along width of grid 5
max ground current(A) 0.2
diameter of conductor 0.2 h
distance between the conductors 5
calculate ground resistance 26.14718

Figure 4.27: Window showing calculated value of ground resistance of the grid (without earth rods)

Hence it was found that with inclusion of earthing rods there is a significant decrease in the value of grounding resistance when compared to the value of resistance obtained without considering earthing rods. Let us now observe the influence of adding earth rods to the grounding resistance,

Table 4.9: Influence of adding earth rods to the ground resistance of rectangular grid

No. of earth rods	Ground Resistance(in Ω)
4	34.423
5	25.16742
6	19.15
7	14.9691

Plotting graph from the above data

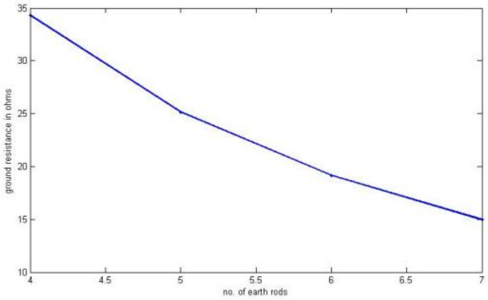


Figure 4.28: Influence of adding earth rods on the ground resistance for rectangular grid

From the above plot it is concluded that with the increase in no. of earth rods the value of grounding resistance decreases hence improves the working of ground grid.

CHAPTER- 5

CONCLUSIONS AND FUTURE SCOPE OF WORK

5.1 Conclusion

In this process of thesis work, simulation software was made in Visual Basic 2013 software. The user is allowed to input the data into the input window, and then the calculated results are displayed simultaneously in the window only. Later on these results were compared and verified with the manual calculations also.

Results obtained are accurate. Line graphs were also plotted based on the behavior of grounding grid resistance with the change in number of earth rods. These line graphs showed that with the increase in no. of earth rod the resistance offered by the grounding grid decreases hence improving the working of the grounding grid arrangements.

5.2 Future Scope

In this thesis work, single soil model has been discussed for the designing of substation grounding grid design. The designing parameters: Step Voltage, Mesh Voltage and Grounding Resistance all has been calculated taking into account the single layer model of the soil. During seasonal changes like in rainy season, freezing season the single soil model changes to a two layer soil model or multilayer soil model. Even when crushed rock layer is spread on the soil base of the substations, the single layer soil model changes to two layer soil model. Hence in future scope, this multilayer soil model and seasonal effects on grounding resistance can be included.

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