بسم الله الرحمن الرحيم

Sudan University of Science and Technology
College of Graduate Studies

Upgrading of Earthing System for Kilo-10 Substation

ترقية نظام التأريض لمحطة كيلو عشرة التحويلية

A Thesis Submitted in Partial Fulfillment of The Requirements for The Degree of Master of Science in Electrical Engineering(Power**)**

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الآيــة

بسم الله الرحمن الرحيم

إِنَّا أَنْزَلْنَاهُ فِي لَيْلَةِ الْقَدْرِ ١ وَمَا أَدْرَاكَ مَا
لَيْلَةُ الْقَدْرِ ٢ لَيْلَةُ الْقَدْرِ خَيْرٌ مِنْ أَلْفِ
شَهْرٍ ٣ تَنَزَّلُ الْمَلَائِكَةُ وَالرُّوحُ فِيهَا بِإِذْنِ
رَبِّهِمْ مِنْ كُلِّ أَمْرٍ ٤ سَلَامٌ هِيَ حَتَّى مَطْلَعِ
الْفَجْرِ ٥

صدق الله العظيم

سورة القدر - عدد آياتها (5)

Dedication

To Sheikh Sheriff Ibrahim Saleh Alhussaini

To my family

To my father Al- Sheikh Adam Abdurrahman Ibrahim

To my mother

To my brothers, especially Sheikh Moukhtar Adam Abdurrahman

And my friends, especially Abulfathi Ibrahim Saleh Alhussaini

Acknowledgments

In the name of Allah the Most Gracious and the most merciful all praises to Allah who created us and granted us everything and give us ability to complete this task, I wish to express my sincere gratitude to my supervisors **Dr. Mohammed Osman Hassan** for his support, valuable advice and guidance throughout my thesis work. Then I would like to express my deepest gratitude to all staff in the faculty of engineering department of power, teachers, workers, students and of course SUST for providing me all the facilities and for being a part of such wonderful environment. Also I would like to thank **Eng. Ahmed Altyib** for his team work cooperation and his available support in a number of ways during the design of the project.

Abstract

This project aims to Upgrading of Earthing System for Kilo-x Substation,

Components starting from the current transformers, voltage transformers, power transformers, lightning arresters, circuit breakers and bus-bar arrangement.

The project also provides ground grid system by using ETAP software program because it is easy to Upgrading and calculate the step potential, the touch potential, the total length of Earthing mat conductors, the size of Earthing mat conductors and the total number of Earthing rod in order to reach the best possible Upgrading of Earthing System for Kilo-x Substation. Kilo-X substation was implemented as the study case, from simulation results obtained, there is a difference between the existing ground design scheme and that obtained with ETAP.

المستخلص

يهدف هذا المشروع الى ترقية نظام التأريض لمحطة كيلو-عشرة التحويلية يأخذ المشروع في الاعتبارترقية لكل مكونات المحطة بدءا من محولات التيار، محولات الجهد، محولات القدرة، مانعات الصواعق، قواطع الدائرة، وقضبان التجميع.

تم ترقية نظام التأريض لمحطة كيلو-عشرة التحويلية باستخدام برنامج إيتاب لتحديد القياسات المطلوبة لحساب احتمال جهد الخطوة، وجهدالتلامس، وقياس حجم وعدد قضبان شبكة التأريض، من خلال نتائج المحاكاه لمحطة كيلو-عشرة التحويلية وجدت النتائج متطابقة مع القيم التصميمية الاساسية للمحطة ووجدت اختلافات طفيفة بين القيم التصميمية للمحطة قبل الترقية، وذالك من أجل الوصول إلى أفضل ترقية ممكنة لمحطة كيلو-عشرة التحويلية.

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List of Abbreviations

GPR	Ground potential rise
Em	Mesh Voltage
HV	High voltage
kA	Kilo amber
E_{touch}	maximum allowable touch potential
E_{step}	maximum allowable step potential
FEM	Finite element method
GGS	Ground Grid System

List of Symbols

Rg	substation ground resistance (Ω)
IG	maximum grid current (A)
LT	total burial length of conductors (m)
ρ	soil resistivity (Ω-m)
A	area of grid (m2)
h	depth of the grid (m)
Df	decrement factor for the duration of the fault
Ig	rms symmetrical grid current (A)
If	rms symmetrical grid fault current (A)
Sf	fault current division factor
LM	effective burial length (m)
Km	geometrical spacing factor
Ki	irregularity factor
D	spacing between parallel conductors (m)
n	geometric factor composed of factors *na*, *nb*, *nc*, and *nd*
Kii	corrective weighting factor adjusting for the effects of inner conductors on the corner mesh
d	diameter of grid conductors (m)
Kh	corrective weighting factor adjusting for

	the effects of grid depth
h0	grid reference depth (*h0* =1)
LC	total length of conductor in the horizontal grid (m)
Lp	peripheral length of grid (m)
Lr	total length of each ground rods (m)
LR	total length of all ground rods (m)
Dm	maximum distance between any two points on the grid (m)
Lx	maximum length of grid in the x-direction (m)
Ly	maximum length of grid in the y-direction (m)

CHAPTER ONE

INTRODUCTION

1.1 Background

Electrical power has become one of the strongest arms in the process of evolution and development especially in the modern engineering. Advanced countries have excellent electric power utilizations and consumptions, mainly in the areas of agriculture, leadership, communication and social services, etc...

The electric power substation, whether generating station or transmission and distribution, remains one of the most challenging and exciting fields of electric power engineering. Recent technological developments have had tremendous impact on all aspects of substation design and operation.

1.2 Objectives

(1) Upgrading grid system of kilo-x substation.

(2) To investigate electrical distribution substation.

1.3 Statement of problem

Power system has many problems such as the substation faults on the system. These abnormal conditions can cause over voltages that may result in equipment flashover or insulation failure. And also designing a proper substation grounding system is quite complicating. Many parameters affect its design. The system design of Sudanese Electricity Transmission Company Limited (Kilo-X) substation is very old, upgrading this system is necessary in order to reach the best possible design for electrical distribution substation.

1.4 Methodology/Approach

In this project the analysis and upgrading of substation grounding in electrical distribution substation would be studied using ETAP-soft ware program because it is make the upgrading of (Kilo-x) substation easier and more accurate and also calculating the Step Potential, the touch Potential, the total Length of Earthling Mat Conductor, the Size of Earthling Mat Conductor and the total Number of Earthing Rods.

1.5 Layout

This project consists of five chapters:

- Chapter one presents the general introduction to the electrical distribution substations.
- Chapter Two presents the literature review
- Chapter three presents Design and investigations of kilo-x substation.
- Chapter four represents the Simulation of kilo-X substation Earthing design and protection methods in general.
- Chapter Five Conclusion and Recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

This chapter gives a brief overview of relationship of substation to overall power system, the importance of adequate substation planning and the types of substation. An electrical substation is a part of an electricity generation, transmission and distribution system where voltage is transformed from high to low or in reverse using transformers. It also serves as a point of connection between various power systems elements such as transmission lines, transformers**,** generators and loads. It also receives electrical power from generating substation via incoming transmission lines and delivers electrical power via the outgoing transmission lines. To allow for flexibility in connecting the elements, circuit breakers are used as high power switches.

Electric power may flow through several substations between generating plant and consumer, and may be changed in voltage in several steps. There are different kinds of substation such as transmission substation, distribution substation, collector substation, switching substation and some other types of substation. The general functions of a substation may include:

(1) Voltage transformation.

(2) Connection point for transmission lines.

(3) Switchyard for network configuration.

(4) Monitoring point for control center.

(5) Protection of power lines and apparatus.

(6) Communication with other substations and regional control center.

Before attempting to study the electrical power distribution system for a building, we must understand the basic elements that make up the overall power distribution system. The overall layout of major components of a power distribution system is often the first step in the design process. At the beginning stage we have to develop a general idea about the nature of the distribution system. For example, in this early stage we will probably establish the location of the service entrance; inquire as to the service voltage (s) available from the local utility company, determine the location of electrical closets and vaults, determine approximate locations for distribution panel boards and switchboards, and so forth.

2.2 Relationship of Substation to Overall Power System

A substation is part of a system and not an entity to itself. Normally, a power system is designed so that the effects of an outage (caused by the failure of a single component such as a transformer, transmission line, or distribution line) will result in minimal interruption of service and affect the fewest customers possible. Failure of one component in a system often forces a greater than normal load to be carried by other components of the system.

When evaluating the switching arrangement for a substation, an engineer needs to be aware of the system configuration of which the substation will be a part. System contingency arrangements need to permit the outage of components in a substation for maintenance and unscheduled outages.

An example of an outage consideration for a substation would include a transmission switching station that operates with a simple main bus. An outage of the bus results in a complete interruption of power through the substation. The engineer will need to consider other equipment in the substation, such as a transfer bus or different multi-bus arrangement. The engineer should also evaluate the adjacent system to determine if the load can be diverted around the substation for outages to minimize the equipment that is installed in a substation, Figure (2.1) below shows substations relationship to overall power system.

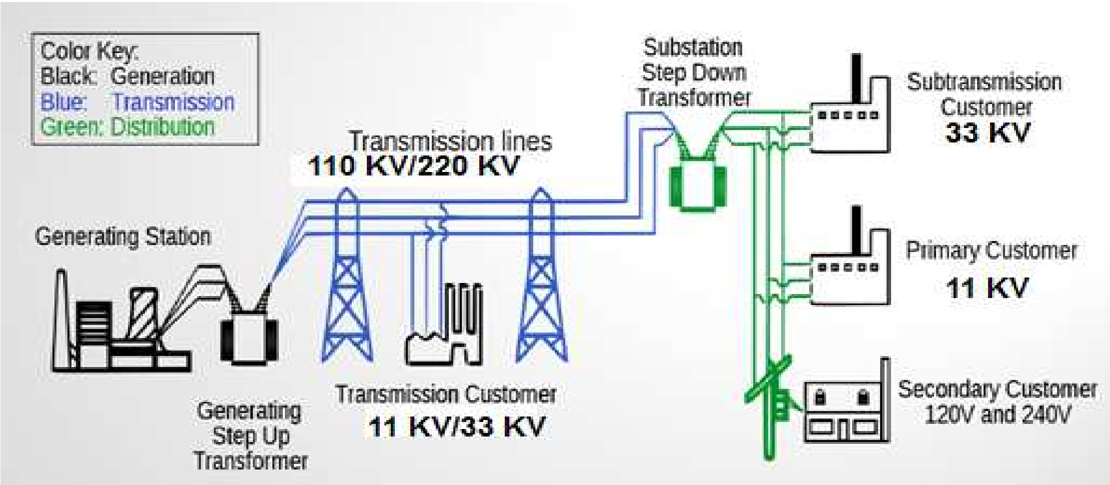


Figure 2.1: shows substations relationship to overall power system

2.3 Importance of Adequate Substation Planning

Substation planning considers the location, size, voltage, sources, loads, and ultimate function of a substation. If adequate planning is not followed, a substation may require unnecessary and costly modification.

The engineer’s detailed work requires use of valid requirements and criteria, appropriate guidelines, and engineer’s own expertise in order to provide construction drawings and associated documents appropriate for needed system improvements. The engineer’s ability to meld the diverse constraints into an acceptable design is essential.

During the design phase, the engineer should avoid personal preferences in solving technical problems that diverge from the use of nationally accepted standards, Rural Utilities Service (RUS) standards, or the concept of the cooperative’s standard designs. Adequate design provides direction for construction, procurement of material and equipment, and future maintenance requirements while taking into account environmental, safety, and reliability considerations.

2.4 Types of Substations

A typical substation may include the following equipment's: transformers, circuit breakers, disconnecting switches, station buses and insulators, reactors, capacitors, current and potential transformers, grounding system, lightning arrestors and spark gaps, wave traps, protective relays, station batteries, etc.

A substation or switching station functions as a connection and switching points for transmission lines, sub transmission feeders, generating units, and transformers. Depending upon the purpose, the substation may be classified into seven categories:

(a) Generating substations or step-up substations

Normally the generating voltages are limited and to be stepped up to the transmission voltage so that large amount of power can be transmitted economically over long. Each generating unit is connected to generating transformers to increase the secondary voltage up to transmission voltage levels.

(b) Grid substations

These substations are located in the intermediate points between the generating stations and load centers. The main purposes of these substations are to provide connection of low-voltage lines, some compensating devices, etc.

(c) Secondary substation

These substations are connected with the main grid substation with help of secondary transmission lines. The voltage at these substations is stepped down to the sub transmission voltage (primary distribution voltage). Some large power consumers are also connected to these substations.

(d) Distribution substation

These are made where the sub transmission voltage is to be stepped down to the supply voltage. These substations feed power to the actual consumers through distributors and service lines.

(e) Pecial purpose substations

Some special substation for bulk power and some industrial loads are set up. The examples of these are Traction substations and mining substations. Some mobile substations are also used for construction purposes, which are temporary as mobile.

(f) Switching substations

This switching substation is a combination of switching and controlling equipment arranged to provide circuit protection and system switching flexibility.

(g)Transmission substations

This transmission substation function as bulk power distribution centers and their importance in the system often justifies bus and switching arrangements that are much more elaborate than distribution substations. Depending upon the physical features, the substations can also classify into four types:

- **Outdoor type** Normally outdoor substations are used 33-kv voltage and above for cost and safety reason. The air clearances required are large. All equipment lie open in the air however control and monitoring is performed inside the control rooms.
- **Indoor type** The equipment of these substations lies in a room, are located in big cities. The operating voltages are normally 400 V and 11 kV.
- **Pole mounted or open kiosk type** These substations are mounted on the poles. These substations are very simple and cheap as no buildings for housing the equipment are required. However, these substations are of low capacity usually having up to 500-KVA transformer.
- **Underground type** These are used when the space is not available. Whole substation is made underground.

In the substation, there may be several transformers and several incoming and outgoing lines. The highest voltage rating of transformer and transmission lines are the rating of a substation. The substation design aims to achieve a high degree of continuity, maximum reliability and flexibility, to meet these objectives with the highest possible economy.

2.5 Bus-Bar Arrangement

Substation bus-bars are the most important part of the substation structure since they carry high amount of energy in a confined space and their failure would have very drastic repercussion on the power supply continuity. Therefore the bus system must be built to be electrically flexible and reliable enough to give continuous service. It must have adequate capacity to carry all loads and robust construction to withstand foreseeable abnormal electro-mechanical forces.

2.6 Substation Bus Schemes

The choice of the bus schemes or arrangements depends on the relative importance assigned to such items as safety, voltage level, simplicity of relaying, flexibility of operation, least cost, ease of maintenance, available ground area, location of connecting lines, ease of rearrangement, and provision of expansion.

2.6.1 Single Bus Scheme

It is commonly used scheme for a voltage of 33 kV or lower and has a simple design. It is used in small outdoor substations having relatively a few outgoing or incoming feeders and lines. The main advantage of single bus scheme is its low cost. Figure 2.2 shows a typical single bus scheme.

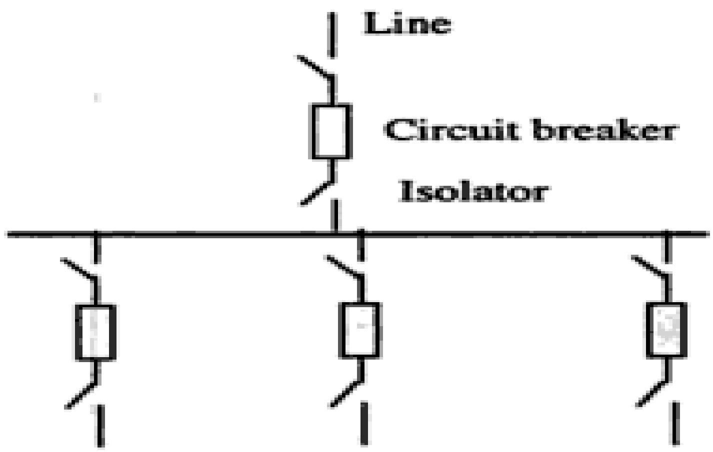


Figure 2.2: Single bus schemes.

In single bus-bar with bus sectionalized scheme, the bus bar is normally divided in two sections with help of a breaker and isolators as shown in Figure 2.3.

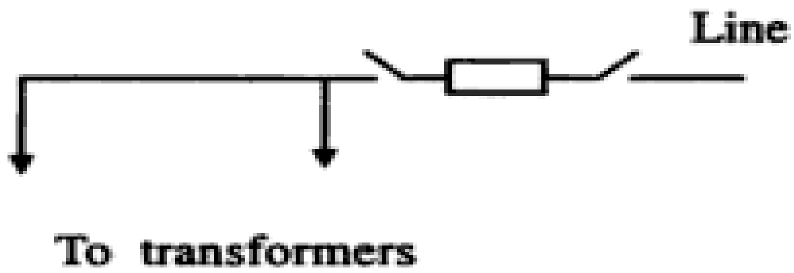


Figure 2.3: Terminal station schemes

The incoming or outgoing circuits are distributed evenly on the sections. When double feed is provided to any single load, it is preferred to have one circuit from each section where each section behaves as a separate bus bar. Differential protection can be used for tripping the faulty section. Figure 2.4 shows as single bus-bar with bus sectionalized scheme.

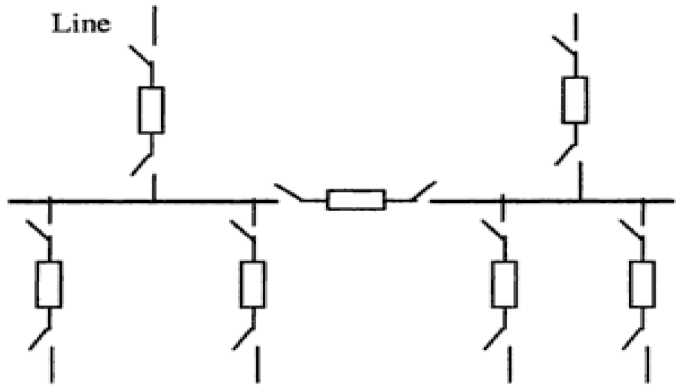


Figure 2.4: single bus scheme with bus sectionalize

2.6.2 Double Bus with Double Breaker

It is useful for most of the purposes where the loads and continuity of supply justify additional costs. Figure 2.5 shows as Double Bus with Double Breaker.

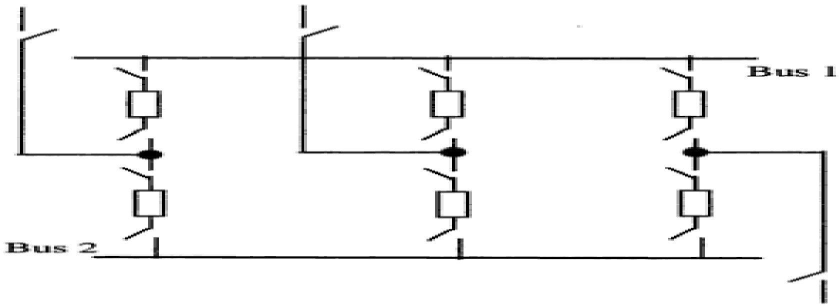


Figure 2.5: double bus double breaker scheme.

The main drawbacks of this scheme are that it is most expensive, and it may lose half the circuits for breaker failure if circuits are not connected to both buses.

2.6.3 Double Bus with Single Breaker

This scheme uses two main buses and connected with two disconnecting switches, as shown in Figure 2.6. In this scheme, a bus tie-circuit breaker (also called bus coupler) is used as it enables a load change over from one bus to another.

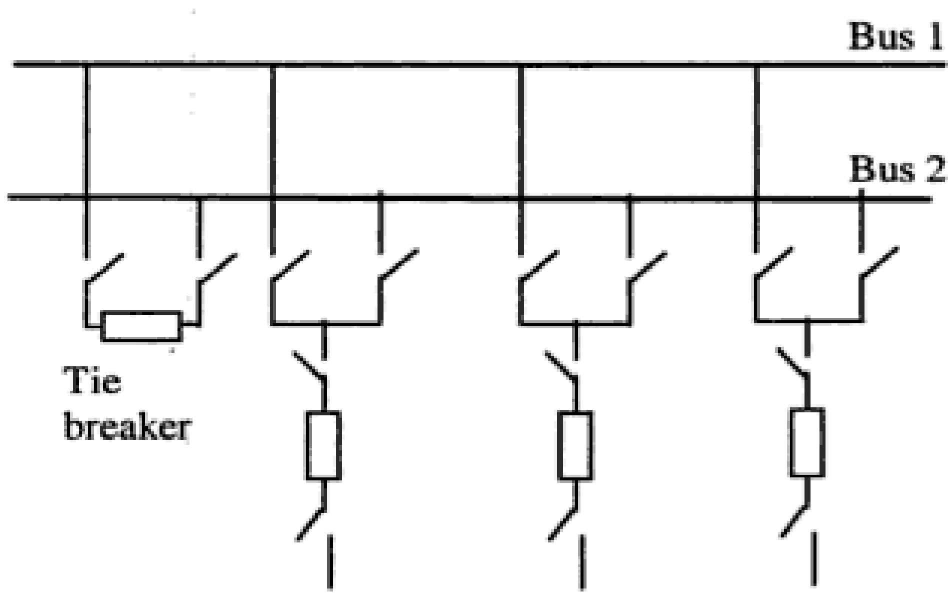


Figure 2.6: Double bus single breaker schemes.

2.6.4 Main and Transfer Bus

The main and transfer bus is used for mostly in distribution substations. The transfer bus is a standby for emergency use. In this scheme several circuit breakers are saved, however one extra breaker is provided to tie the main and transfer bus together when the need arises. The main advantages of this scheme are its low initial and ultimate cost. The main and transfer bus as shown in Figure 2.7.

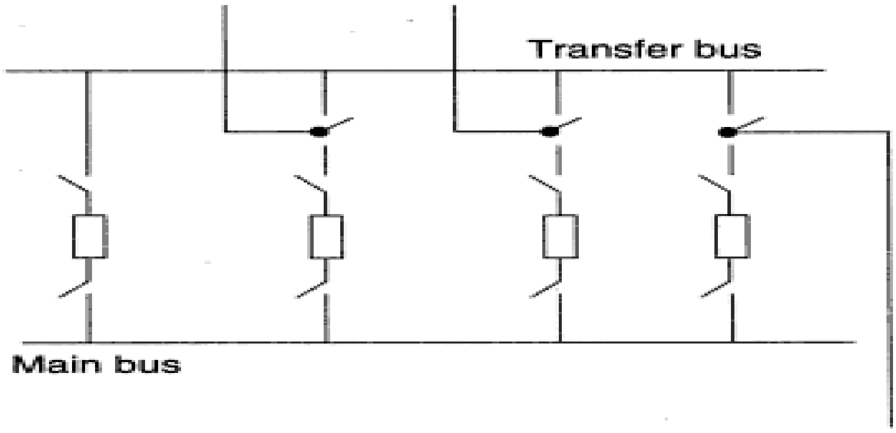


Figure 2.7: Main and transfer bus.

2.6.5 Ring Bus

This scheme is also known as mesh scheme. Figure 2.8 shows a ring bus scheme. It requires only one circuit breaker per circuit. Moreover, each outgoing circuit has two source of supply.

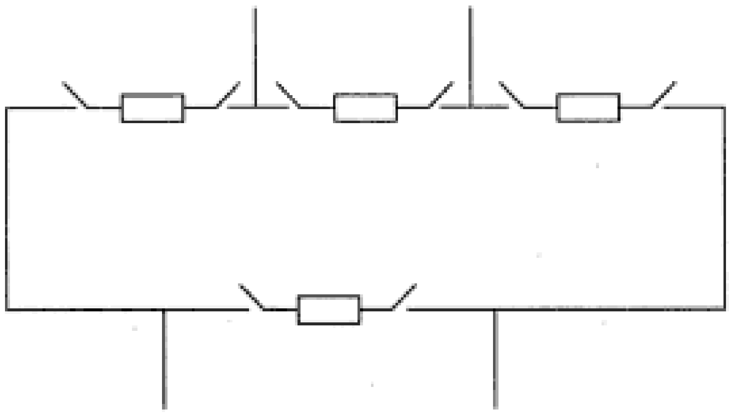


Figure 2.8: Ring bus or mesh scheme.

2.6.6 Breaker-and-a-Half with two Main Buses

Breaker-and-a-half scheme is an improvement of double-bus double-breaker scheme to save the cost of breakers. In this scheme, three breakers are used in series between the main buses, as shown in Figure 2.9. Under normal operating condition, all breakers are closed and the main buses are energized.

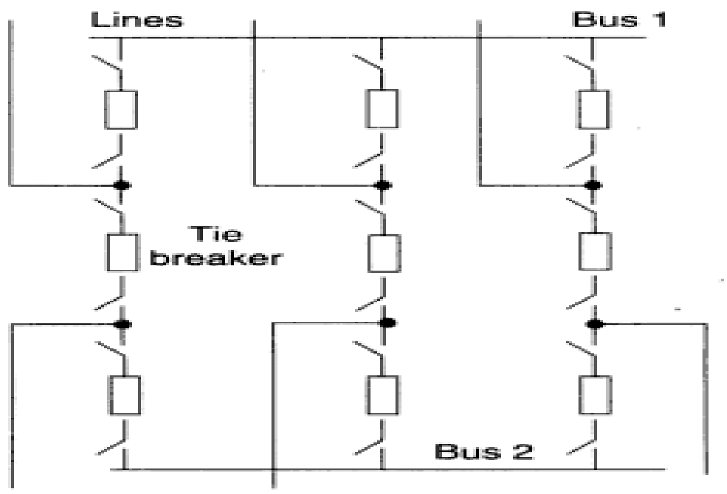


Figure 2.9: Breaker-and-a-half schemes.

2.6.7 Double Bus-bar with Bypass Isolators

This is a scheme similar to main and transfer bus, where transfer bus is also a main bus. The transfer from bus-1 to bus-2 is done through the isolators. As shown in Figure 2.10 any bus can act as main bus and second bus as transfer bus. The main advantage of this scheme is that any breaker can be taken out of service without interrupting the supply of any feeder. This scheme is very simple and economical.

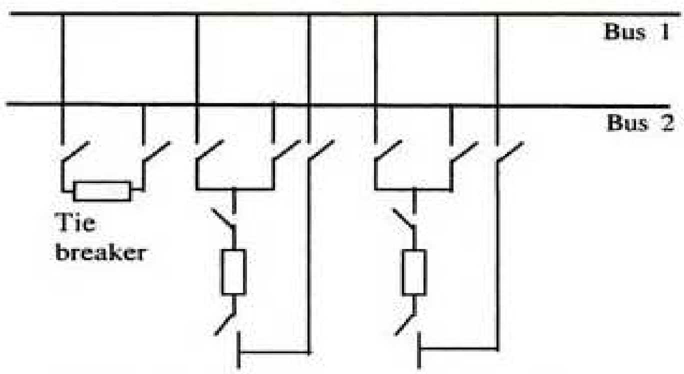


Figure 2.10: Double buses with bypass isolators.

2.7 Site Considerations

The most critical factors in the design of a substation are its location and sitting.

2.8 Substation Location

Location of distribution substation depends on the several technical factors such as voltage levels, voltage regulation considerations, sub transmission cost, substation costs, and the cost of primary feeders, mains and distribution transformers. The availability of land, public safeties, etc., is also important factor of non-technical. The most economical position of the substation is at the center of gravity of the loads to be supplied. As far as the industrial and commercial substations are concerned.

To select an idea location for a distribution substation, following rules should be observed:

(1) Locate the substation as much as close to the load center of it services area.

(2) Locate the substation such that proper voltage regulation can be obtained without taking extensive measures.

(3) Select the substation location such that it provides proper access for incoming sub transmission line and outgoing primary feeders and also capable to handle the future expansion.

(4) Select location should be in accordance with the electricity rule and land use regulation.

(5) The selected substation should help minimize the numbers affected by any service discontinuity.

2.9 Reliability Considerations

A prime objective in the operation of an electric power system is to provide reliable service within acceptable voltage limits. Cooperatives that design substations to operate within the voltage levels specified in this ANSI Standard should have reasonably reliable substations.

2.10 Operating Considerations

A substation may occasionally experience emergency operating conditions requiring equipment to perform under abnormal situations. Depending on the length of time, the provision of unusual current carrying capacity of some equipment or connections should always be considered and appropriately accounted for in the design.

2.11 Safety Considerations

It is paramount that substations be safe for the general public and for operating and maintenance personnel. Practical approaches include the employment and training of qualified personnel, appropriate working rules and procedures, proper design, and correct construction. The safe guarding of equipment also needs to be considered in substation design.

2.12 Maintenance Considerations

Substation design needs to allow maintenance to be accomplished with a minimum impact on a substation's operation. Allocation of adequate working space is necessary. In selecting equipment, consider the service intervals recommended by the manufacturers and past experience in using a particular manufacturer's equipment.

CHAPTER THREE

DESIGN AND INVESTIGATION OF KILO-X SUBSTATION

3.1 Backgrounds

Kilo-X located at east Khartoum was completed by the year 1978 under BBC; it is one of the largest power substations in the region of Soba and the eastern Khartoum in Sudan.

This substation has capacity of 220 KV and can step down to 110 KV using two input lines through the transmission line.

The input feeders of the transmission lines are namely:

(1) Giad (double circuit, 220 KV)

(2) Eid Babiker (double circuit, 220 KV)

All these feeders come into the substation with 220 KV (300 MVA).

The substation has another bus bar substation rated as 110 KV and the capacity of it is 135 MVA. This substation was completed by the year 2008 under Setco company the purpose of this substation was to step down the 220 KV/110KV to direct distribution to the 110 KV/33 KV/11 KV. This substation divided into four different areas namely:

(i) Farouk double circuit,

(ii) Bagar one circuit,

(iii) Local Market two circuit and

(iv) Kuku double circuit

These outgoing feeders' transmission lines are of 33 KV line.

The figure 3.1 below shows General view of Kilo-X Substation.

Figure 3.1: General view of Kilo-X Substation

The plant can be divided in itself into two parts:

3.1.1Inner section Indoor

the interior section includes all the equipment and protection devices that are inside the station or the building and contain the existing control devices, battery, and telecommunication device, in the control room and also there is a section includes special distribution operations (11KV).

3.1.2 Outer section Outdoor Switchyard

This includes equipment that is located inside a fence substation:

(i) Three Bus bar

(ii) Five Transformers (3 TR 220/110/11KV rated 100MVA, 2 TR 110/33/11KV rated 100MVA).

(iii) Bus post insulator and string insulators

(iv) Substation Equipment such as Circuit-breakers, Isolators, Earthing Switches, Surge Arresters, CTs, VTs, Neutral Grounding equipment.

(v) The substation has an Earthing system comprising ground mat, risers, auxiliary mat, Earthing strips, Earthing spikes & earth electrodes.

(vi) Overhead ground wire shielding against lightening strokes. Galvanized steel structures for towers, gantries, equipment supports.

(vii) The PLCC equipment including line trap, tuning unit, coupling capacitor, etc.

(viii) Control cables for protection and control

(ix) Power cables and Roads, Railway track, cable trenches and

(x) Station illumination system.

3.2 Preliminary Arrangements for the Distribution Electrical Substation

3.2.1 Select the substation site

The space of transformers substations different from one station to another, because of the space on the tension and the number of lines and associated equipment assembly rod and also have a relationship with equipment assistance vehicle in an area of the station and also with taking into account the costs and workingconditions.

3.2.2 The Conditions that satisfied the Selection of Kilo-X Substation

(i) Topographic and geological conditions reduce dust loads and increase settlement and concrete work rules.

(ii) The value of the quality of the soil resistance as possible is not greater than the station grounding resistors.

(iii) Provide the availability of water discharge for the station.

(iv) The air pollution is less as possible.

(v) It is far away from the main and branch roads and railways.

(vi) It is far away from the phone lines.

(vii) The possibility of expanding the plant in the future.

(Viii) Placed on land where there is no natural resources utilized.

(ix) No damage to agricultural land.

(x) Station located in an open area to facilitate the entry and exit of overhead lines to and from the station.

3.3 Earthing Calculation

From a proper design, safe substation grounding system, various safety parameters must be found such as the touch and step voltage levels. Each grounding system must be uniquely designed in order to have the mesh and step voltages below the tolerable touch and step voltages of the personnel that might be working at the site when a fault occurs.

Step 1: Soil Resistivity

The soil resistivity around the site was measured with a Wenner four-pin probe and found to be approximately 3000 Ω.m.

Step 2: Surface Layer Materials

A thin 100mm layer of blue metal (3,000 Ω.m) is proposed to be installed on the site. The surface layer derating factor is:

$$C_s = 1 - \frac{0.09\left(1 - \frac{\rho}{\rho_s}\right)}{2h_s + 0.09} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.1$$

$$= 1 - \frac{0.09\left(1 - \frac{300}{3000}\right)}{2x0.1 + 0.09} \quad = 0.7207$$

Step 3: Earthing Grid Resistance

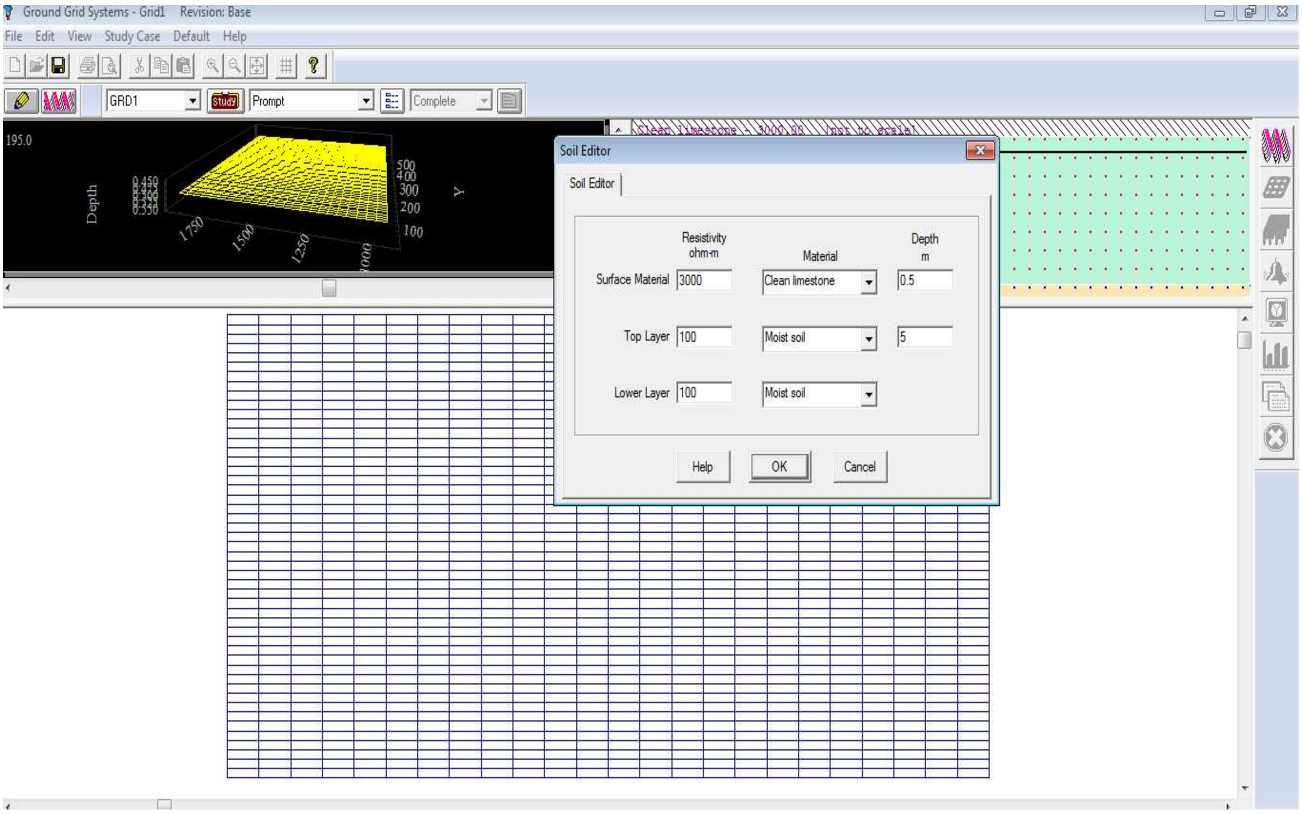


Figure 3.2: shows earthing grid resistance design etap

A rectangular Earthing grid (see figure 3.2) with the following parameters are actual value:

Length of 1000m and a width of 500m.

Using the simplified equation, the resistance of the Earthing grid with respect to remote earth is:

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1+h\sqrt{20/A}}\right)\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3.2$$

$$R_g = 300\left[\frac{1}{1000} + \frac{1}{\sqrt{20*4500}}\left(1 + \frac{1}{1+0.5\sqrt{20/4500}}\right)\right] \quad = 2.558\ \Omega$$

Step 4: Maximum Grid Current

The maximum single phase to earth fault at the HV winding of the transformer is 13.77 kA and that the current division factor is 1 (all the fault current flows back to remote earth).

The X/R ratio at the fault is approximately 15, the maximum fault duration 150ms and the system nominal frequency is 50Hz. The DC time offset is therefore:

$$T_A = \frac{X}{R} \cdot \frac{1}{2\pi f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3.3$$

$$= 15 \text{ x } \frac{1}{2\pi 50} = 0.04774$$

The decrement factor is then:

$$D_f = \sqrt{1+\frac{T_a}{t_f}\left(1-e^{\frac{-2t_f}{T_a}}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.4$$

$$= \sqrt{1+\frac{0.04774}{0.15}\left(1-e^{\frac{-2 \times 0.15}{0.04774}}\right)} \qquad = 1.1479$$

Finally, the maximum grid current is:

$$I_G = I_g D_f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.5$$

$$= 13.77 \text{ X } 1.147 = 15.79419 \text{ KA}$$

Step 5: Touch and Step Potential Criteria

Based on the average weight of the workers on the site, a body weight of 70kg is assumed for the maximum touch and step potential. A maximum fault clearing time of 150ms is also assumed.

The maximum allowable touch potential is:

$$E_{touch,70} = (1000 + 1.5C_s \;\; \rho_s)\frac{0.157}{\sqrt{t_s}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.6$$

From equation (1) given value of C_s = 0.727

$$= (1000 + 1.5 \text{ x } 0.727 \text{ x } 300)\frac{0.157}{\sqrt{0.15}} = 537.9 \text{ V}$$

The maximum allowable step potential is:

$E_{touch,70}$ = (1000 + 6C_s ρ_s) $\frac{0.157}{\sqrt{t_s}}$ 3.7

From equation (1) we find value of C_s = 0.727

= (1000 + 6 x 0.7207 x 300)$\frac{0.157}{\sqrt{0.15}}$ = 931.3 V

Step 6: Ground Potential Rise (GPR)

The maximum ground potential rise is:

GPR = I_G R_g 3.8

From equation (5) we find value of $I_{G,}$ then

GPR = 15.79419 KA x 0.062 = 979.24 V

The GPR far exceeds the maximum allowable touch and step potentials, and further analysis of mesh and step voltages need to be performed.

Step 7: Earthing Grid Design Verification

Mesh Voltage Calculation

The components of the geometric factor n_a, n_b, n_c and n_d for the rectangular grid are:

$n_b = \sqrt{\frac{L_p}{4\sqrt{A}}}$ 3.9

$$= \sqrt{\frac{280}{4\sqrt{4500}}} = 1.022$$

$n_{c} = n_{d} = 1$

Therefore the geometric factor n is:

$$n = n_a \times n_b \times n_c \times n_d \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3.10$$

$$= 6.357 \times 1.022 \times 1 \times 1 = 6.4939$$

The average spacing between parallel grid conductors D is:

$$D = \frac{1}{2}\left(\frac{W_g}{n_r - 1} + \frac{L_g}{n_{c-1}}\right) \qquad = \frac{1}{2}\left(\frac{500}{50-1} + \frac{1000}{24-1}\right) = 26.84 \ \ldots\ldots\ 3.11$$

Where W_g and $L_g$are the width and length of the grid respectively (e.g. 500m and 1000m)

n_r And $n_c$is the number of parallel rows and columns respectively

The geometric spacing factor K_m is:

$$K_m = \frac{1}{2\pi}\left(\ln\left[\frac{D^2}{16h \times d} + \frac{(D+2h)^2}{8D \times d} - \frac{h}{4d}\right] + \frac{K_{ii}}{K_h}\ln\left[\frac{8}{\pi(2n-1)}\right]\right) \ \ldots 3.12$$

$$K_m = \frac{1}{2\pi}\left(\ln\left[\frac{26.84^2}{16*0.5*0.01236} + \frac{(26.84+2*0.05)^2}{8*26.84*0.01236} - \frac{0.5}{4*0.01236}\right] + \frac{1}{1.26}\ln\left[\frac{8}{\pi(2*6.4939-1)}\right]\right)$$

$$= 0.9964$$

The irregularity factor K_i is:

K_i = 0.644 + 0.148n = 0.644 + 0.148 x 6.4939 = 1.605 ……….. 3.13

The effective buried length L_M is:

$$L_M = L_c + \left[1.55 + 1.22\left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right] L_R \quad \text{………………………} \; 3.14$$

$$890 + \left[1.55 + 1.22\left(\frac{66}{\sqrt{1000^2+500^2}}\right)\right]*66 \;= 997.05m$$

Finally, the maximum mesh voltage is:

$$E_m = \frac{\rho_s\, K_i\, I_G}{L_M} \quad \text{…………………………………………….} \; 3.15$$

From equation (5) we find value of I_G, then E_m:

$$= \frac{300x0.9964x1.605x15.79419}{997.05} = 7.5999 \text{ V}$$

Step Voltage Calculation

The geometric spacing factor K_s is:

$$K_s = \frac{1}{\pi}\left[\frac{1}{2h} + \frac{1}{D+h} + \frac{1}{D}\left(1 - 0.5^{n-2}\right)\right] \quad \text{……………………….. } 3.16$$

From equation (11) we find value of D then:

$$K_s = \frac{1}{\pi}\left[\frac{1}{2*0.6} + \frac{1}{26.84+0.6} + \frac{1}{26.84}(1 - 0.5^{6.4939-2})\right] = 0.288$$

The effective buried length L_s is:

$$L_S = 0.75L_c + 0.85L_R \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.17$$

= 0.75 x 890 + 0.85 x 66 = 723.6 m

Finally, the maximum allowable step voltage is:

$$E_s = \frac{\rho_S \; K_S \; K_i \; I_G}{L_S} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.18$$

From equation (5) and (17) we find value of $I_{G,}$ L_S then:

$$= \frac{300x0.288x1.605x3559}{723.6} = 682 \text{ V}$$

3.4 Investigate of Kilo-x substation

3.4.1 Elements of Kilo-x substation

3.4.1.2 Voltage transformer (VT) and Current transformer (CT)

Voltage transformers are used to step down the voltage for measurement, protection and control. Current transformers are used for Stepping down current for measurement, protection and control, as shown in fig (3.3).

Figure 3.3: Voltage transformer and Current transformer

3.4.2 Circuit Breaker

Circuit Breaker is used for Switching during normal and abnormal operating conditions. It is used to interrupt the short circuit currents, as shown in fig (3.4).

Figure 3.4: The Circuit Breaker

3.4.3 Lighting Arrestor

Lightning Arresters discharge the over voltage surges to ground and protect the equipment insulation from switching surges and lightning surges.

Surge arresters are generally connected between phase conductor and ground. The figure 3.5 below shows the Lightning Arresters.

Figure 3.5: Light Arrestor

3.4.4 Isolator Switch

Isolators are provided for isolation from live parts for the purpose of maintenance and disconnecting under no-load condition for safety, as shown in fig (3.6).

Figure 3.6: The Isolator Swit

3.4.5 Bus-bar Arangement

Various incoming and outgoing circuits are connected to bus bars. Bus bars receive power from incoming circuits and deliver power to outgoing circuits, as shown in fig (3.7)

Figure 3.7: the Bus bars Arrangment

3.4.6 Grounding Wire

It used to discharge the voltage on dead lines to earth, as shown in fig (3.8).

Figure 3.8: the grounding wire

3.4.7 Main Transformer

These are used in substation to step up or step down the voltage, as shown in fig (3.9).

Figure 3.9: The Main Transformer 220/110/11KV

CHAPTER FOUR

SIMULATION OF KILO-X SUBSTATION EARTHING DESIGN AND PROTECTION METHODS IN GENERAL

4.1 Substation Grounding Overview

Grounding is an important aspect of every substation. The function of a grounding system is:

(i) To ensure the safety of personnel and the public

(ii) To minimize hazard from transferred potential

(iii) To protect equipment,

(iv) To provide a discharge path for lightning strikes, and

(v) To provide a low resistance path to ground.

A good grounding system has a low resistance to remote ground to minimize the ground potential rise (GPR) [2, 4].

In order for a grounding design to be safe, it needs to provide a way to carry the electric currents into the ground under both normal and faulted conditions. Also, it must provide assurance that a person in the vicinity would not be endangered. Because there is no simple relation between the resistance of the grounding system and the maximum shock current a person can experience, a complete analysis must be done to consider many different aspects such as the location of the ground electrodes, soil characteristics, etc. [6].

4.2 Design of a Substation Grounding System

The substation ground grid design is based on the substation layout plan. The following points serve as guidelines to start a grounding grid design:

(a) The substation should surround the perimeter and take up as much area as possible to avoid high current concentrations. Using more area also reduces the resistance of the grounding grid.

(b) Typically conductors are laid in parallel lines. Where it is practical, the conductors are laid along the structures or rows of equipment to provide short ground connections.

(c) Ground rods may be installed at grid corners and junction points along the perimeter.

(d) The grid should extend over the entire substation and beyond the fence line [1-3].

(e) The ratio of the sides of the grid meshes is usually 1:1 to 1:3 [1, 4].

To get started on the preliminary design, the following steps can be taken:

(i) Draw the largest square, rectangular, triangular, T-shaped, or L-shaped grid that will fit on the layout drawing.

(ii) Place grid conductors to produce square meshes, approximately 6.1-12.2 m.

(iii) Set the grid height equal to 0.4572 m (18 inches).

(iv) Set thickness of the surface material to 0.1016 m (4 inches).

(v) Place ground rods around the perimeter.

4.3 Ground Potential Rise (GPR)

The maximum voltage that a ground grid may attain relative to a distant grounding point assumed to be at the potential of remote ground. The GPR is equal to the product of the ground current and the equivalent impedance of the grounding system.

4.4 Mesh Voltage

The Mesh Voltage is maximum touch voltage within a mesh of a ground grid.

4.5 Grid Connections

Typically different sized conductors are used in linking the substation to the grounding grid. Any above ground conductive material which could possibly become energized such as a metal structures, machine frames, and transformer tanks or any metal parts that could have a different potential from others should be tied together by the grounding grid [4]. The grid connection is shown in figure 4.1.

Usually the grid connections are securely welded together to prevent any failure during high fault current.

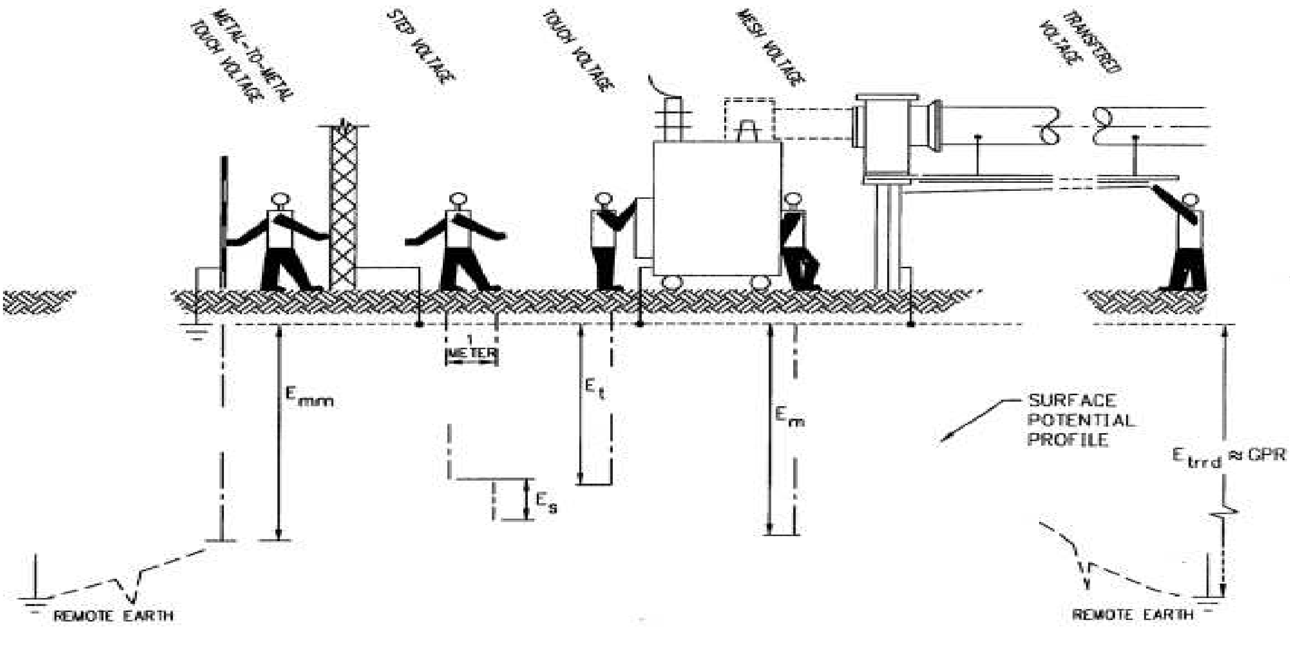


Figure 4.1: Basic Shock Situations

4.6 Material Selection

Conductors can be of various materials including copper, copper clad steel and aluminum or steel. Each type of conductor has advantages and disadvantages. Copper is the most commonly used material for grounding. Copper has high conductivity. Also, it is resistant to most underground corrosion because it is cathodic with respect to most other metals [4]. It also has good temperature characteristics and thermal capacity.

The disadvantage of copper is that it is expensive and often stolen, leaving the equipment ungrounded.

4.7 Soil Characteristics

The earth's soil can be considered to be a pure resistance and thus is the final location that a fault current is dispersed. Soil resistance can contain a current up to a critical amount which varies depending on the soil and at this point, electrical arcs can develop on the surface of the soil that can electrify objects on the surface such as a person [4].

Wet soil has much less resistance than that of dry soil so ideally the grounding grid and rods should be located in moist earth. Typically soil resistance quickly increases when its moisture content is less than 15% of the soil weight and the resistance barely changes once the moisture content is at least 22% [4]. Table 5.1 shows a basic collection of soil resistivity depending on the moisture and type.

Table 4.1: the Basic Range of Soil Resistivity

Type of Earth	Average Resistivity (Ω.m)
Wet Organic Soil	10
Moist Soil	10^2

Dry Soil	10^3
Bedrock	10^4

4.8 Substation Fence Grounding

It is critical to ground the substation fence because the fence is generally accessible to the public. The touch potential on both sides of the fence needs to be within the calculated tolerable touch potential limit. The substation fence should be connected to the main ground grid. An outer grid conductor should be installed a minimum of 0.91 m outside the fence.

Connections to the outer grid conductor should be made at all corners posts and at line posts every 12.92-15.24 m. The gate post should be bonded securely to the fence [1, 4].

4.9 Wenner's Four-Pin Method

The Wenner's four pin method is the most common. This method is also called the Equally Spaced Four Pin method [5]. In this technique, four probes are driven into the ground in a straight line to a depth b, at equal distances an apart. The voltage between the two inner probes is measured and is divided by the current of the two outer probes. This gives a value of the mutual resistance R. The Wenner's four pin method is shown in Figure 4.2 below.

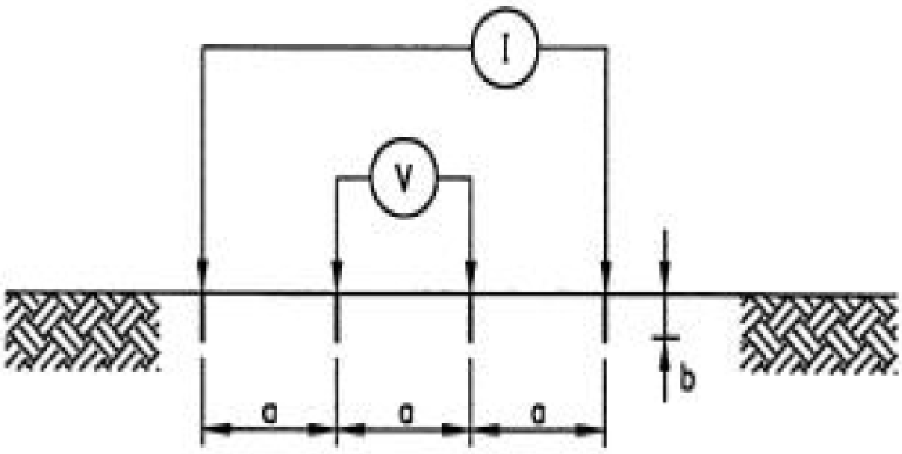


Figure 4.2: Wenner's Four-Pin Method

4.10 Earth Resistance

Ground Resistance is the resistance offered by the ground electrode to the flow of current in to the ground; to provide a sufficiently low resistance path to the ground to minimize the rise in ground potential with respect to a remote ground fault. Generally lower ground resistance is preferable but for certain applications following earth resistance are satisfactory**:**

(1) Large Power Stations-**0.5 Ω**

(2) Major Power Stations-**1.0 Ω**

(3) Small Substation-**2.0 Ω**

(4) In all Other Cases-**8.0 Ω**

4.11 Step Potential and Touch Potential

Grounding system in an electrical system is designed to achieve low earth resistance and also to achieve safe 'Step Potential' and 'Touch potential'.

4.11.1 Step Potential

Step potential is the potential difference between the feet of a person standing on the floor of the substation, with 0.5 m spacing between the feet (one step), through the flow of ground fault current through the grounding system.

4.11.2 Touch Potential

Touch potential is a potential difference between the fingers of raised hand touching the faulted structure and the feet of the person standing on the substation floor. The person should not get a shock even if the grounded structure is carrying fault current, i.e. the touch potential should be very small. The step and touch potential are shown in Figure 4.3 below.

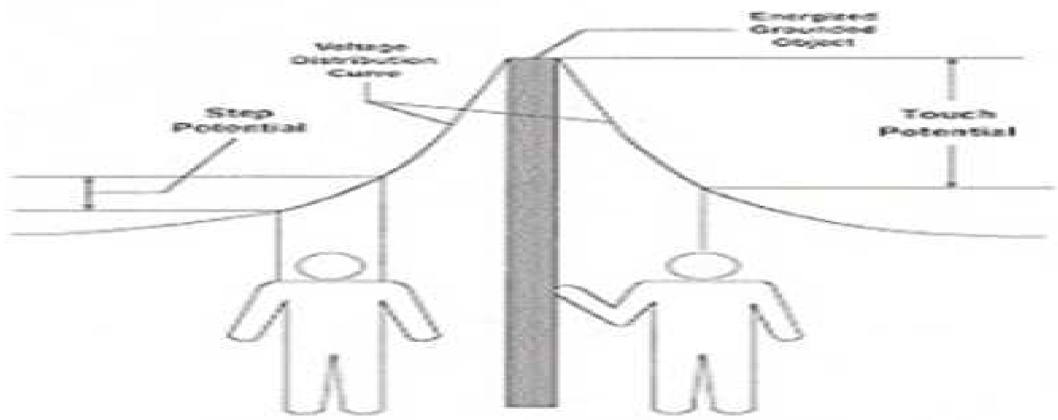


Figure 4.3: Step Potential and Touch Potential

4.12 Types of Grounding

4.12.1 Ungrounded System

It is rarely used; the neutral is not connected to the earth, also called as insulated neutral system.

4.12.2 Solid grounding or Effective Grounding

The neutral is directly connected to the earth without any impedance between neutral and ground.

4.12.3 Resistance Grounding

Resistance is connected between the neutral and the ground.

4.12.4 Reactance Grounding

Reactance is connected between the neutral and the ground.

4.12.5 Resonant Grounding

An adjustable reactor of correctly selected value to compensate the capacitive ground current is connected between the neutral and the earth. The coil is called Arc Suppression Coil or Ground Fault Neutralizer.

4.13 Different Grounding Equipment in Electrical Substation

(1) Grounding Electrodes

(2) Grounding Mat

(3) Riser and

(2) Overhead shielding wire (Grounded).

Table 4.2: Different Equipment's and Ground Connections

Apparatus	**Parts to be Earthed**	**Method Of Connection**
Power Transformer	Transformer tank	Connect the Earthing bolt on transformer tank to station earth. Connect the neutral to Earthing system
High Voltage Circuit Breakers	Operating mechanism, frame	Connect the Earthing bolt on the frame and the operating mechanism of Circuit Breaker to Earthing system
Surge Arrester	Lower Earth Point	To be directly connected to the earth mat
Support of bushing insulators, lightning arresters, fuse, etc...	Device Flange or Base Plate	Connect the Earthing bolt of the device to the station Earthing system
Potential Transformer	Potential transformer tank, LV neutral.	Connect the transformer Earthing bolt to Earthing system Connect LV neutral of phase lead to case with flexible copper conductor
Isolator	Isolator frame, operating mechanism, bedplate	Weld the isolator base frame, connects it to the bolt on operating mechanism base plate and station earth.
Current Transformer	Secondary winding and metal case	Connect secondary winding to Earthing bolt on transformer case with a flexible copper conductor.

4.14 Design of Kilo-x electrical substation Using Etap Software Program

In this section we making design single line diagram of Kilo-x substation, the programs have been developed to make the substation design easier, and more accurate.

The following figures (4.4 - 4.9) explaining design of single line diagram of Kilo-x substation Using Etap-Software Program.

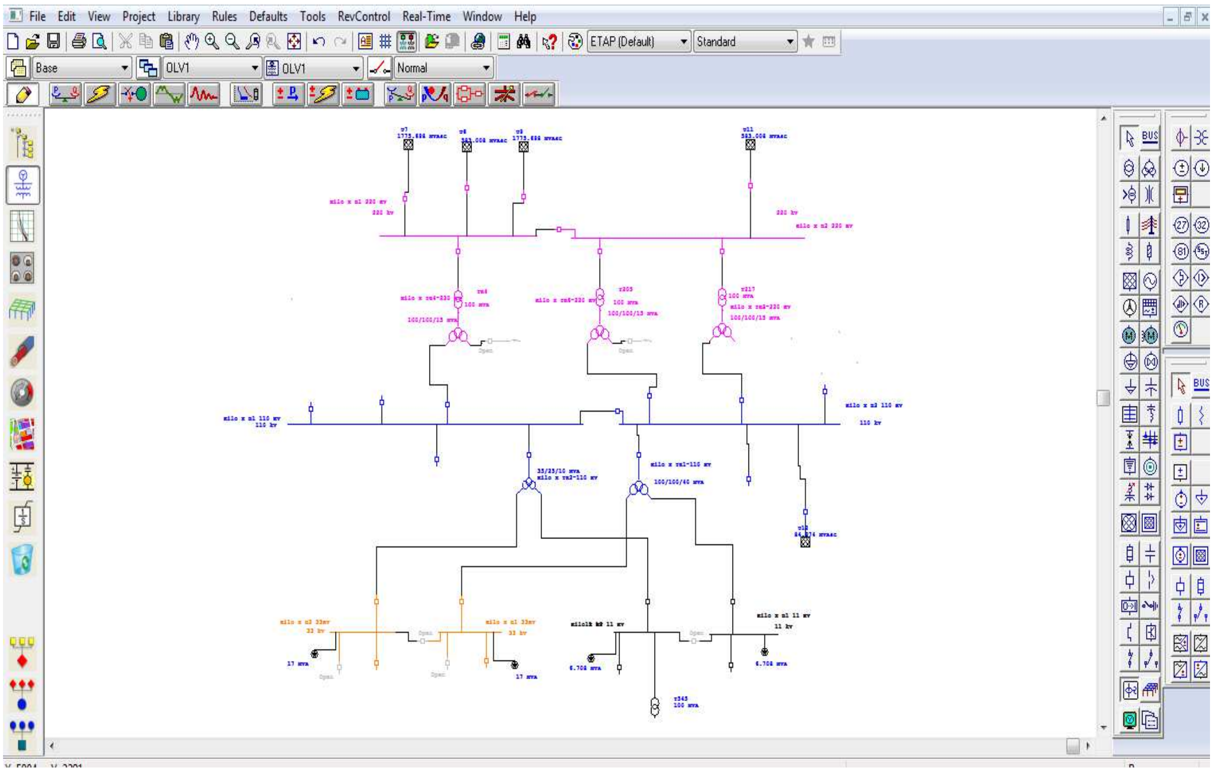


Figure 4.4: single line diagram of Kilo-x substation using etap Software Program

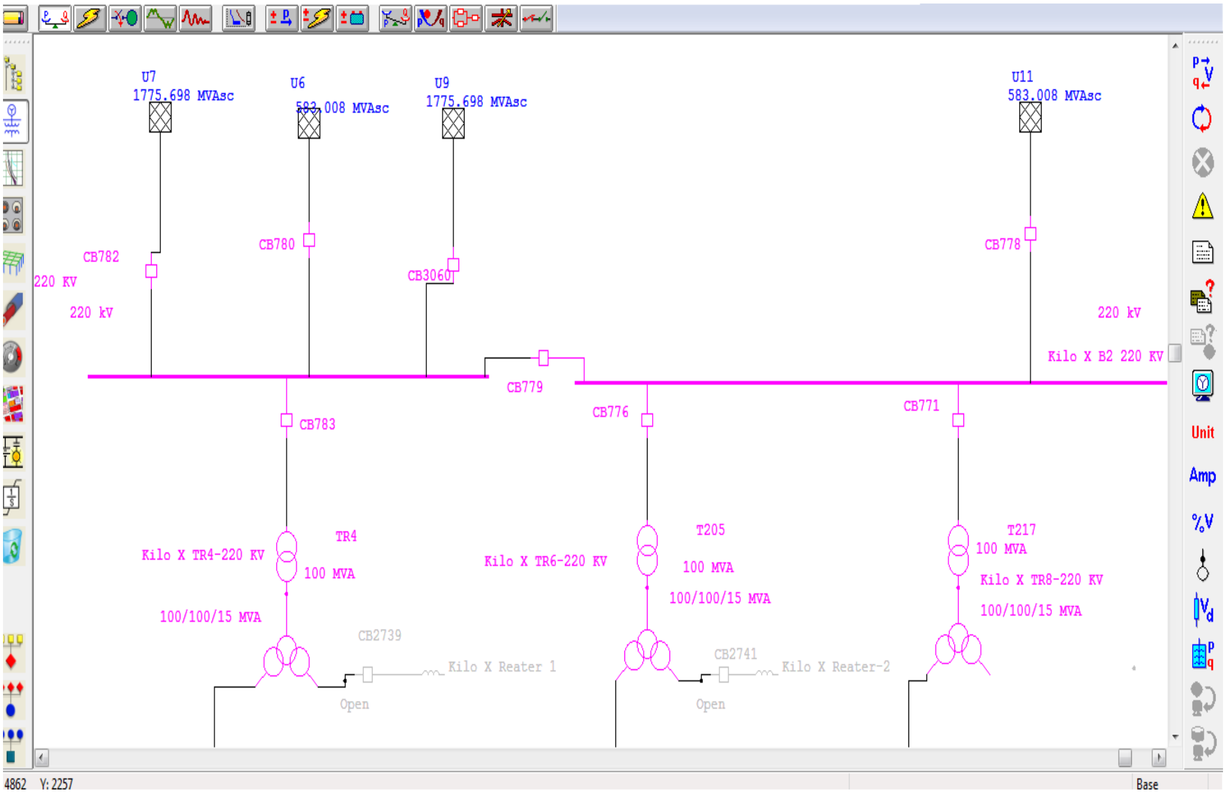


Figure 4.5: single line diagram side 220kv

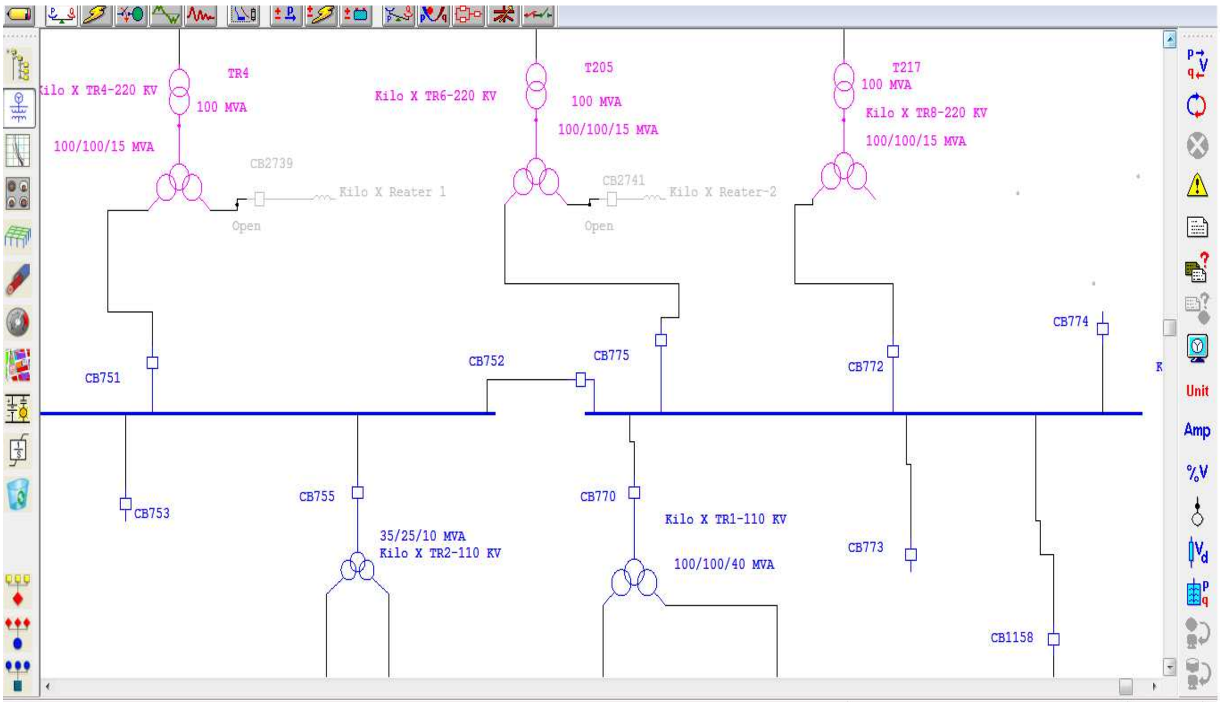


Figure 4.6: single line diagram side 110 Kv in kilo-x substation

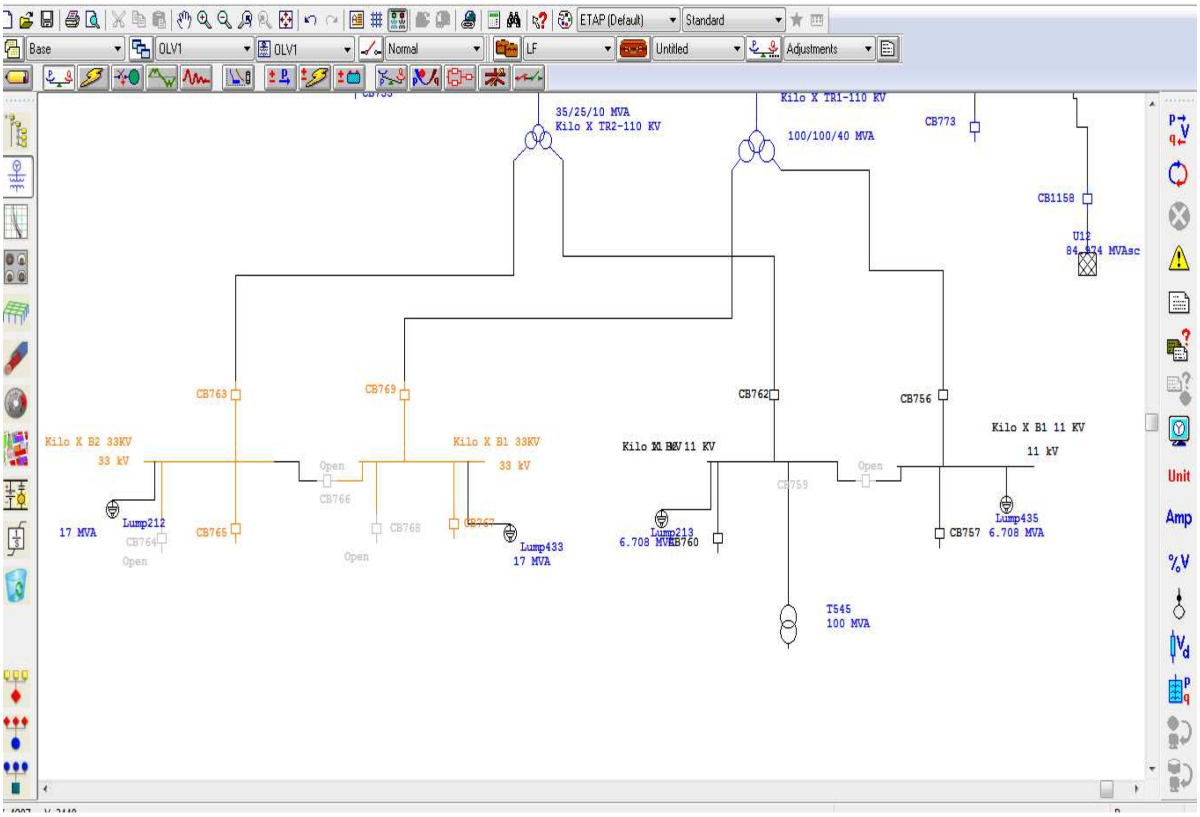


Figure 4.7: single line diagram side 11kv and 33kv

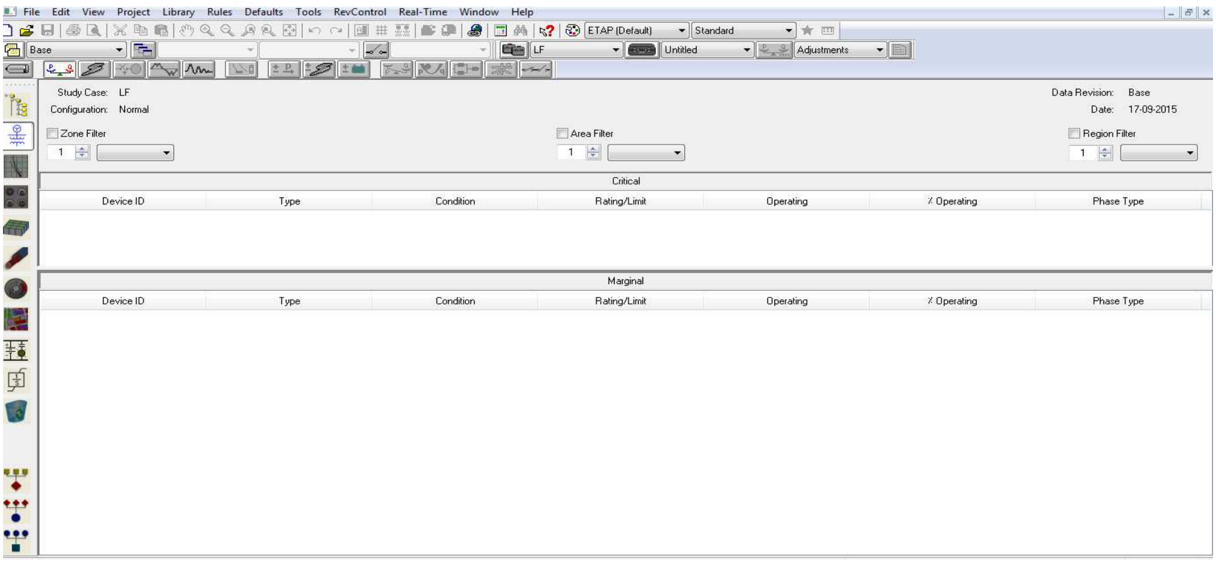


Figure 4.8: show alert view (the system in normal condition or the system is stable)

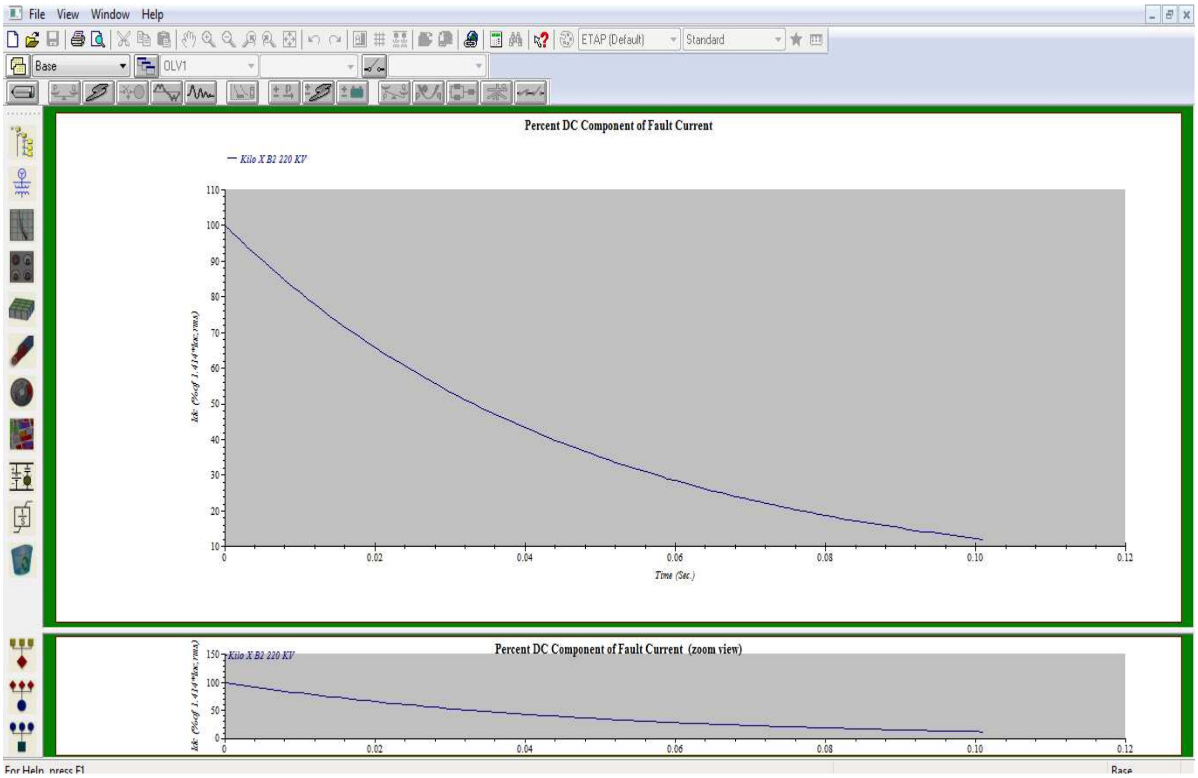


Figure 4.9: fault current of Kilo-x substation

4.15 Method of designing substation

In Etap Software Program the ground grid system program utilizes the following four methods of computation:

- FEM - Finite Element Method.
- IEEE 80 – 1986
- IEEE80 – 2000
- IEEE 665 – 995

In this project used Finite Element Method (FEM), FEM is based on a method of images and assumes that the grounding system is an equipotential structure, it gives a curate result.

The structure of finite element methods:

Finite element methods are numerical methods for approximating the solutions of mathematical problems that are usually formulated so as to precisely state an idea of some aspect of physical reality, FEM allows entire designs to be constructed, refined, and optimized before the design is manufactured.

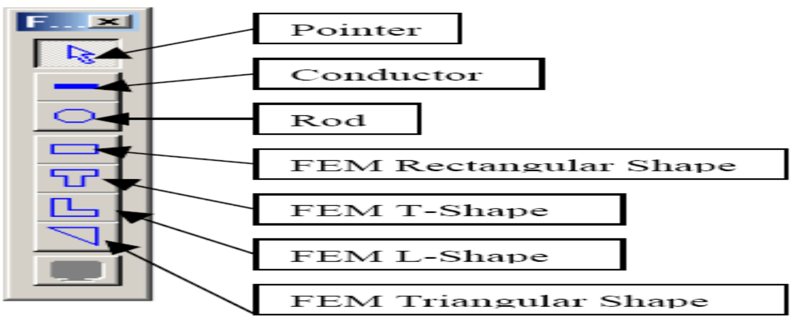
A finite element method is characterized by a variation formulation, a discretization strategy, one or more solution algorithms and post-processing procedures.

4.15.1 ETAP Ground Grid Design

After selecting the FEM study model the ground grid system graphical user window will be displayed.

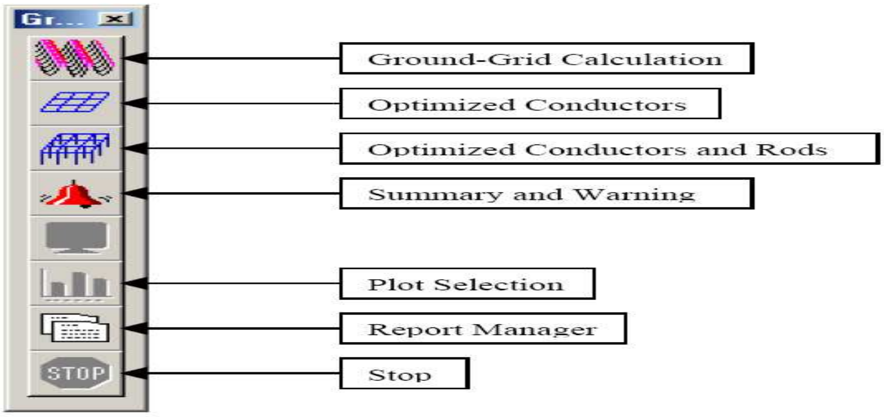
4.15.2 FEM Editor Toolbar

The FEM editor toolbar appears when the fem study model is selected and when in the ground grid system edit mode this toolbar has the following function keys:



4.15.3 Ground grid study method toolbar

The Ground grid study method toolbar appears when the GGS study mode is selected. This toolbar has the following function keys.



4.16 Simulation earthing design for Kilo-X Substation

In this section simulating the grounding grid of the substation, the programs have been developed to make the substation grounding design easier, and more accurate. The method of simulation described in details, also using Etap soft ware, the following figures are showed:

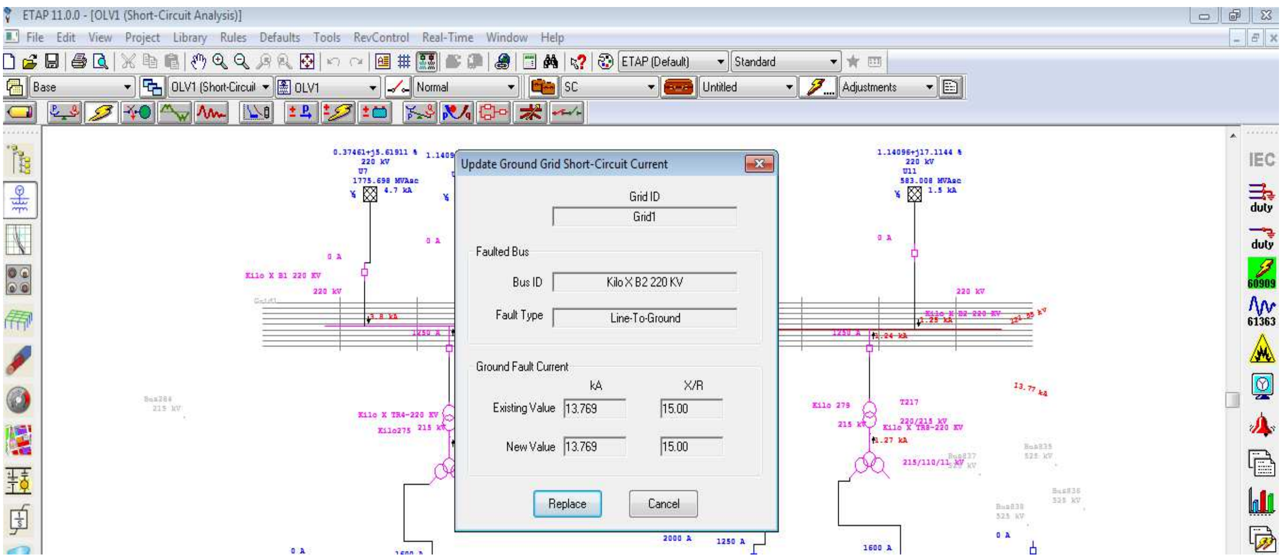


Figure 4.10: show ground grid short-circuit current

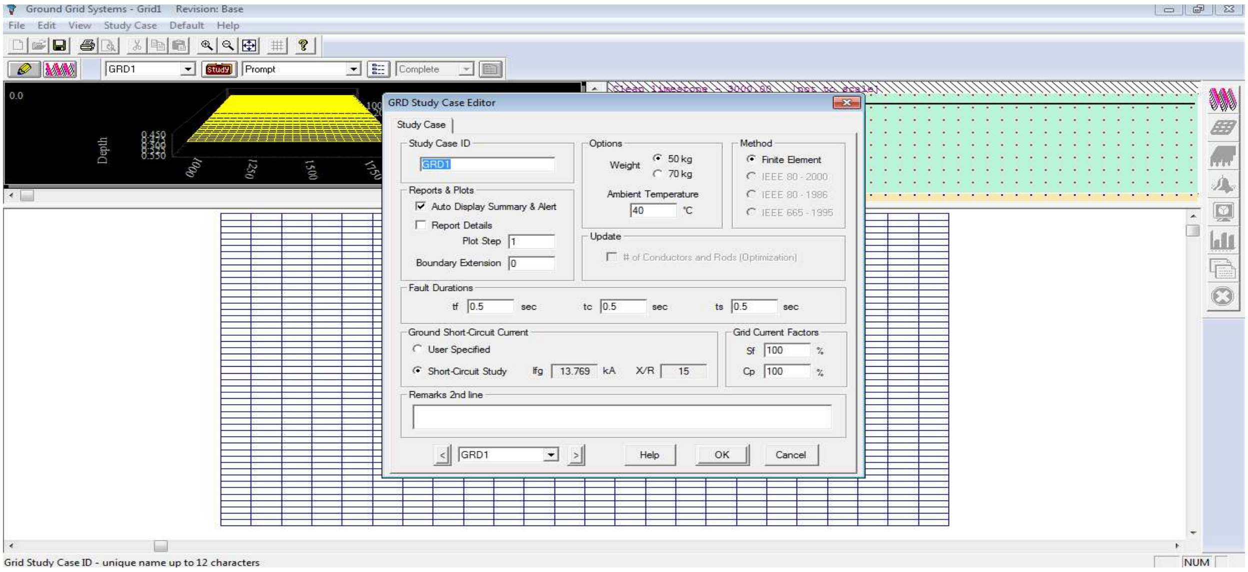


Figure 4.11: show the rectangular earthing grid of Kilo-x in etap soft-ware using FEM

4.16.1 Summary and warning

After running the ground grid system study click on the summary and warning button located on the ground grid system toolbar, to open the GRD analysis Alert view dialog box. If the Auto Display of summary and warning box located on the study case Editor dialog box is checked, this view will open automatically after the ground grid systems calculation are executed, as shown below.

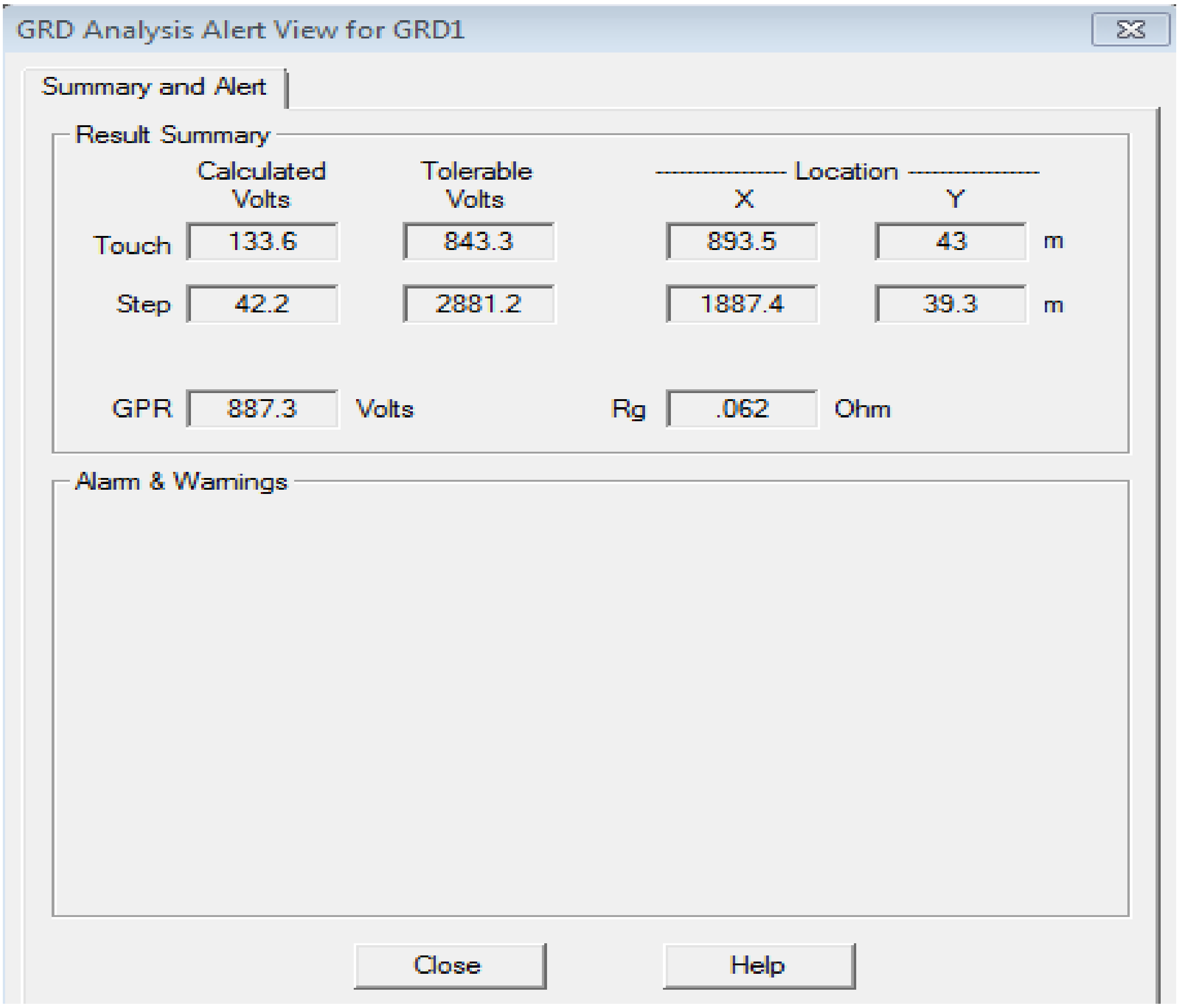


Figure 4.12: show result summary of grounding grid calculation

4.16.2 Plot selection

Plots are used only with the FEM, and are available for Absolute/ step / touch voltages.

To select a pot, open up the plot selection dialog box by clicking on the plot selection button located on the ground grid system toolbar, as shown in fig (4.11).

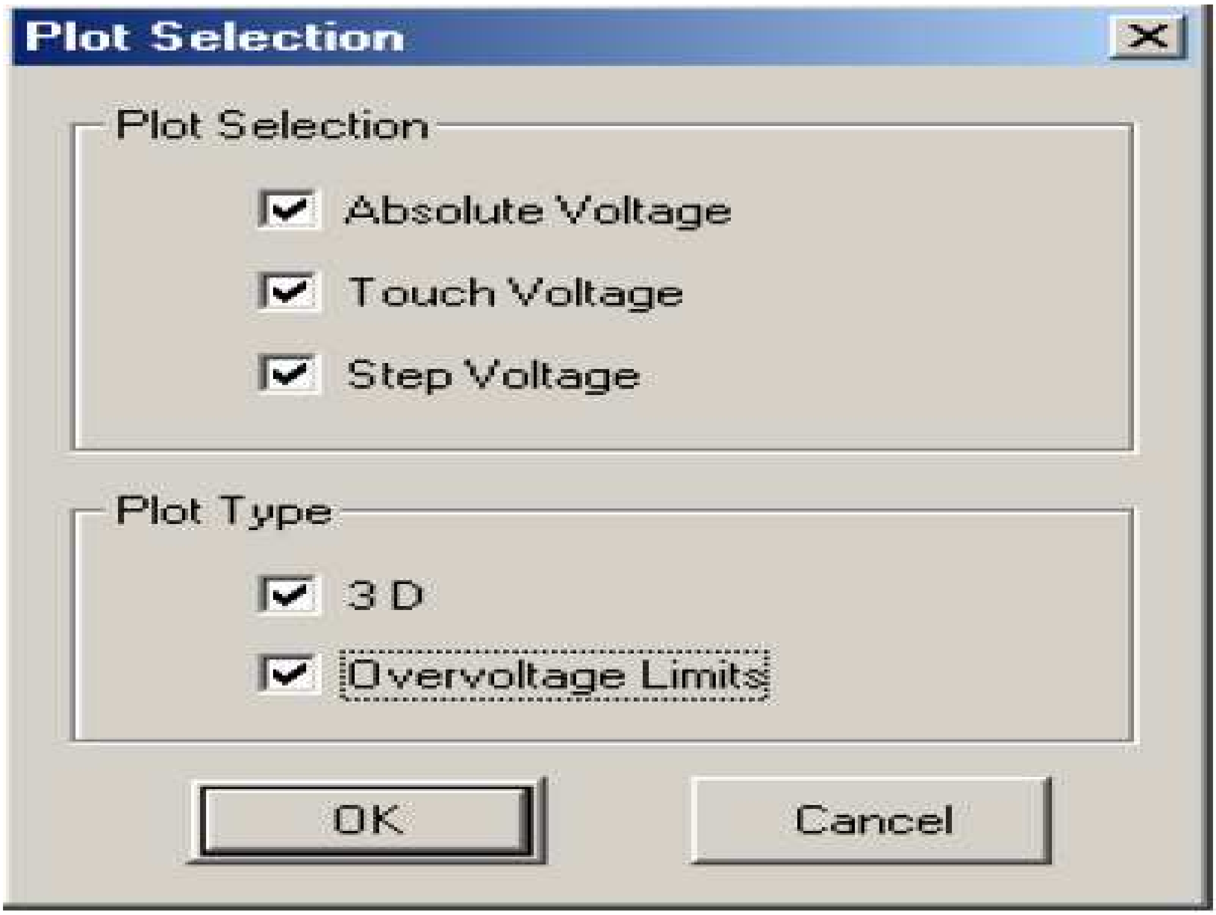


Figure 4.13: show plot selection.

The following 3-D potential profiles are available for analysis of GGS study case result:

Absolute voltage: select to plot an Absolute potential profile.

Touch voltage: select to plot a touch potential profile.

Plot type: the following plot types are available for analysis of GGS study Case result:

3- D: plot a 3- D potential profile for the Absolute / touch / step voltage.

Contour: plot a contour potential profile for the Absolute / touch / step voltage.

4.16.3 Display over limit voltage

Show areas potential exceeding the tolerable limits for 3-D touch / step potential profile.

This function is disabled when the contour plot type is selected. A select of sample plot is shown in figures (4.14 – 4.15 – 4.16).

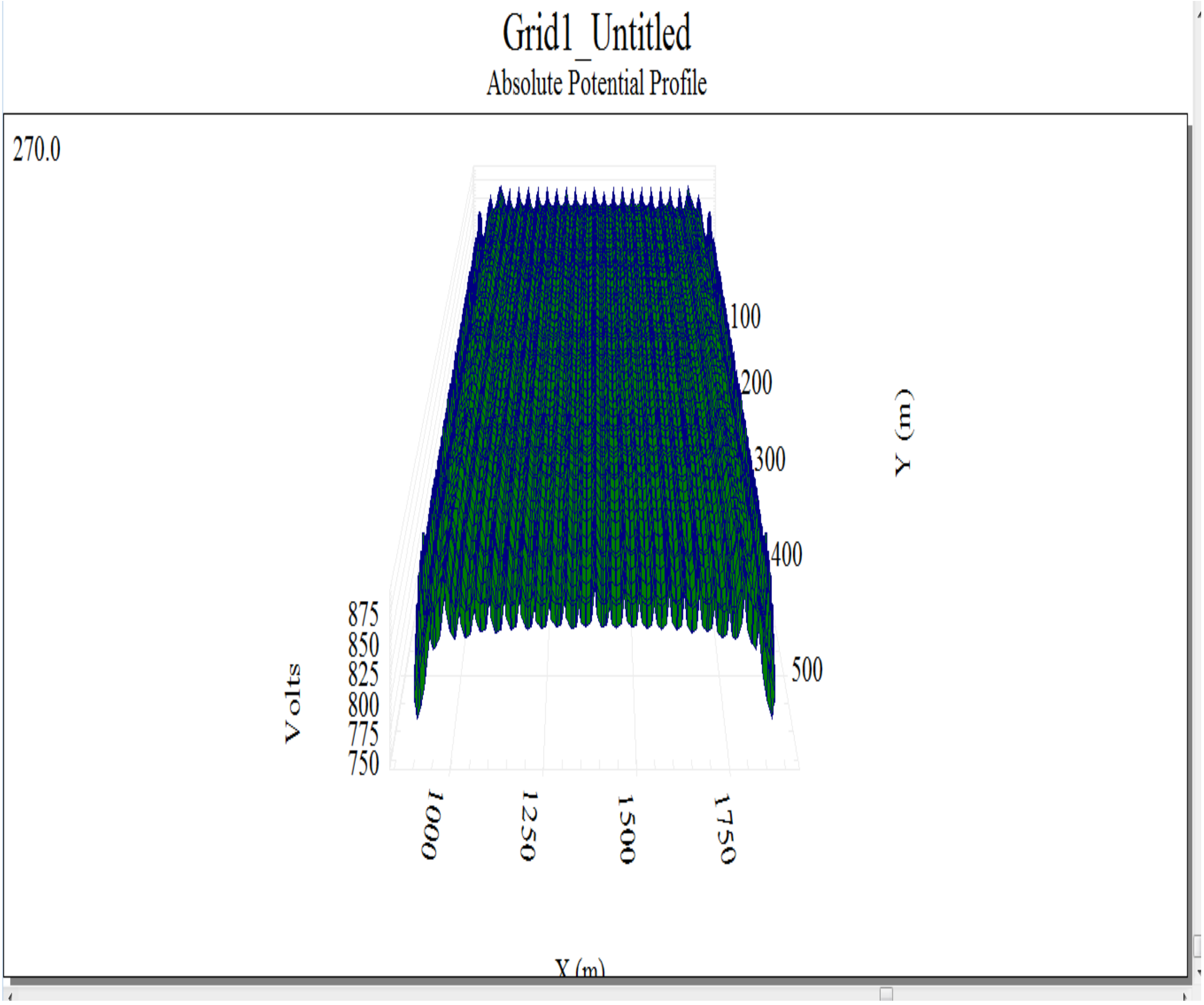


Figure 4.14: absolute potential profile

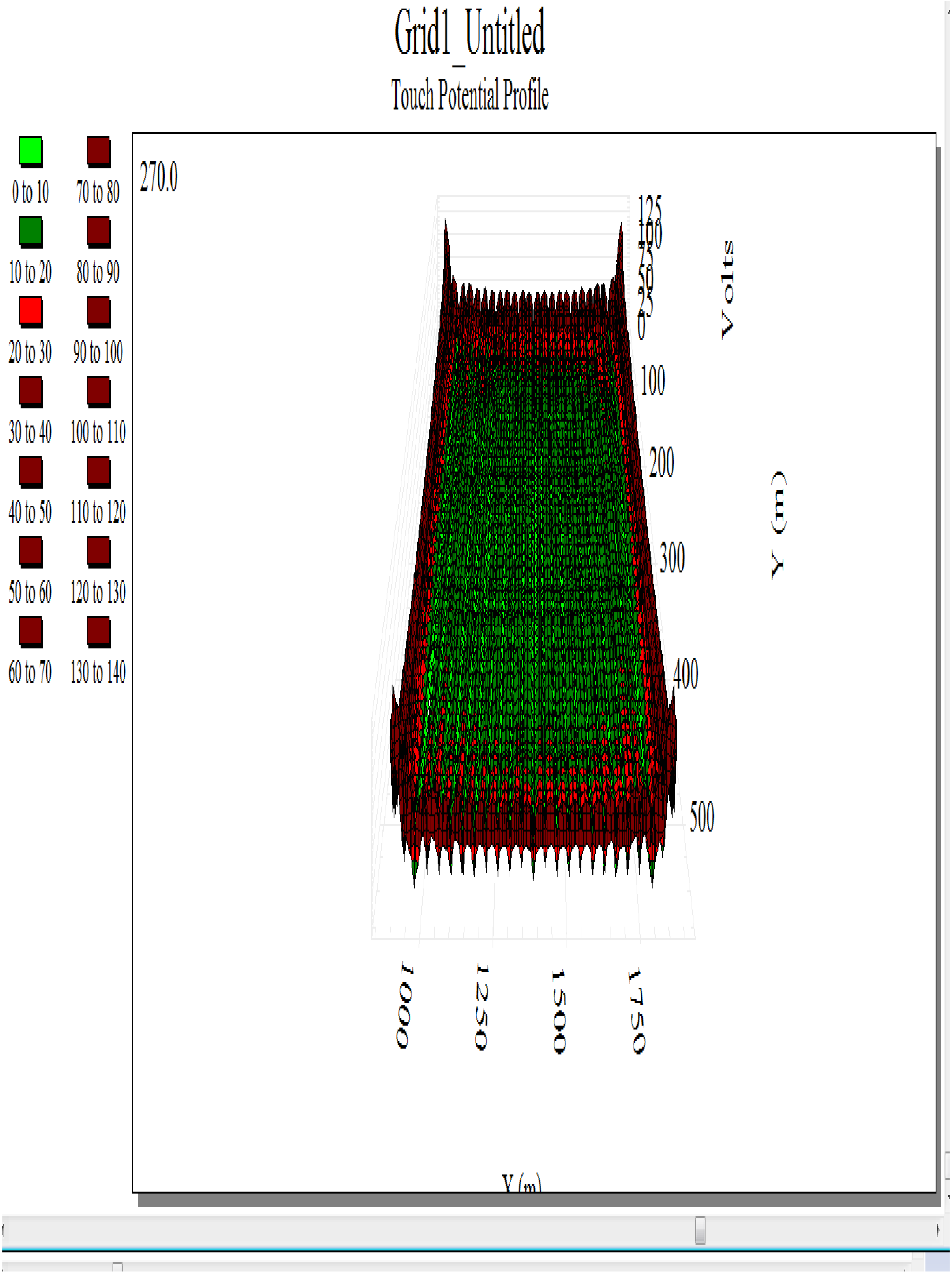
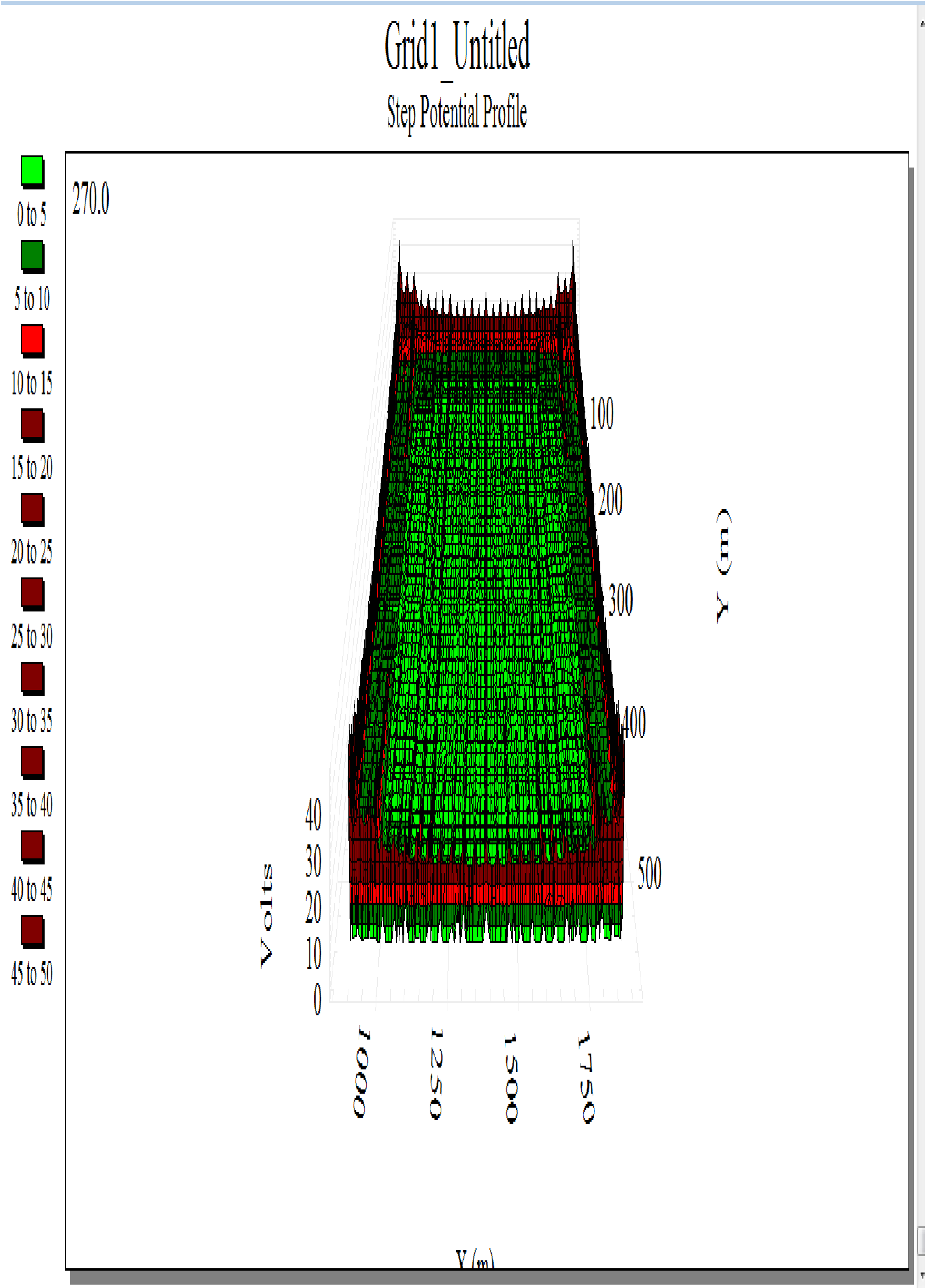


Figure 4.15: touch potential profile



Grid1_Untitled
Step Potential Profile
0 to 5
5 to 10
10 to 15
15 to 20
20 to 25
25 to 30
30 to 35
35 to 40
40 to 45
45 to 50
270.0
Volts
0
10
20
30
40
100
200
300
400
500
Y (m)
1000
1250
1500
1750
X (m)

Figure 4.16: show step potential profile

4.17 Securing and Protection devices

The substation contracted with ABB Company for the supply and installation of the systems and insurance with the following:

(1) Securing the main doors Access Control Door System
(2) By surveillance cameras (fixed and mobile) CCTV System
(3) The outer wall is protected by red rays.

4.17.1 The Control Systems device

The systems are controlled via computers and displays images of cameras rooms control stations, sub-rooms and security stations as well as via the communications network that connects all stations can be controlled from the Information Centre of the unit Kilo-X substation.

4.17.2 Protection system

Protection system in this substation used modern methods by digital relays and Numerical Relays.

Figure 4.17: The Controlling Room

4.17.3 Protection of Transformers and Reactors

It consists of the transformers and reactors RET521 differential protection, Differential protection and RET316 differential protection for ground damage Restricted ground Fault.

(1) Protection against over current (Over Current Protection)

(2) Protection against overload magnetic flux (over flex)

(3) Various mechanical protections.

4.17.4 Bus bar Protection

It protects the poles assembly by REB500 with different characteristics in addition to the protection of Breaker Failure.

Chapter Five

Conclusion and Recommendation

5.1 Conclusion

In this project discussed the electrical substation in general and investigate the substation in depth, taking into account the size, area, etc...

The project also provides ground grid system by using ETAP software program because it is easy to Upgrade and calculate the step potential, the touch potential, the total length of Earthing mat conductors, the size of Earthing mat conductors and the total number of Earthing rod in order to reach the best possible Upgrading of Earthing System for Kilo-x Substation. Kilo-X substation was implemented as the study case, from simulation results obtained, there is a difference between the existing ground design scheme and that obtained with ETAP, the result of ground grid Upgrading almost coincides with the existing grounding system.

5.2 Recommendations

From this project I can recommended the following for future research:

(1) Design the digital automatic controlling room.

(2) Contactless Electrical Energy Transmission System.

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