DESIGN OF EARTHING SYSTEM FOR HV/EHV SUBSTATION AND ITS SAFETY

A thesis report submitted to the department of Electrical & Electronic Engineering (EEE), Sonargaon University, for partial fulfillment of the requirements for the degree of Science in Electrical & Electronic Engineering.

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It is declared hereby that this thesis paper or any part of it has not been submitted to anywhere else for the award of any degree.

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ABSTRACT

This paper presents the **Design of Earthing System for HV/EHV Substation and its Safety;** Successful operation of entire power system depends to a considerable extent on efficient and satisfactory performance of substations. Hence substations in general can be considered as heart of overall power system. In any substation, a well-designed grounding plays an important role. Since absence of safe and effective grounding system can result in mal-operation or non-operation of control and protective devices, grounding system design deserves considerable attention for all the substations. Grounding system has to be safe as it is directly concerned with safety of persons working within the substation. Main purpose of this work is designing safe and cost effective grounding systems for HV / EHV substations situated at such locations where soil of the substation site is not uniform. Initially significance of Earthing is explained & methodology for design of substation grounding system is discussed for HV / EHV substations. Standard equations are used in the design of Earthing system to get desired parameters such as touch and step voltage criteria for safety, earth resistance, grid resistance, maximum grid current, minimum conductor size and electrode size, maximum fault current level and resistivity of soil. By selecting the proper horizontal conductor size, vertical electrode size and soil resistivity, the best choice of the project for safety can be performed. This paper mentions the calculation of the desired parameters for 400 kV substation.

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Chapter 4: Safety and Security

CHAPTER-1

INTRODUCTION

1.1 An Electrical Sub-Station:

An electrical substation is a subsidiary station of an electricity generation, transmission and distribution system where voltage is transformed from high to low or the reverse using transformers. Electric power may flow through several substations between generating plant and consumer, and may be changed in voltage in several steps.

A substation that has a step-up transformer increases the voltage while decreasing the current, while a step-down transformer decreases the voltage while increasing the current for domestic and commercial distribution. The word *substation* comes from the days before the distribution system became a grid. The first substations were connected to only one power station where the generator was housed, and were subsidiaries of that power station.

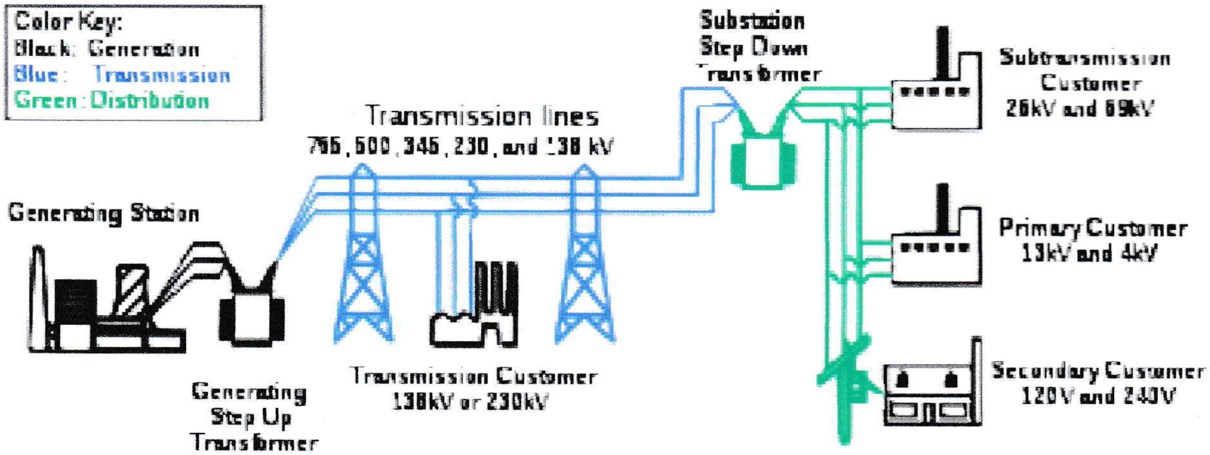


Fig 1.1: Diagram of an electrical system.

An Electrical Power Substation receives electric power from generating station via transmission lines and delivers power via the outgoing transmission lines. Substations are integral parts of a power system and form important links between the generating stations, transmission systems, distribution systems and the load points. Various power substations located in generating stations, transmission and distribution systems have similar layout and similar electrical components. Electrical power substation basically consists of number of incoming circuit connections and number of outgoing circuit connections connected to the bus bars. Bus bars are conducting bars to which number of circuit connections is connected. Each circuit has certain number electrical components such as circuit breakers, Isolators, earth switches, current transformers, voltage transformers, etc.

In a Power Substation there are various indoor and outdoor switchgear and equipment. Transformers are necessary in a substation for stepping up and stepping down of a.c voltage. Besides the transformers, the several other equipment include bus bars, circuit breakers, isolators, surge arresters, Substation Earthling System, Shunt reactors, Shunt Capacitors etc . Each equipment has certain functional requirement. The equipment are either indoor or outdoor depending upon the voltage rating and local conditions In a large power System large number of Generating stations, Electrical Power Substations and load centers are interconnected. This large internet work is controlled from load dispatch center. Digital and voice signals are transmitted over the transmission lines via the Power substations. The substations are interlinked with the load control centers via Power Line Carrier Systems (PLCC). Modern Power System is controlled with the help of several automatic, semi - automatic equipment. Digital Computers and microprocessors are installed in the control rooms of large substations, generating stations and load control centers for data collection, data monitoring, automatic protection and control.

1.2 Functions of Electrical Power Substations are:

- Supply electric power to the consumers continuously
- Supply of electric power within specified voltage limits and frequency limits
- Shortest possible fault duration.
- Optimum efficiency of plants and the network
- Supply of electrical energy to the consumers at lowest cost

1.3 Types of Electrical Power Substations:

Based ON Nature of Duties:

a) Step up or primary Electrical Power substation:

Primary substations are associated with the power generating plants where the voltage is stepped up from low voltage (3.3, 6.6, 11, 33kV) to 220kV or 400kV for transmitting the power so that huge amount of power can be transmitted over a large distance to load centers.

b) Primary Grid Electrical Power Substation:

Such substations are located at suitable load centers along with the primary transmission lines. At primary Grid Power Substations the primary transmission voltage (220kV or 400kV) is stepped down to secondary transmission voltages (110kV). This Secondary transmission lines are carried over to Secondary Power Substations situated at the load centers where the voltage is further stepped down to Sub transmission Voltage or Primary Distribution Voltages (11kV or 33kV).

c) Step Down or Distribution Electrical Power Substations:

Such Power Substations are located at the load centers. Here the Sub transmission Voltages of Distribution Voltages (11kV or 33kV) are stepped down to Secondary Distribution Voltages (400kV or 230kV). From these Substations power will be fed to the consumers to their terminals.

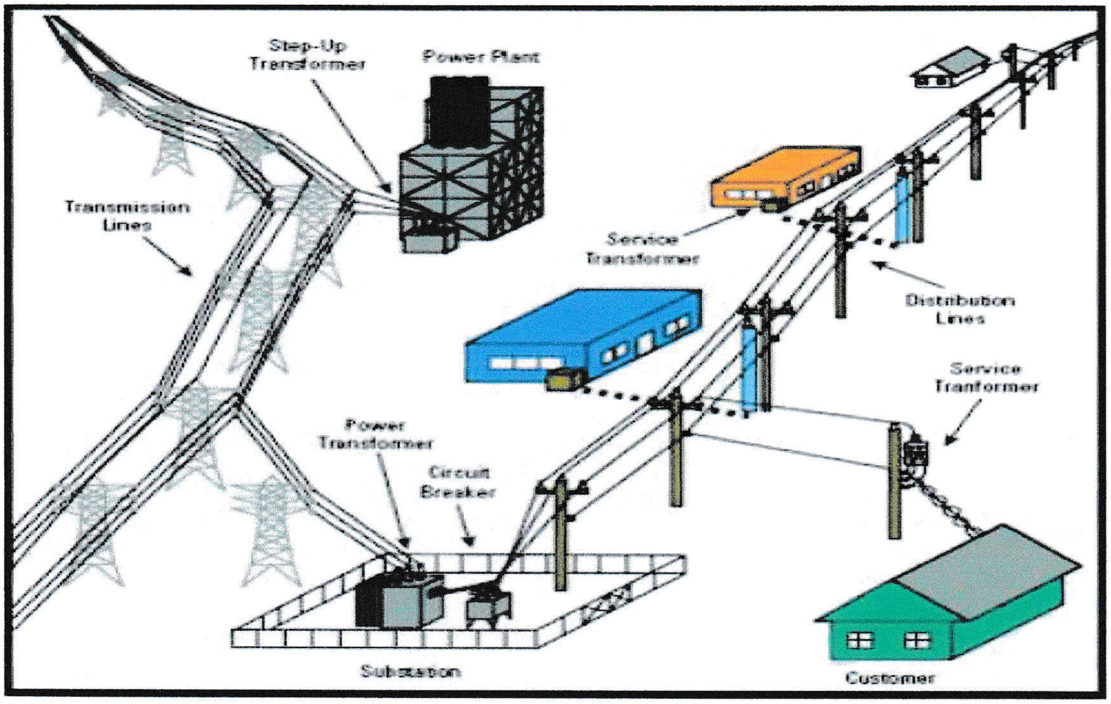


Fig 1.3: Basic Substation for Transmission & Distribution.

1.4 Basis of Service Rendered:

a) Transformer Substation:

Transformers are installed on such Substations to transform the power from one voltage level to other voltage level.

b) Switching Substation:

Switching substations are meant for switching operation of power lines without transforming the voltages. At these Substations different connections are made between various transmission lines. Different Switching Schemes are employed depends on the application to transmit the power in more reliable manner in a network.

c) Converting Substation:

Such Substations are located where AC to DC conversion is required. In HVDC transmission Converting Substations are employed on both sides of HVDC link for converting AC to DC and again converting back from DC to AC. Converting Power Substations are also employed where frequency is to be converted from higher to lower and lower to higher. This type of frequency conversion is required in connecting to Grid Systems.

1.5 Based on Operation Voltage:

a) High Voltage Electrical Power Substation:

This type of Substation associated with operating voltages between 11kV and 66kV.

b) Extra High Voltage Electrical Power Substation:

This type of Substation is associated where the operating voltage is between 132kV and 400kV.

c) Ultra High Voltage Electrical Power Substation:

Substations where Operating Voltages are above 400kV is called Ultra High Voltage Substation.

1.6 Based On Substation Design:

a) Outdoor Electrical Power Substations:

In Outdoor Power Substations, the various electrical equipments are installed in the switchyard below the sky. Electrical equipment are mounted on support structures to obtain sufficient ground clearance.

b) Indoor Electrical Power Substation:

In Indoor Power Substations the apparatus is installed within the substation building. Such substations are usually for the rating of 66kV. Indoor Substations

Are preferred in heavily polluted areas and Power Substations situated near the seas (saline atmosphere causes Insulator Failures results in Flashovers)

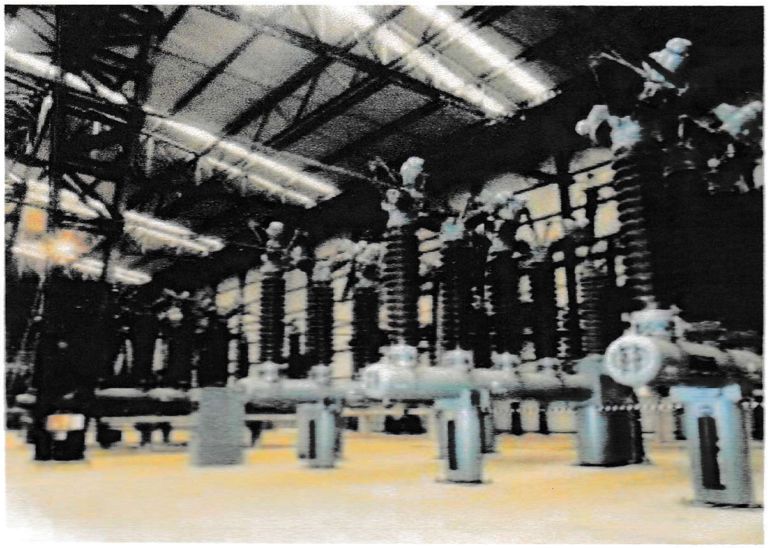


Fig 1.6: Indoor Substation

1.7 Based Design Configuration:

a) Air Insulated Electrical Power Substation:

In Air Insulated Power Substations bus bars and connectors are visible. In this Power Substations Circuit Breakers and Isolators, Transformers, Current Transformers, Potential Transformers etc are installed in the outdoor. Bus bars are supported on the post Insulators or Strain Insulators. Substations have galvanized Steel Structures for supporting the equipment, insulators and incoming and outgoing lines. Clearances are the primary criteria for these substations and occupy a large area for installation.

b) Gas Insulated Electrical Power Substation:

In Gas Insulated Substation Various Power Substation equipments like Circuit Breakers, Current Transformers, Voltage Transformers, Bus bars, Earth Switches, Surge Arresters Isolators etc are in the form of metal enclosed SF6 gas modules. The modules are assembled in accordance with the required Configuration. The various Live parts are enclosed in the metal enclosures (modules) containing SF6 gas at high pressure. Thus the size of Power Substation reduces to 8% to 10% of the Air Insulated Power Substation.

c) Hybrid Electrical Power Substation:

Hybrid Substations are the combination of both Conventional Substation and Gas Insulated Substation. Some bays in a Power Substation are Gas Insulated Type

And some are Air Insulated Type. The design is based on convenience, Local Conditions available, area available and Cost.

Fig 1.7: Gas Insulated Substation

1.8 Different Components of Substation:

Complete Explanation of all the Substation Components Such as Circuit breakers, isolators, Earth Switch, Bus bars, Substation Ear thing, CVT, Current Transformer, and Voltage Transformer etc with Pictures.

1.9 Gas Insulated Substation:

Indoor Gas Insulated Substation: Gas Insulated Substation uses sulfur hex fluoride (SF6) gas which has a superior dielectric properties used at moderate pressure for phase to phase and phase to ground.

1.10 Substation Grounding or Ear thing:

The sole purpose of substation grounding/earthing is to protect the equipment from surges and lightning strikes and to protect the operating persons in the substation. The substation earthing system.

1.11 Distribution substation:

A distribution substation receives power from the transmission system and distributes it to an area. It is uneconomical to directly connect electricity Consumers to the high-voltage main transmission network, unless they use large amounts of energy, so the distribution sub-station reduces voltage to a value suitable for local distribution.

The input for a distribution substation is typically at least two transmission or sub transmission lines. Input voltage may be, for example, 132 kV, or whatever is common in the area. The output consists of a number of feeders. Distribution voltages are typically medium voltage, between 11 and 33 kV depending on the size of the area served and the practices of the local utility. The feeders will then run overhead, along streets (or under streets, in a city) and eventually power the distribution transformers at or near the customer premises.

Besides changing the voltage, the job of the distribution substation is to isolate faults in either the transmission or distribution systems. Distribution substations may also be the points of voltage regulation, although on long distribution circuits (several km/miles), voltage regulation equipment may also be installed along the line. Complicated distribution substations can be found in the downtown areas of large cities, with high-voltage switching and backup systems on the low-voltage side. More typical distribution substations have a switch, one transformer, and minimal facilities on the low-voltage side.

1.12 Classification of Sub-Stations:

There are several ways of classifying sub-station. The most

Important ways of classifying them are according to

(1) Service requirement and

(2) Constructional features

According to service requirement- A sub-station may be called upon to change voltage level or improving power factor or convert a.c power etc. According to the service requirement, sub stations may be classified into.

i) Transformer sub-stations

ii) Switching sub-stations

iii) Power factor correction substations

iv) Frequency changer sub-stations

v) Converting sub-stations

vi) Industrial sub-stations
vii) According to constructional features- A sub-station has

Many components (e.g. circuit breakers, switches, fuses, instruments etc) which must be housed properly to ensure continuous and reliable service. According to constructional features, the sub-station are classified as-

i) Indoor sub-stations

ii) Outdoor sub-stations

iii) Underground sub-stations

iv) Pole mounted sub-stations

1.13 Elements of a Sub-Station:

Substations generally contain one or more transformers, and have switching, protection and control equipment. In a large substation, circuit breakers are used to interrupt any short-circuits or overload currents that may occur on the network. Smaller distributions stations may use reclose circuit breakers or fuses for protection of branch circuits. Substations do not (usually) have generators, although a power plant may have a substation nearby. A typical substation will contain line termination structures, high-voltage switchgear, one or more power transformers, low voltage switchgear, surge protection, controls, grounding (ear thing) system, and metering. Other devices such as power factor correction capacitors and voltage regulators may also be located at a substation. Substations may be on the surface in fenced enclosures, underground, or located in special-purpose buildings. High-rise buildings may have indoor substations. Indoor substations are usually found in urban areas to reduce the noise from the transformers, for reasons of appearance, or to protect switchgear from extreme climate or pollution conditions. Where a substation has a metallic fence, it must be properly grounded to protect people from high voltages that may occur during a fault in the transmission system. Earth faults at a substation can cause ground potential rise at the fault location. Currents flowing in the earth's surface during a fault can cause metal objects to have a significantly different voltage than the ground under a person's feet; this touch potential presents a hazard of electrocution.

1.14 Site Selection for Sub-Stations:

Sub-stations are important part of power system. The continuity of supply depends to a considerable extent upon the successfully operation of sub-stations. While selecting the site for sub-stations following factors should be considered.

1) It should be located at a proper site. As per as possible, it should be located at the centre of gravity of load. This will minimize the cost of distribution lines, the maintenance and power losses through them.

2) It should provide safe and reliable arrangement. for safety, consideration must be given to the maintenance of regulation clearances, facilities for carrying out repairs and maintenance, abnormally occurrences such as possibility of explosion or fire. For reliability, consideration must be given for good design and construction, the provision of suitable protective gear etc.

3) It should involve minimum capital cost. Sub-station conditions should be such that a foundation at a reasonable depth should be capable of providing a strong support to the equipment.

4) The site should be selected where easy access road is available so that the operations and maintenance could be easy and less expensive.

5) Climate Conditions (Ambient air temperature).

Extremities 5 to 40°C, Normal range 20 to 35°C, Ambient average annual temp 25°C, Average in any one day does not exceed 35°C, Rainfall-average annual 3000mm, Average relative humidity 50-100%, Maximum wind velocity 160 Km/hour.

1.15 General Technical Requirements of a Sub-Station:

The general technical requirements of a substation are as follows

i) Economy of expenditure (i.e.) minimum capital cost & operation and maintenance cost.
ii) Safety of sub-station and personnel.
iii) Reliability.
iv) High efficiency.
v) Good working conditions.
vi) Minimum losses.
vii) Standards- All equipment supplied under this specification is conform to the latest editions to the International Electromechanical Commission (I.E.C) or BS specifications.

CHAPTER-2

ALL ABOUT TRANSFORMER

2.1 Transformer:

A transformer is a device that transfers electrical energy from one circuit to another through magnetically coupled electrical conductors. A changing current in the first circuit (the primary) creates a changing magnetic field; in turn, this magnetic field induces a changing voltage in the second circuit (the secondary). By adding a load to the secondary circuit, one can make current flow in the transformer, thus transferring energy from one circuit to the other.

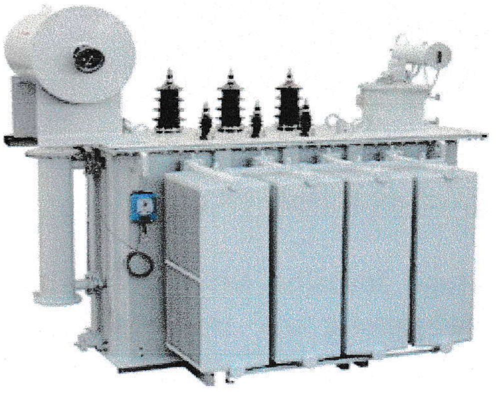


Fig2.1 (a): Transformer

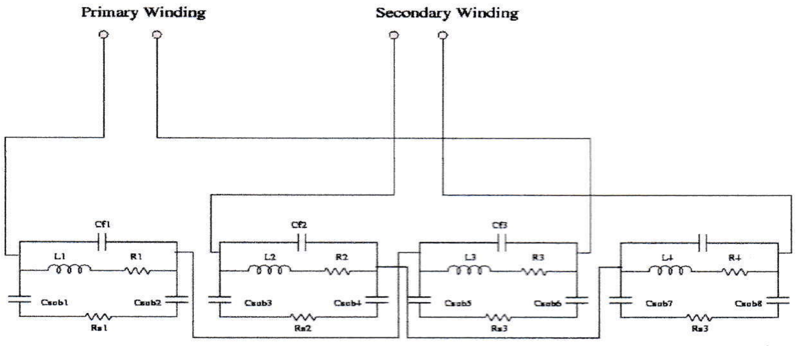


Fig2.1 (b): Transformer showing the primary and secondary windings

2.2 Working Principle of Transformer:

The transformer is based on two principles: first, that an electric current can produce a magnetic field (electromagnetism), and, second that a changing magnetic field within a coil of wire induces a voltage across the ends of the coil (electromagnetic induction) . Changing the current in the primary coil changes the magnetic flux that is developed. The changing magnetic flux induces a voltage in the secondary coil.

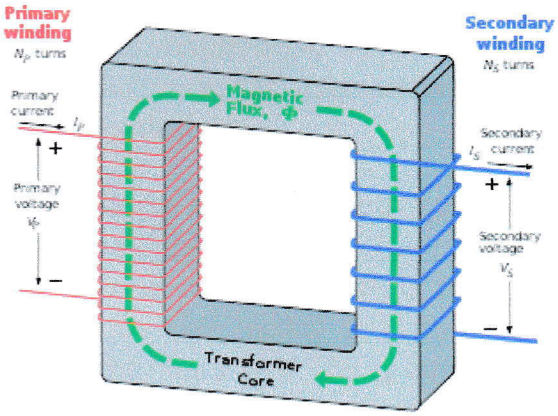


Fig2.2: An ideal transformer

An ideal transformer is shown in the adjacent figure. Current passing through the primary coil creates a magnetic field. The primary and secondary coils are wrapped around a core of very high magnetic permeability such as iron so that most of the magnetic flux passes through both the primary and secondary coils.

2.3 Induction law:

The voltage induced across the secondary coil may be calculated from Faraday's law of induction which states that:

$$V_s = N_s \frac{\mathrm{d}\Phi}{\mathrm{d}t},$$

Where V_s is the instantaneous voltage N_s is the number of turns in the secondary coil and Φ is the magnetic flux through one turn of the coil. If the turns of the coil are oriented perpendicular to the magnetic field lines, the flux is the product of the magnetic flux density B and the area A through which it cuts. The area is constant, being equal to the cross-sectional area of the transformer core, whereas the magnetic field varies with time according to the excitation of the primary. Since the same magnetic flux

2.5 Detailed operation:

The simplified description above neglects several practical factors, in particular the primary current required to establish a magnetic field in the core, and the contribution to the field due to current in the secondary circuit.

Models of an ideal transformer typically assume a core of negligible reluctance with two windings of zero resistance when a voltage is applied to the primary winding, a small current flows, driving flux around the magnetic circuit of the core. The current required to create the flux is termed the *magnetizing current*; since the ideal core has been assumed to have near-zero reluctance, the magnetizing current is negligible, although still required to create the magnetic field.

The changing magnetic field induces an electromotive force (EMF) across each winding. Since the ideal windings have no impedance, they have no associated voltage drop, and so the voltages V_P and V_S measured at the terminals of the transformer, are equal to the corresponding EMFs. The primary EMF, acting as it does in opposition to the primary voltage, is sometimes termed the "back EMF This is due to Lenz's law which states that the induction of EMF would always be such that it will oppose development of any such change in magnetic field.

2.6 Practical considerations:

a) Leakage flux

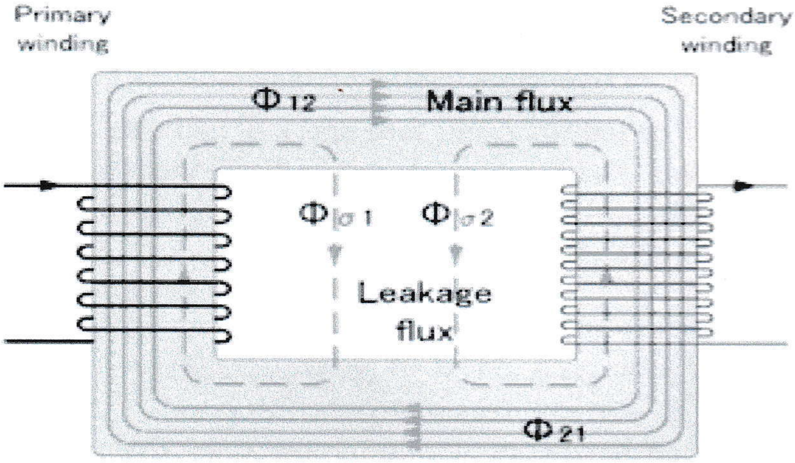


Fig2.6: Leakage flux of a transformer.

passes through both the primary and secondary coils in an ideal transformer, the instantaneous voltage across the primary winding equals.

$$V_p - N_p \frac{d\Phi}{dt}.$$

Taking the ratio of the two equations for V_s and V_p gives the basic equation for stepping up or stepping down the voltage

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}.$$

2.4 Ideal power equation:

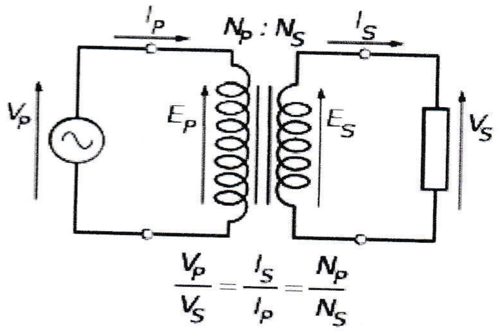


Fig2.4: The ideal transformer as a circuit element

If the secondary coil is attached to a load that allows current to flow, electrical power is transmitted from the primary circuit to the secondary circuit. Ideally, the transformer is perfectly efficient; all the incoming energy is transformed from the primary circuit to the magnetic field and into the secondary circuit. If this condition is met, the incoming electric power must equal the outgoing power:

$$P_{\text{incoming}} = I_p V_p = P_{\text{outgoing}} = I_s V_s,$$

If the voltage is increased, then the current is decreased by the same factor. The impedance in one circuit is transformed by the *square* of the turns ratio For example, if an impedance Z_s is attached across the terminals of the secondary coil, it appears to the primary circuit to have an impedance of $(N_p/N_s)^{2Z_s}$. This relationship is reciprocal, so that the impedance Z_p of the primary circuit appears to the secondary to be $(N_s/N_p)^{2Z_p}$.

The ideal transformer model assumes that all flux generated by the primary winding links all the turns of every winding, including itself. In practice, some flux traverses paths that take it outside the windings. Such flux is termed *leakage flux*, and results in leakage inductance in series with the mutually coupled transformer windings. Leakage results in energy being alternately stored in and discharged from the magnetic fields with each cycle of the power supply. It is not directly a power loss (see "Stray losses" below), but results in inferior voltage regulation causing the secondary voltage to fail to be directly proportional to the primary, particularly under heavy load. Transformers are therefore normally designed to have very low leakage inductance.

However, in some applications, leakage can be a desirable property, and long magnetic paths, air gaps, or magnetic bypass shunts may be deliberately

Introduced to a transformer's design to limit the short-circuit current it will supply.

Leaky transformers may be used to supply loads that exhibit negative resistance such as electric arcs mercury vapor lamps and neon signs or for safely handling loads that become periodically short-circuited such as electric arc welders.

Air gaps are also used to keep a transformer from saturating, especially audio-frequency transformers in circuits that have a direct current flowing through the windings.

Leakage inductance is also helpful when transformers are operated in parallel. It can be shown that if the "per-unit" inductance of two transformers is the same (a typical value is 5%), they will automatically split power "correctly" (e.g. 500 kVA unit in parallel with 1,000 kVA unit, the larger one will carry twice the current).

2.7 Effect of frequency:

Transformer universal EMF equation

If the flux in the core is purely sinusoidal the relationship for either winding between its **rms** voltage E_{rms} of the winding , and the supply frequency f, number of turns N, core cross-sectional area a and peak magnetic flux density B is given by the universal EMF equation:

$$E_{\mathrm{rms}} = \frac{2\pi f N a B_{\mathrm{peak}}}{\sqrt{2}} \approx 4.44 f N a B$$

If the flux does not contain even harmonics the following equation can be used for half-cycle average voltage E_{avg} of any wave shape:

$$E_{\text{avg}} = 4fNaB_{\text{peak}}$$

The time-derivative term in Faraday's Law shows that the flux in the core is the integral with respect to time of the applied voltage. Hypothetically an ideal transformer would work with direct-current excitation, with the core flux increasing linearly with time. In practice, the flux would rise to the point where magnetic saturation of the core occurs, causing a huge increase in the magnetizing current and overheating the transformer. All practical transformers must therefore operate with alternating (or pulsed) current.

The EMF of a transformer at a given flux density increases with frequency. By operating at higher frequencies, transformers can be physically more compact because a given core is able to transfer more power without reaching saturation and fewer turns are needed to achieve the same impedance. However, properties such as core loss and conductor skin effect also increase with frequency. Aircraft and military equipment employ 400 Hz power supplies which reduce core and winding weight. Conversely, frequencies used for some railway electrification systems were much lower (e.g. 16.7 Hz and 25 Hz) than normal utility frequencies (50 – 60 Hz) for historical reasons concerned mainly with the limitations of early electric traction motors. As such, the transformers used to step down the high over-head line voltages (e.g. 15 kV) are much heavier for the same power rating than those designed only for the higher frequencies.

Operation of a transformer at its designed voltage but at a higher frequency than intended will lead to reduced magnetizing current; at lower frequency, the magnetizing current will increase. Operation of a transformer at other than its design frequency may require assessment of voltages, losses, and cooling to establish if safe operation is practical. For example, transformers may need to be equipped with "volts per hertz" over-excitation relays to protect the transformer from overvoltage at higher than rated frequency.

One example of state-of-the-art design is those transformers used for electric multiple unit high speed trains particularly those required to operate across the borders of countries using different standards of electrification. The position of such transformers is restricted to being hung below the passenger compartment. They have to function at different frequencies (down to 16.7 Hz) and voltages (up to 25 kV) whilst handling the enhanced power requirements needed for operating the trains at high speed.

Knowledge of natural frequencies of transformer windings is of importance for the determination of the transient response of the windings to impulse and switching surge voltages.

2.8 Energy losses:

An ideal transformer would have no energy losses, and would be 100% efficient. In practical transformers energy is dissipated in the windings, core, and surrounding structures. Larger transformers are generally more efficient, and those rated for electricity distribution usually perform better than 98%.

Experimental transformers using superconducting windings achieve efficiencies of 99.85%. The increase in efficiency from about 98 to 99.85% can save considerable energy, and hence money, in a large heavily-loaded transformer; the trade-off is in the additional initial and running cost of the superconducting design.

Losses in transformers (excluding associated circuitry) vary with load current, and may be expressed as "no-load" or "full-load" loss. Winding resistance dominates load losses, whereas hysteresis and eddy currents losses contribute to over 99% of the no-load loss. The no-load loss can be significant, so that even an idle transformer constitutes a drain on the electrical supply and a running cost; designing transformers for lower loss requires a larger core, good-quality silicon steel or even amorphous steel for the core, and thicker wire, increasing initial cost, so that there is a trade-off between initial cost and running cost. (Also see energy efficient transformer.

Transformer losses are divided into losses in the windings, termed copper loss and those in the magnetic circuit, termed iron loss. Losses in the transformer arise from:

a) Winding resistance:

Current flowing through the windings causes resistive heating of the conductors. At higher frequencies, skin effect and proximity effect create additional winding resistance and losses.

b) Hysteresis losses:

Each time the magnetic field is reversed, a small amount of energy is lost due to hysteresis within the core. For a given core material, the loss is proportional to the frequency, and is a function of the peak flux density to which it is subjected.

c) Eddy currents:

Ferromagnete materials are also good conductors and a core made from such a material also constitutes a single short-circuited turn throughout its entire length. Eddy currents therefore circulate within the core in a plane normal to the flux, and are responsible for resistive heating of the core material. The eddy current loss is a complex function of the square of supply frequency and Inverse Square of the material thickness. Eddy current losses can be reduced by making the core of a stack of plates electrically insulated from each other, rather than a solid block; all transformers operating at low frequencies use laminated or similar cores.

Stray losses:

Leakage inductance is by itself largely lossless, since energy supplied to its magnetic fields is returned to the supply with the next half-cycle. However, any leakage flux that intercepts nearby conductive materials such as the transformer's support structure will give rise to eddy currents and be converted to heat. There are also radiative losses due to the oscillating magnetic field, but these are usually small.

Dot convention:

It is common in transformer schematic symbols for there to be a dot at the end of each coil within a transformer, particularly for transformers with multiple primary and secondary windings. The dots indicate the direction of each winding relative to the others. Voltages at the dot end of each winding are in phase; current flowing into the dot end of a primary coil will result in current flowing out of the dot end of a secondary coil.

CHAPTER-3

EARTHING DESIGN FOR A H.V. /E.H.V SUBSTATION

3.1Earthing

"Earthing means an electrical connection to the general mass of earth to provide safe passage to fault current to enable to operate protective devices and provide safety to personnel and Equipments.

- **System Earthing**

This is primarily concerned with the protection of Electrical equipment by stabilizing the voltage with respect to ground (Connection between part of plant in an operating system like LV neutral of a Power Transformer winding and earth).

- **Equipment Earthing** (Safety grounding)

This is primarily concerned with the protection of personnel from electric shock by maintaining the potential of noncurrent carrying equipment at or near ground potential. Connecting frames of equipment (like motor body, Transformer tank, Switch gear box, operating rods of Air break switches, etc) to earth.

The system earthing and safety earthing are interconnected and therefore fault current flowing through system ground raises the potential of the safety ground and also causes steep potential gradient in and around the Substation. But separating the two earthing systems have disadvantages like higher short circuit current, low current flows through relays and long distance to be covered to separate the two earths. After weighing the merits and demerits in each case, the common practice of common and solid (direct) grounding system designed for effective earthing and safe potential gradients is being adopted.[5-6]

3.2 Types of Earth Electrode

1. Rod electrode.
2. Pipe electrode.
3. Plate electrode

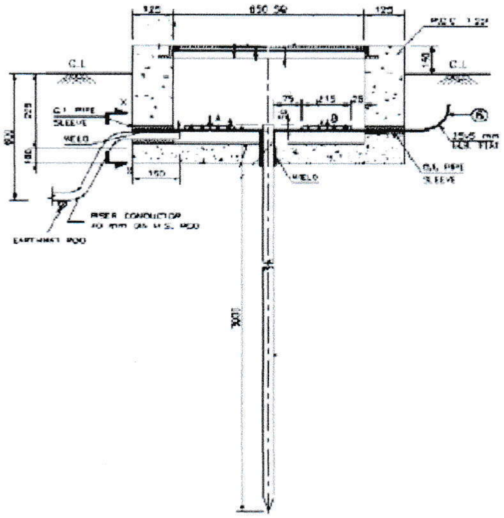


Figure1. Rod type electrode

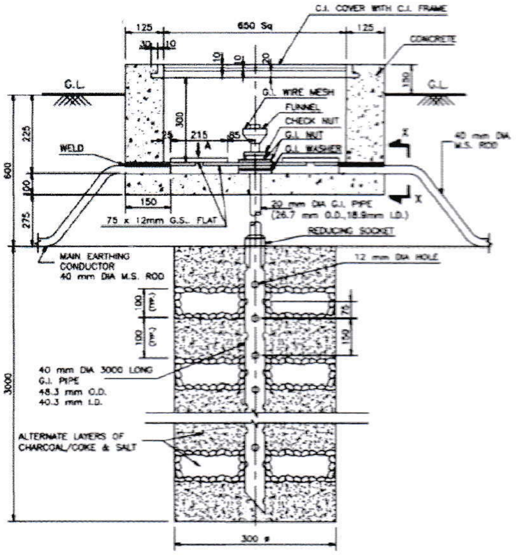


Fig 2. Pipe electrode

Fig 3. Plate electrode

3.3 Factors That Change the Requirement of Earth Electrode

a) If an electrical facility can expand in system, it creates different routes in the electrode. What was formerly a suitable low earth resistance can become obsolete standard.

b) More number of metallic pipes, which were buried underground become less and less dependable as effective low resistance ground connection.

c) Most of the location, the water table gradually falling. In a year or two, area ends up with dry earth of high resistance.

d) These factors emphasize the importance of a continuous, periodic program of earth resistance testing

3.4 The earth resistance shall be as low as possible and shall not exceed the following limits

Sr.No.	Particulars	Permissible values
1.	Power Stations	0.5 Ohms
2.	EHT Substations	1.0 Ohms
3.	33KV Stations	2.0 Ohms
4.	D/T centers	5.0 Ohms
5.	Tower foot resistance	10.0 Ohms

Table1. Earth resistance values

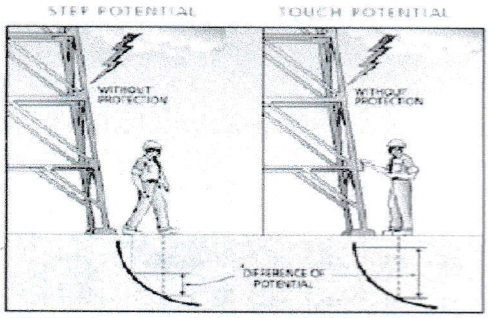
3.5 Terms & Definitions

A. Step Potential

Step Potential is the difference in the voltage between two points which are one meter apart along the earth when ground currents flowing

B. Touch Potential

Touch Potential is the difference in voltage between the object touched and the ground point just below the person touching the object when ground currents are flowing.[7]



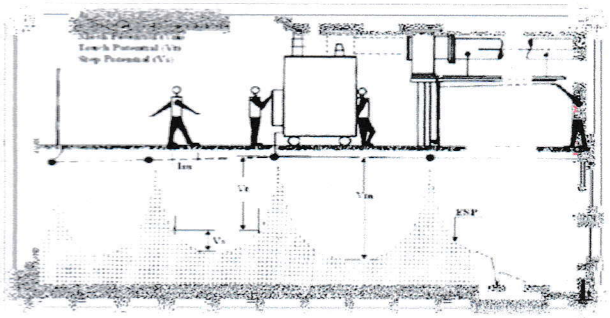
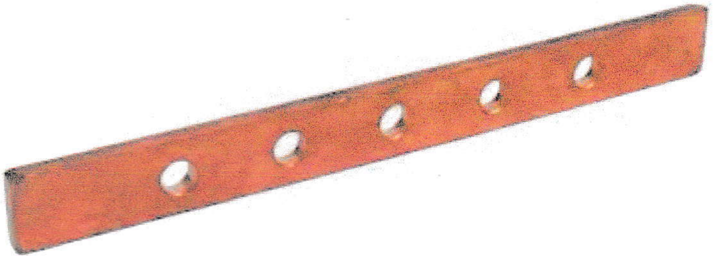


Figure 4. Step & Touch potentials

Figure 5. Ground Potential Rise



C. Ground Potential Rise (GPR)

The maximum electrical potential that a sub-station grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth. This voltage is equal to:

$$GPR = (I_G \times R_g)$$

Where, I_G = Maximum earth grid current

R_g= Earth Grid resistanc

Transferred potential:

A special case of touch potential where a potential is transferred into or out of the sub-station from or to a remote point external to the sub-station site.

A person standing in a sub-station coming in contact with say rails/water pipeline/neutral coming from an adjacent sub-station at the time of occurrence of earth-fault at that sub-station gets exposed to the transferred potential which equals difference in GPRs of the two sub-stations.

➢Specification of Earthing

Depending on soil resistivity, the earth conductor (flats) shall be buried at the following depths.

Table 2.

Sr. No.	Soil Resistivity in ohms/meter	Economical depth of Burial in meters
1)	50 – 100	0.5
2)	100 – 400	1.0
3)	400 – 1000	1.5

To keep the earth resistance as low as possible in order to achieve safe step and touch voltages, an earth mat shall be buried at the above depths below ground and the mat shall be provided with grounding rods at suitable points. All non-current carrying parts at the Substation shall be connected to this grid so as to ensure that under fault conditions, none of these parts are at a higher potential than the grounding grid.

➢Following points should be fallow to keep the earth resistance as low as possible.

- Remove Oxidation on joints and joints should be tightened.
- Poured sufficient water in earth electrode.
- Used bigger size of Earth Electrode.
- Electrodes should be connected in parallel.
- Earth pit of more depth & width- breadth should be made.

Plate Earths

Taking all parameters into consideration, the size of plate earths are decided as

- Power Stations & EHV Station - Main - 100 x 16mm
  - Auxiliary - 50 x 8mm
- Small Stations - 75 x 8mm

3.6 Earth Mat Design

Earthing System in a Sub Station comprises of Earth Mat or Grid, Earth Electrode, Earthing Conductor and Earth Connectors.

3.6.1 Earth Mat or Grid

Primary requirement of Earthing is to have a low earth resistance. Substation involves many Earthlings through individual Electrodes, which will have fairly high resistance. But if these individual electrodes are inter linked inside the soil, it increases the area in contact with soil and creates number of parallel paths. Hence the value of the earth resistance in the inter linked state which is called combined earth value which will be much lower than the individual value.

The inter link is made thro flat or rod conductor which is called as Earth Mat or Grid. It keeps the surface of substation equipment as nearly as absolute earth potential as possible. To achieve the primary requirement of Earthing system, the Earth Mat should be design properly by considering the safe limit of Step Potential, Touch Potential and Transfer Potential.

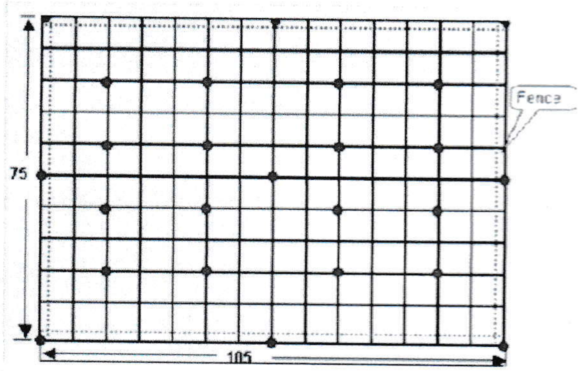


Figure 6. General configuration of earth mat

3.6.2 The factors which influence the Earth Mat design are:

- Magnitude of Fault Current
- Duration of Fault
- Soil Resistivity
- Resistivity of Surface Material
- Shock Duration

- Material of Earth Mat Conductor
- Earthing Mat Geometry

3.6.3 The design parameters are:

- Size of Earth Grid Conductor
- Safe Step and Touch Potential
- Mesh Potential (Emesh)
- Grid configuration for Safe Operation
- Number of Electrodes required
-

III. MATHEMATICAL CALCULATION

3.7 Prerequisites

The following information is required / desirable before starting the calculation:

- A layout of the site.
- Maximum earth fault current into the earthing grid.
- Maximum fault clearing time.
- Ambient (or soil) temperature at the site.
- Soil resistivity measurements at the site (for touch and step only).
- Resistivity of any surface layers intended to be laid (for touch and step only).

3.8 Step and touch voltage criteria

The safety of a person depends on preventing the critical amount of shock energy from being absorbed before the fault is cleared and the system de-energized. The maximum driving voltage of any accidental circuit should not exceed the limits defined as follows.

For step voltage the limit is

- The tolerable step voltage criteria is

$$E_{Step} = [1000 + (6 \times C_s \times \rho_s)]\frac{0.116}{\sqrt{t_s}} \quad (1)$$

- The tolerable touch voltage criteria is

$$E_{Touch} = [1000 + (1.5 \times C_s \times \rho_s)]\frac{0.116}{\sqrt{t_s}} \quad (2)$$

Where,

Estep = the step voltage in V

Etouch = the touch voltage in V
Cs= 1for no protective layer

ρs = the resistivity of the surface material in
Ω·mts = the duration of shock current in
seconds

- The earth grid conductor size formula is mentioned below

$$I = A\sqrt{\frac{(TCAP\times 10^4)}{t_c\times\alpha_r\times\rho_r}\, ln\left(\frac{k_0+T_M}{k_0+T_a}\right)} \qquad (3)$$

Where,

I = r.m.s value in kA

A = conductor sectional size in mm² Tm =
maximum allowable temperature in ˚C Ta =
ambient temperature for material constants
in˚C $\alpha_\circ$= thermal coefficient of resistivity at 0˚C
α_r = thermal coefficient of resistivity at reference temperature Tr

ρᵣ = the resistivity of the ground conductor at reference temperature Tr
in uA/cm3 $K_\circ$ = 1/$\alpha_\circ$ or 1/$\alpha_\circ$ - Trtc = time of current flow in sec TCAP =
thermal capacity factor

☐ Spacing factor for mesh voltage (Km)

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

Where,

D = spacing between conductor of the grid
in m d = diameter of grid conductor in m
Km = spacing factor for mesh voltage
Kii = 1 for grids with rods along perimeter

Kh = Corrective weighting factor for grid depth

☐ Spacing factor of step voltage (Ks)

$$K_S = \frac{1}{\pi}\left[\frac{1}{2h}+\frac{1}{(D+h)}+\frac{1}{D}(1-0.5^{n-2})\right] \qquad (5)$$

Where

D = spacing between conductor of the grid
in m h = depth of burial grid conductor in m
n = number of parallel conductor in one direction

Evaluation of ground resistance

A good grounding system provides a low resistance to remote earth in order to minimize the GPR. For most transmission and other large substations, the ground resistance is usually about 1 Ω or less. In smaller distribution substations, the usually acceptable range is from 1 Ω to 5 Ω, depending on the local conditions.[3]

For calculation of grounding resistance, the following formula is used

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}}\right)\right] \qquad (6)$$

Where

ρ = soil resistivity Ωm

Lt = total length of grid conductor m
A = total area enclosed by earth grid
m2 h = depth of earth grid conductor
m

- For calculation of grid current, equation[11]

$$I_G=(C_P \times D_f \times S_f \times I) \qquad (7)$$

- For calculation of grid potential rise

$$GPR = (I_G \times R_g) \qquad (8)$$

Actual Step Potential & Touch Potential Calculations

Formula for calculation of mesh voltage is

$$E_m = \left[\frac{\rho \times K_m \times K_i \times K_{im}}{LL+LB+LA+(1.15 \times LE)}\right] \quad (9)$$

Formula for calculation of step voltage is

$$E_s = \left[\frac{\rho \times K_m \times K_i \times K_{is}}{LL+LB+LA+(1.15 \times LE)}\right] \quad (10)$$

Where

ρ = soil resistivity, ohms-m

Em = mesh voltage at the center of corner mesh in V

Es = step voltage between point in V

Km = spacing factor for mesh voltage

K_s = spacing factor of step voltage

K_m = correct factor for grid geometry

LL= Length of grid conductor along length of switch yard

LB= Length of grid conductor along breadth of switch yard

LA= Length of riser and auxiliary mat in switch yard

LE= Length of earth electrodes in switch yard

LT= Total length of earth conductor in switch yard

$$LT = (LL + LB + LA + LE) \quad (11)$$

3.10. RESULT

The Input Constant values for design calculations & Output results for grid construction design are given in following tables

Parameters	Symbol	Value	Units
Ambient temperature	Ta	45	°c
Maximum allowable temperature	Tm	450	°c
Fault duration time	ts	1s	Sec
Thermal coefficient of	αr	0.0032	

resistivity			
Resistivity of conductors	ρr	20.1	μΩ/cm
Resistivity of substation soil	ρ	201.8	Ωm
Resistivity of surface material	ρs	2000	Ωm
Thermal capacity factor	TCAP	3.931	j/cm^3/°c
Depth of burial conductor	h	0.6	m
Reference depth of grid	ho	1	m
Conductor spacing	D	7	m
Diameter of grid conductor	d	34	mm
Length of one earth rod	Lr	3	m

Table 3 Input Constant values for design calculations

Parameters	Symbol	Value	Units
Earth conductor size	A	793.1	mm^2
Maximum grid current	IG	20	KA
Ground resistance	Rg	0.301732	Ω
Ground potential rise	GPR	6034.633	Volt
Spacing factor for mesh voltages	Km	0.380395	
Spacing factor for step voltages	Ks	0.352793	
Touch voltage criteria	Etouch	554.0823	Volt
Step voltage criteria	Estep	1724.183	Volt
Maximum attainable step voltage (Actual step voltage)	Es	389.6783	Volt
Maximum attainable mesh voltage(Actual touch voltage)	Em	374.1747	Volt
Total length of earth conductor in switch yard	LT	34405.5	m

Table 4 Output results for grid construction design

The main electrical properties of an earthing system are:

- Earthing resistance
- Earth surface potential distribution
- Current carrying ability

The most favorable earth surface potential distribution concepts have horizontal earth electrodes, especially meshed ones, whose surface potential can be controlled relatively simply. The potential distribution of vertical electrodes is the most unfavorable, with high values of touch potential. On the other hand, vertical electrodes can easily reach low earthing resistance with stable values, largely independent from seasons. Vertical electrodes are also used in combination with horizontal ones in order to reach lower values of earthing resistance. These results are obtained above prove that this earth grid design is safe for 400 kV substation in the range of soil resistivity 100-350 Ωm.

CHAPTER-4

SAFETY AND SECURITY

4.1 EARTHING AND CABLES:

Earthing, The process of connecting the metallic frame (i.e. non-current carrying part) of electrical equipment or some electrical part of the system (e.g. neutral point in star-connected system, one conductor of the secondary of a transformer etc) to earth is called grounding or earthing.

It is strange but true that grounding of electrical system is less understood aspect of power system. It is a very important, if grounding is done systematically in the line of the power system, we can effectively prevent accidents, and damage to the equipment of the power system and at the same time continuity of supply can be maintained. Grounding or ear thing may be classified as

(1) Equipment of earthing (2) System earthing.

Equipment grounding deals with ear thing the non-current-carrying metal parts of the electrical equipment. On the other hand, system grounding means ear thing some part of the electrical system e.g. ear thing of neutral point of star-connected system in generating stations and substations.

4.2 Sub-Station Earthing:

The earthlings of all equipment shall be in accordance with the IEEE Recommendation No. 80:1976-Guide for safety in alternating current sub-station grounding the British standard code of practice CP1013:1965 or other approved standard. The contract includes the provision of materials and Installation of the complete Sub-station ear thing system, including the earth connections of all equipment supplied under this contract, earth connections to panel and any other auxiliary equipment's commissioning and testing of the ear thing system.

In electricity supply systems, an ear thing system defines the electrical potential of the conductors relative to that of the Earth's conductive surface. The choice of ear thing system has implications for the safety and electromagnetic compatibility of the power supply. Note that regulations for ear thing (grounding) systems vary considerably between different countries.

A protective earth (PE) connection ensures that all exposed conductive surfaces are at the same electrical potential as the surface of the Earth, to avoid the risk of electrical shock if a person touches a device in which an insulation fault has occurred.

It ensures that in the case of an insulation fault (a "short circuit"), a very high current flows, which will trigger an over current protection device (fuse, circuit breaker) that disconnects the power supply.

A functional earth connection serves a purpose other than providing protection against electrical shock. In contrast to a protective earth connection, a functional earth connection may carry a current during the normal operation of a device. Functional earth connections may be required by devices such as surge suppression and electromagnetic-compatibility filters, some types of antennas and various measurement instruments. Generally, the protective earth is also used as a functional earth, though this requires care in some situations

4.3 Ear thing System:

The earthing system shall be based on soil resistively of 1 ohm-meter for wet soil and 10 ohm-meters for dry soil.

Earthing points shall be provided such that the combined resistance of the earth network and ear thing points does not exceed 1.0 ohms under any climatic conditions.

The operating mechanisms of isolators, earth switches and circuit breaker are not integral with the circuit breaker shall be connected to the earth system by a branch entirely separated from that employed to earth their buses. The branch is to be installed such that the connection would pass beneath where an operator would stand, so as to minimize step potential. Connections to plant and equipment shall be made using the ear thing terminals specified. When a strip has to be drilled to fit earth terminals the diameter of the hole shall not be greater than half width of the strip.

Joints in ear thing strip shall employ chemical welding or high compression joints or clamp.

4.4 Equipment to be connected the Earthing:

1) Switchgear:

All metal parts including any relays, instruments, etc. Mounted on the switchboard, shall be connected to a Copper earth bar which runs along the full length of the switchboard. The cross-section of the bar shall be sufficient to carry the rated short-time withstand current of the switchgear for five seconds.

The frame of the draw-out circuit breakers shall be connected to the earth bar through a substantial plug type contact.

2) Low voltage panels:

Earth metal of switchboards, fuse boards, and distribution boards shall be bounded together and earthed to the main station ear thing system. Earthing connections shall be carried out in bare copper strip having a 3 second rating not less than 20KA.

3) Control Panels:

Each control panel shall be provided with a copper earth bar of not less than 80sq. mm. cross section and arranged so that the bar of adjacent panel can be joined together to form a common bar. The common ear thing bus bar of control and relay panels shall be

Connected to the main station ear thing systems via a copper ear thing connection of not less than 80sq

4.5 BUSBAR:

In electrical power distribution a bus bar is a thick strip of copper or aluminum that conducts electricity within a switchboard distribution board substation or other electrical apparatus. Bus bars are used to carry very large currents, or to distribute current to multiple devices within switchgear or equipment. For example, a household circuit breaker panel board will have bus bars at the back, arranged for the connection of multiple branch circuit breakers. An aluminum smelter will have very large bus bars used to carry tens of thousands of amperes to the electrochemical cells that produce aluminum from molten salts. The size of the bus bar is important in determining the maximum amount of current that can be safely carried. Bus bars can have a cross-sectional area of as little as 10 mm^2 but electrical substations may use metal tubes of 50 mm in diameter (1,963 mm^2) or more as bus bars.

Fig 4.5 : 1500 ampere bus bars within a power distribution rack for a large building

4.6 Design and placement:

Bus bars are typically either flat strips or hollow tubes as these shapes allow heat to dissipate more efficiently due to their high surface area to cross-sectional area ratio. The skin effect makes 50–60 Hz AC bus bars more than about 8 mm (1/3 in) thick inefficient, so hollow or flat shapes are prevalent in higher current applications. A hollow

Section has higher stiffness than a solid rod of equivalent current-carrying capacity, which allows a greater span between bus bar supports in outdoor switchyards.

A bus bar may either be supported on insulators, or else insulation may completely surround it. Bus bars are protected from accidental contact either by a metal earthed enclosure or by elevation out of normal reach. Neutral bus bars may also be insulated. Earth bus bars are typically bolted directly onto any metal chassis of their enclosure. Bus bars may be enclosed in a metal housing, in the form of bus duct or bus way, segregated-phase bus, or isolated-phase bus.

Bus bars may be connected to each other and to electrical apparatus by bolted or clamp connections. Often joints between high-current bus sections have matching surfaces that are silver-plated to reduce the contact resistance. At extra-high voltages (more than 300 kV) in outdoor buses, corona around the connections becomes a source of radio-frequency interference and power loss, so connection fittings designed for these voltages are used.

Bus bars are typically contained inside of either a distribution board or bus way.

4.7 Distribution boards:

Distribution boards split the electrical supply into separate circuits at one location.

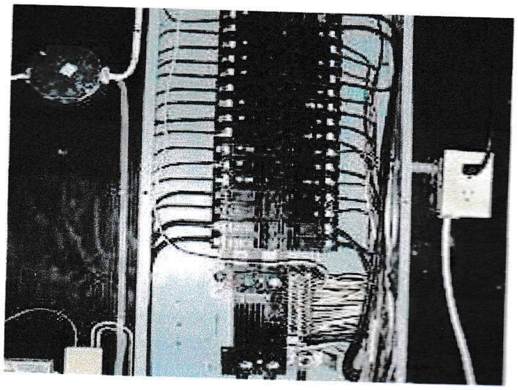


Fig 4.7: Two hot bus bars are visible in this distribution board, traveling vertically from the main circuit breaker at top to feed the rows of breakers below it.

4.8 Bus ducts:

Branching the main Bus ways, or bus ducts, are long bus bars with a protective cover. Rather than supply at one location, they allow new circuits to branch off anywhere along the route of the bus way.

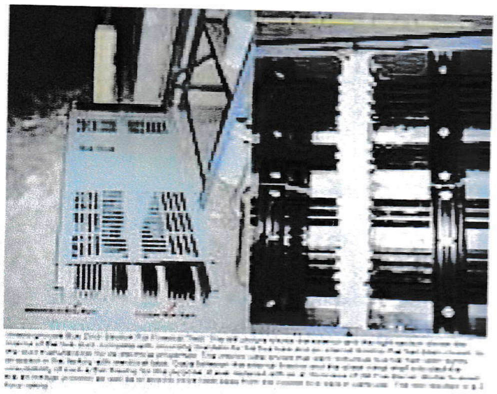


Fig 4.8: The bus bars contained within are visible in this opened bus way, above the arrows at left and traveling horizontally at right. This bus way section was used in a fire test of a fire stop system, achieving a 2 hour fire-resistance rating

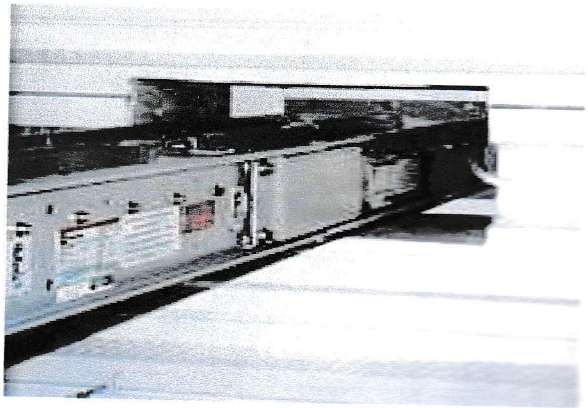


Fig 4.8 (a) : Bus duct penetration, awaiting fire stop

4.9 Represent of Supply to Metering:

- The different methods of MV service connection, which may be one of four types: Single-line service

- Single-line service (equipped for extension to form a ring main)
- Duplicate supply service
- Ring main service

- General protection at MV, and MV metering functions
- Protection of outgoing MV circuits
- Protection of LV distribution circuits

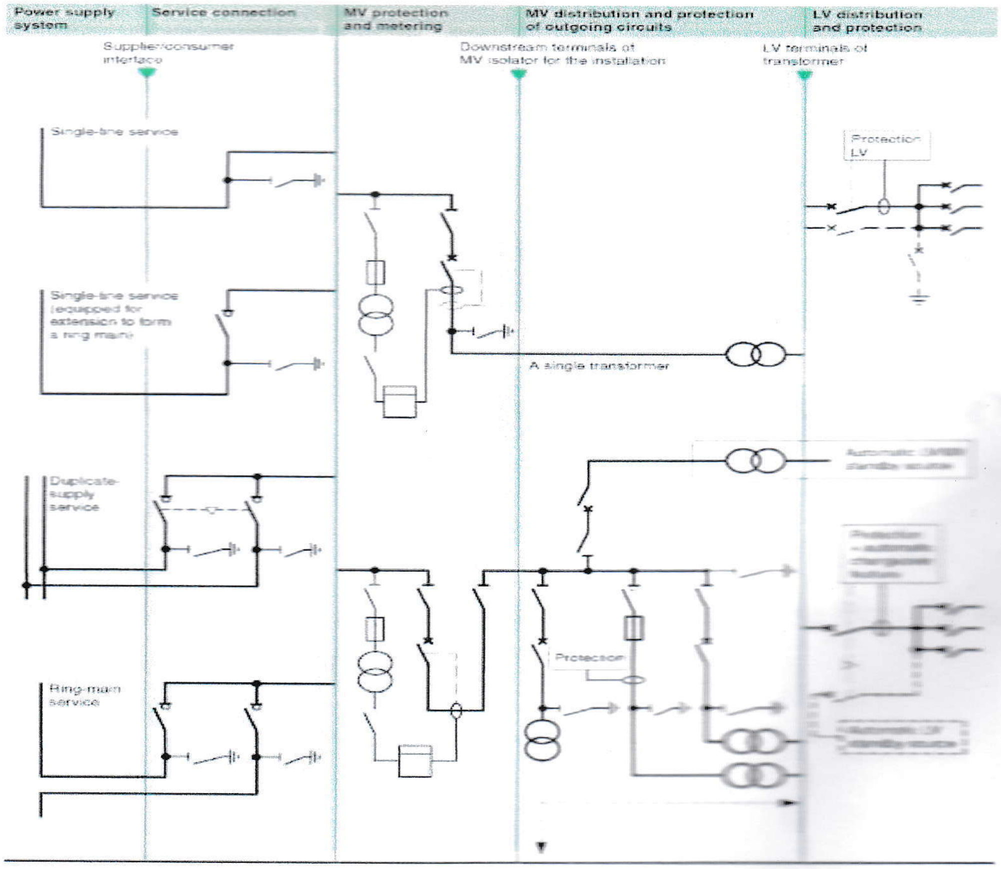


Fig 5.9: Consumer substation with MV metering

4.10 Neutral Ear thing:

The 0.38kv neutral of the 11/0.415 kv transformer shall incorporate provision for the scheduled current transformers and shall be directly connected to the main station ear thing system. The connection shall be formed of twin conductors and shall be capable of carrying 20 KA for five seconds.

4.11 Ear thing Materials:

2 Sets Earthing Block

2 Nos. Copper ear thing block with required Nos. of ¼ inch. Hole for ECC connection. Size- 254mm x 40mmx10mm. One for transformer neutral and another for all substation equipments ECC connections.

4 Sets Earth Electrode:

1.5 inch dia GI Pipe buried up to the depth of 80 fit in the damp soil including 2 SWG copper wires from bottom of GI pipe up to ground level.

150-rft Earthing lead:

2 SWG copper wire through 1 inc dia PVC pipe (if required) from ear thing block to earth electrode.

100 rft Earth Continuity Conductor:

Installation of 2 SWG copper earth continuity conductor running from the bodies of substation equipment to the ear thing block.

CONCLUSION

This paper has a focus on designing of a 400 kV HV/EHV AC substation earthing system. The results for earthing system are obtained by computational method. For earthing conductor and vertical earth electrode, mild steel are used. The step by step approach for designing a substation earthing system is presented. The various kinds of conductor sizes for earth equipment are mentioned in this paper. Construction of earthing grid is expressed in here. The step and touch voltages are dangerous for human body. Human body may get electric shocks from step and touch voltages. When high voltage substations are to be designed, step and touch voltages should be calculated and values must be maintained specified standard. Importance to be given to the transfer of Ground Potential rise (GPR) under fault conditions to avoid dangerous situations to the public, customer and utility staff. The values of step and mesh voltages obtained for 400 kV substation are respectively 389.6783 Volt and 374.1747 Volt which are within the permissible limits.

FUTURE WORK

- Mathematical modeling and simulation.
- Programming and Designing by using MATLAB & E-TAP Software.
- Focus on the study to minimize the problems in earthing.
- Recommendation to minimize the problems in earthing in Existing substation.

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