II. Transmission Line

1. TRANSMISSION LINE FACILITIES

Ghana Grid Company

M01 –TRANSMISSION LINE COMPONENTS OVERVIEW

1.1 Objectives

Through this module participant will be able to;

- Identify the various types of towers in terms of their classifications, shapes, and designation.
- Identify the various types of insulators, conductors and related accessories.

1.2 Introduction

The electricity supply network can be broadly divided into three main sections as generation, transmission and distribution. The generation consists of the power stations where electricity is generated at a relatively lower voltage. These power stations are located close to the sources of the fuel used to fire the plant and are usually far away from the main load centers (city and industrial centres).

The generated power is transmitted to the main load centres at high voltages through the transmission network. The transmission lines terminate at substations where the voltage level is stepped down to a level suitable for use by consumers. The length of the transmission network between the substations and the main load centers can span several thousand kilometers with many substations located in the cities, towns, villages, industrial parks, etc.

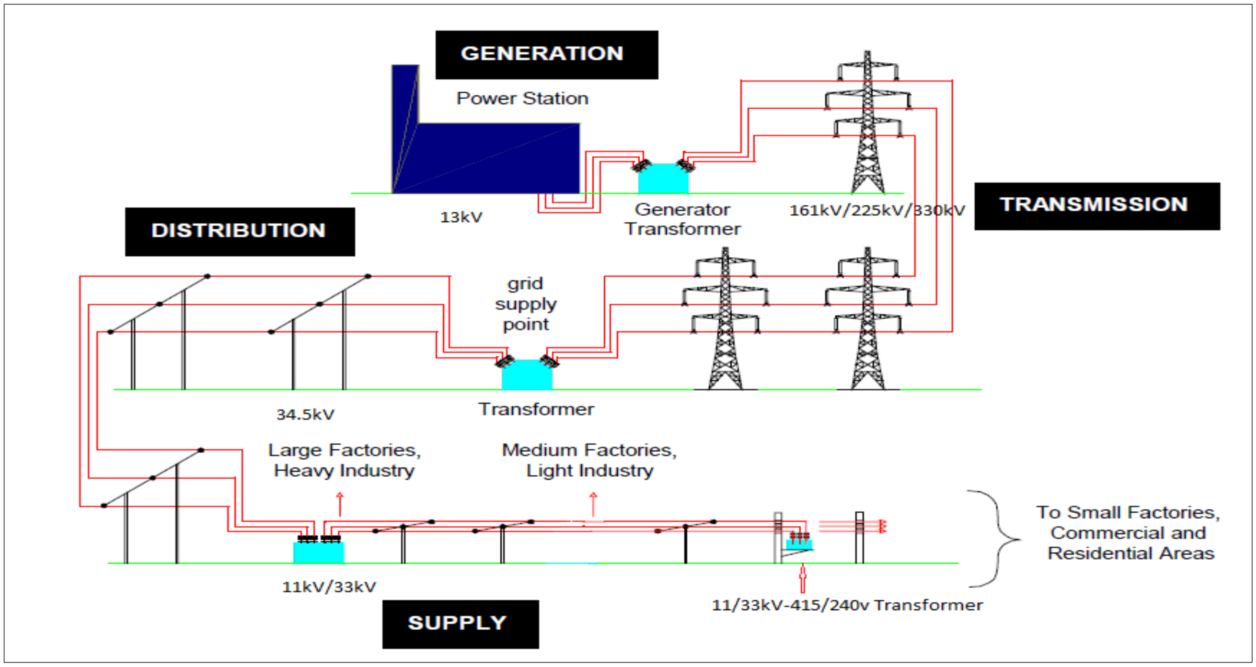


Figure 1-1. Typical Interconnected Electricity Supply System

A power transmission line is a structure used in electric power transmission and distribution to transmit electrical energy along large distances. It consists of one or more conductors (commonly multiples of three) suspended by towers or poles. Since most of the insulation is provided by air, overhead power lines are generally the lowest-cost method of power transmission for large quantities of electric energy. In this module, we will have an opportunity to understand major components which make an overhead power transmission line.

1.2.1 A Brief about Ghana Grid Company Limited (GRIDCo)

Before the establishment of GRIDCo, Volta River Authority (VRA) was responsible for Generation and Transmission of power in Ghana. VRA was also responsible for power distribution in 4 regions of Northern part of Ghana.

GRIDCo was established in 2008 for the exclusive operation of the National Interconnected Transmission System in Ghana as an independent utility. The transmission functions of the Volta River Authority (VRA) was therefore separated from its other activities within the framework of the Power Sector Reforms.

1.2.2 GRIDCo's Function

Undertake economic dispatch and transmission of electricity from wholesale suppliers (generating companies) to bulk customers, i.e. Electricity Company of Ghana (ECG), Northern Electricity Company (NEDCO) and the Mines

Provide fair and non-discriminatory transmission services to all power market participants

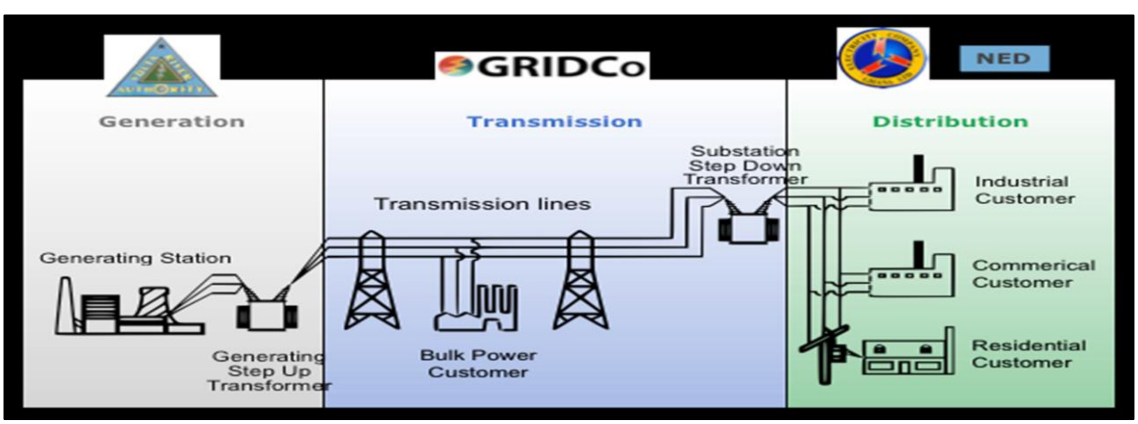


Figure 1-2. Where GRIDCo stands in Ghana Power System

1.2.3 GRIDCo's Customers

GRIDCO supplies power to various industrial loads above 5MVA allowed by the Grid Code. These includes

- Major Mining Companies in Ghana (e.g. AGA, NEWMONT)
- VALCO (Aluminum Smelter)
- Domestic Distribution Companies (ECG and NEDCo)

Customers are required to have Transmission Service Agreement with GRIDCo.

1.2.4 GRIDCo Transmission Line

GRIDCo transmission grid comprises 4,159 kilometers of single circuit 161kV transmission lines, 1,037 kilometers of double circuit 161kV transmission lines, 74.5 kilometers of single circuit 225 kV transmission line, 133 kilometers of 69 kV line and 365 kilometers of 330kV transmission line. There are 66 substations that either serve as switching stations with no power transformers, step-up stations for the generation plants and/or step-down stations that step down the high voltages to various medium voltages (34.5kV, 11.5kV) meant for the distribution system.

Volta Level	Circuit Length (Km)	Remarks
330kV	365	Backbone Transmission Network (WAPP)
225kV	74.5	Ghana – Cote d'Ivoire Interconnection
161kV	5,196	Main transmission Voltage
69kV	133	In Volta Region

Table 1-1. Transmission Line Length by Voltage

1.2.5 Components of the Transmission Line

GRIDCo's transmission line towers are almost entirely built of steel lattice, self-supporting, four legged structures except for an 8km steel tubular monopole line which was constructed between Tarkwa and New Tarkwa substations in 2004 and a section of the Bogoso – Akyempim line which was partly built in 2005 of guyed steel towers.

Conductors on double circuit lines are arranged in vertical configuration, single circuit lines in a triangular configuration mainly with two shieldwires on top of the tower peak except the system inherited from ECG, the Togo/Benin lines and the 161kV "light" lines in Northern Ghana where only a single shieldwire is provided. The phase conductors are mainly single conductor All Aluminium Conductors (AAC) for the 1965 lines and Aluminium Conductor Steel Reinforced (ACSR) for the newer lines. Some of the lines developed under Northern Electrification and System Reinforcement Project (NESRP) and thereafter are twin-bundle conductors.

The insulators are either porcelain or glass. A number of the porcelain insulators which are on the older lines are however being changed to glass.

The high voltage lines have a Right-Of-Way (ROW) of between 30 and 40 meters (15 to 20 meters on either side of the center line) within which no physical and permanent development is to be carried out.

The optical fiber ground wires (OPGW) was installed on the transmission lines for the first time during the construction of transmission lines associated with the Takoradi Thermal Power Project.

For existing lines, one shieldwire is replaced with the OPGW and for new lines one shieldwire and one OPGW is installed. The use of OPGW therefore started with the coast lines Takoradi to Achimota and today the entire southern ring and all new lines are fitted with OPGW.

1.3 TOWERS

1.3.1 Definition

The main supporting structures of overhead transmission lines are transmission towers. Transmission towers have to carry the heavy transmission conductor at a sufficient safe height from ground. In addition to that, all towers have to sustain all kinds of natural calamities. So transmission tower designing is an important engineering job where all three basic engineering concepts, civil, mechanical and electrical engineering concepts are equally applicable. This module is going to briefly introduce the various parts of a transmission tower and the various classifications of towers available.

1.3.2 Classification of Transmission Towers

According to different considerations, transmission towers are classified into different categories as follows:

- Classification by features
- Classification by materials used
- Classification by purpose

1.3.2.1 Tower Classification by Features

There are two types of towers under this category-.

- Self-supporting tower
- Guyed tower

Self-supporting tower

Quadrangular tower: The strength from a direction of a line is the same as the strength at a right angle and usually lattice tower.

Figure1- 3. Self-supporting tower

Guyed tower

In a guyed tower, the guy wires support the tower and share the load of the tower.

Figure 1-4. Guyed tower

1.3.2.2 Classification by Material Used

- **Lattice tower**

Steel lattice towers are used at under-voltage levels below 345kV transmission line.

Figure1- 5. Lattice tower

- **Pipe tower**

Pipe towers are used at voltage levels above 345kV transmission lines.

Figure 1-6. Pipe tower

- **Tubular steel poles**

Steel transmission poles are fabricated from uniformly tapered hollow steel sections. The cross sections of the poles vary from round to 16-sided polygonal with the 12-sided dodecagonal as the most common shape. The poles are formed into design cross-sections by braking, rolling, or stretch bending. For these structures the usual industry practice is that the analysis, design, and detailing are performed by the steel pole supplier. This facilitates the design to be more compatible with fabrication practice and available equipment.

Figure 1-7. Tubular steel poles

1.3.2.3 Classification by Purpose

(a) According to the angle of deviation

The transmission line goes as per available corridors. Due to unavailability of shortest distance straight corridor transmission line has to deviate from its straight way when obstruction comes. In total length of a long transmission line there may be several deviation points. According to the angle of deviation there are four types of transmission tower-

- A – Type tower – angle of deviation 0_o to 2_o.
- B – Type tower – angle of deviation 2_o to 15_o.
- C – Type tower – angle of deviation 15_o to 30_o.
- D – Type tower – angle of deviation 30_o to 60_o.

(b) According to the force applied

As per the force applied by the conductor on the cross arms, the transmission towers can be categorized in another way-

- **Suspension-tower:** it is generally A - type tower.
- **Angle tower or tension-tower:** All B, C and D types of transmission towers come under this category.

1.3.2.4 Classification According to the Number of Circuits

Based on numbers of circuits carried by a transmission tower, it can also be classified as-

- Single circuit tower
- Double circuit tower
- Multi circuit tower.

Figure 1-8: SINGLE CIRCUIT TOWER DOUBLE CIRCUIT TOWER MULTI CIRCUIT TOWERS

1.3.2.5 Classification According to the Arrangement of the Phase Conductors

Towers have one of these three basic configurations:-

- Horizontal
- Vertical
- Delta

Depending on the arrangement of the phase conductors.

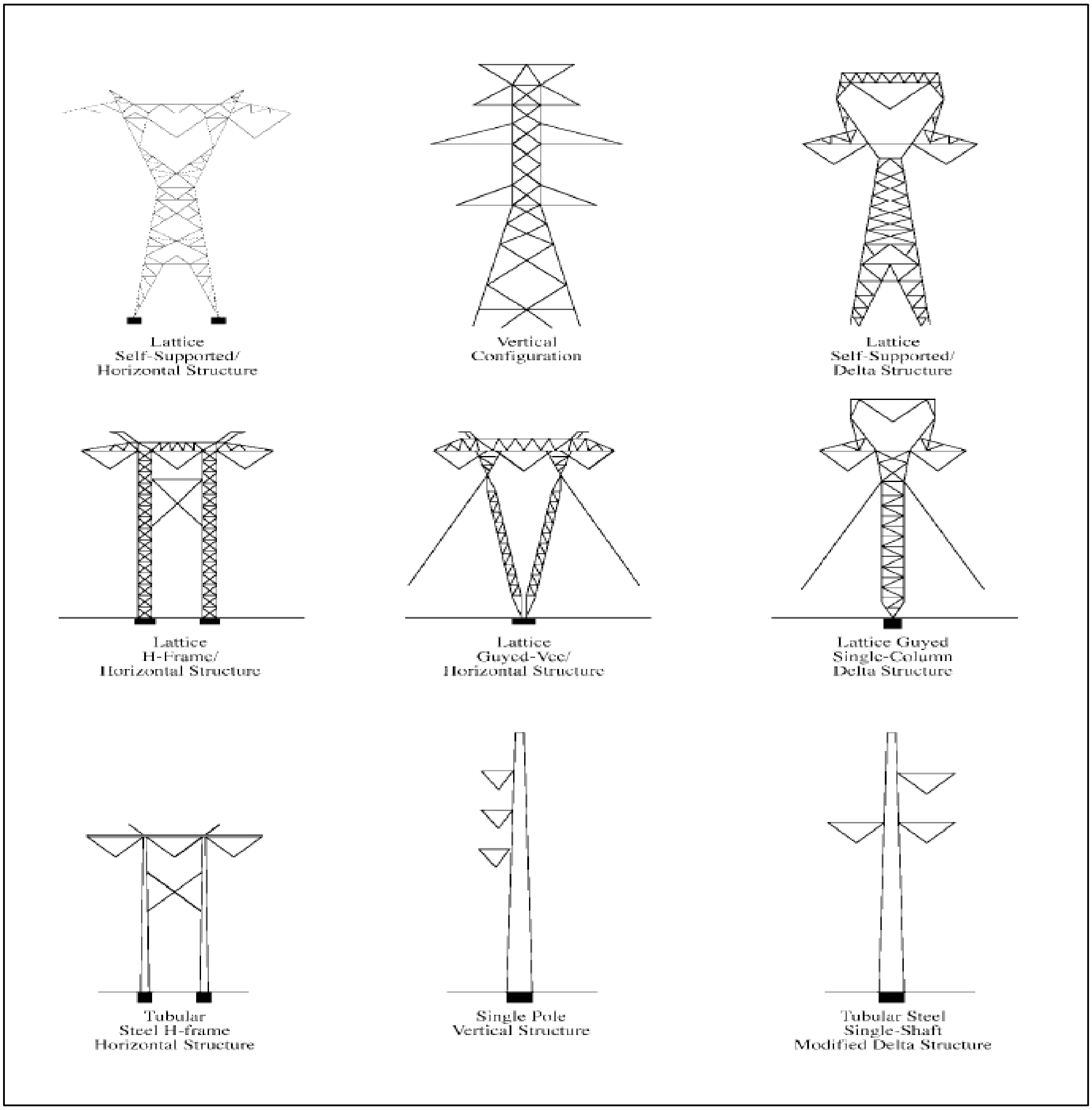


Figure 1-9. The arrangement of the phase conductors

1.3.2.6 Special Purpose Towers

Apart from the above customized towers, there are towers designed to meet special usages listed below:

- River crossing tower
- Railway/ Highway crossing tower
- Transposition tower

1.3.3 Structure Configuration and Material

Structure cost usually accounts for 30 to 40% of the total cost of a transmission line. Therefore, selecting an optimum structure becomes an integral part of a cost-effective transmission line design. A structure study usually is performed to determine the most suitable structure configuration and material based on cost, construction, and maintenance considerations and electric and magnetic field effects. Some key factors to consider when evaluating the structure configuration are:

- A horizontal phase configuration usually results in the lowest structure cost.
- If right-of-way costs are high, or the width of the right-of-way is restricted or the line closely parallels other lines, a vertical configuration may be lower in total cost.
- In addition to a wider right-of-way, horizontal configurations generally require more tree clearing than vertical configurations.
- Although vertical configurations are narrower than horizontal configurations, they are also taller, which may be objectionable from an aesthetic point of view.
- Where electric and magnetic field strength is a concern, the phase configuration is considered as a means of reducing these fields. In general, vertical configurations will have lower field strengths at the edge of the right-of-way than horizontal configurations, and delta configurations will have the lowest single-circuit field strengths and a double-circuit with reverse or low-reactance phasing will have the lowest possible field strength.

1.4 INSULATORS

1.4.1 Definition

These are mechanically strong materials with high resistance that support and anchor the conductors and insulate them from the tower. The main cause of failure of overhead line insulator, is flash over, occurs in between line and earth during abnormal over voltage in the system. During this flash over, the huge heat produced by arcing, causes puncher in insulator body. Viewing this phenomenon the materials used for electrical insulator, has to possess some specific properties.

1.4.2 Properties of Insulating Materials

The materials generally used for insulating purpose is called insulating material. For successful utilization, this material should have some specific properties as listed below-

- It must be mechanically strong enough to carry tension and weight of conductors.
- It must have very high dielectric strength to withstand the voltage stresses in High Voltage System.
- It must possesses high Insulation Resistance to prevent leakage current to the earth.
- The insulating material must be free from unwanted impurities.
- It should not be porous.
- There must not be any entrance on the surface of electrical insulator so that the moisture or gases can enter in it.
- There physical as well as electrical properties must be less effected by changing temperature.

1.4.3 Types of Insulators

Insulators are usually made of the following materials-

- Porcelain,
- Glass
- Polymer

1.4.3.1 Porcelain Insulator

Porcelain is the most commonly used material for overhead insulator in present days. The porcelain is aluminium silicate. The aluminium silicate is mixed with plastic kaolin, feldspar and quartz to obtain the final hard and glazed porcelain insulator material. The surface of the insulator should be glazed enough so that water should not be traced on it. Porcelain should also be free from porosity since porosity is the main cause of deterioration of its dielectric property. It must also be free from any impurity and air bubble inside the material which may affect the insulator properties.

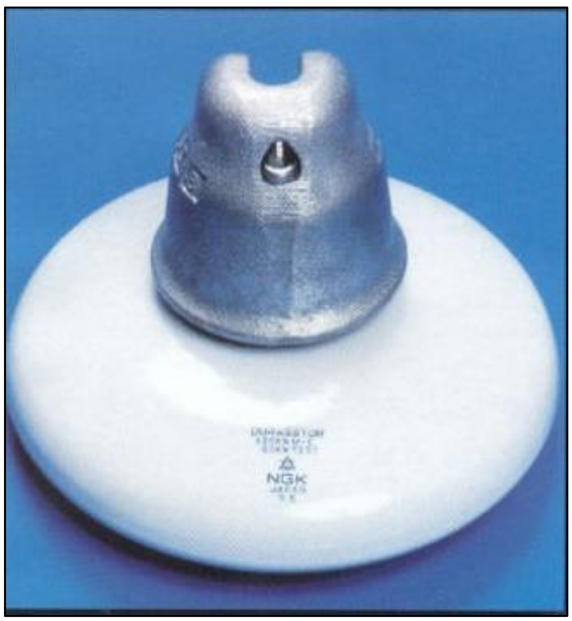


Figure 1-10. Porcelain Insulator

1.4.3.2 Glass Insulator

Nowadays, the glass insulator become popular in transmission and distribution systems. Annealed tough glass is used for insulating purpose. Glass insulator has a number of advantages over conventional porcelain insulator.

Figure 1-11. Glass Insulator

Advantages of Glass Insulator

- It has very high dielectric strength compared to porcelain.
- Its resistivity is also very high.
- It has low coefficient of thermal expansion.
- It has higher tensile strength compared to porcelain insulator.
- As it is transparent in nature there is no heating up in sunlight as porcelain.
- The impurities and air bubble can be easily detected inside the glass insulator body because of its transparency.
- Glass has a very long service life as the mechanical and electrical properties of glass are not affected by ageing.
- Glass is cheaper than porcelain.

Disadvantages of Glass Insulator

- Moisture can easily condensed on glass surface and hence air dust will be deposited on the wet glass surface which will provide paths to the leakage current of the system.
- For higher voltage glass cannot be cast in irregular shapes since due to irregular cooling internal strains are caused.

Properties of Glass Insulators	Value(Approximate)
Dielectric Strength	140 KV / cm
Compressive Strength	10,000 Kg / cm^2
Tensile Strength	35,000 Kg / cm^2

1.4.3.3 Polymer Insulators

A polymer insulator has two parts, one is glass fiber reinforced epoxy resin rod shaped core and other is silicone rubber or EPDM (Ethylene Propylene Diene Monomer) made weather sheds. Rod shaped core is covered by weather sheds. Weather sheds protect the insulator core from outside environment. As it is made of two parts, core and weather sheds, polymer insulator is also called composite insulator. The rod shaped core is fixed with hot dip galvanized cast steel end fittings at both ends.

Advantages of Polymer Insulators

- It is very light in weight compared to porcelain and glass insulator.
- As the composite insulator is flexible the chance of breakage becomes minimum.
- Because it is lighter in weight and smaller in size, this insulator has lower installation cost.
- It has higher tensile strength compared to porcelain insulator.
- Its performance is better particularly in polluted areas.
- Due to lighter weight, polymer insulator imposes less load to the supporting structure.
- Less cleaning is required due to hydrophobic nature of the insulator.

Disadvantages of Polymer Insulators

- Moisture may enter in the core if there is any unwanted gap between core and weather sheds. This may cause electrical failure of the insulator.
- Over crimping in end fittings may result to cracks in the core which leads to mechanical failure of polymer insulator.
- Subject to bird attack
- Not resilient to bushfire

Figure 1-12. Polymer Insulators

1.5 Conductors

1.5.1 Definition

A conductor is a physical medium to carry electrical energy form one place to another. It is an important component of overhead and underground electrical transmission and distribution systems. The choice of conductor depends on the cost and efficiency. An ideal conductor has following features.

- It has maximum electrical conductivity
- It has high tensile strength so that it can withstand mechanical stresses
- It has least specific gravity i.e. weight / unit volume
- It has least cost without sacrificing other factors

1.5.2 Types of Overhead Conductors

In early days copper 'Cu' conductors was used for transmitting energy in stranded hard drawn form to increase tensile strength. But now it has been replaced by aluminum 'Al' due to following reasons.

- It has lesser cost than copper.
- It offers larger diameter for same amount of current which reduces corona.

[Corona: is ionization of air due to higher voltage (usually voltage above critical voltage) which causes violet light around the conductor and hissing sound. It also produces ozone gas therefore it is undesirable condition]

Aluminium also has some disadvantages compared to copper i.e.

- It has lesser conductivity
- It has larger diameter which increase surface area to air pressure thus it swings more in air than copper so larger cross arms are required which increases the cost.
- It has lesser tensile strength ultimately larger sag
- It has lesser specific gravity (2.71gm/cc) than copper (8.9 gm/cc) *cc = cubic centimeter

Due to lower tensile strength aluminium is used with some other materials or its alloys. Generally, all types of conductors are in stranded form in order to increase the flexibility. Solid wires, except for very small cross sectional area, are very difficult to handle and, also, they tend to crystallize at the point of support because of swinging in winds.

1.5.2.1 AAC (All Aluminium Conductor)

- It has lesser strength and more sag per span length than any other category
- Therefore, it is used for lesser span i.e. it is applicable at distribution level
- It has slightly better conductivity at lower voltages than ACSR i.e. at distribution level
- Cost of ACSR is equal to AAC.

1.5.2.2 ACAR (Aluminium Conductor, Aluminium Reinforce)

- It is cheaper than AAAC but pro to corrosion.
- It is most expansive.

1.5.2.3 AAAC (All Aluminium Alloy Conductor)

- It has same construction as AAC except the alloy.
- Its strength is equal to ACSR but due to absence of steel it is light in weight.
- The presence of formation of alloy makes it expensive.
- Due to stronger tensile strength than AAC, it is used for longer spans.

- It can be used in distribution level i.e. river crossing.
- It has lesser sag than AAC.
- The difference between ACSR and AAAC is the weight. Being lighter in weight, it is used in transmission and sub-transmission where lighter support structure is required such as mountains, swamps etc.

1.5.2.4 ACSR (Aluminium Conductor Steel Reinforced)

- It is used for longer spans keeping sag minimum.
- It may consist of 7 or 19 strands of steel surrounding by aluminium strands concentrically. The number of strands are shown by x/y/z, where 'x' is number of aluminium strands, 'y' is number of steel strands and 'z' is diameter of each strand.
- Strands provide flexibility, prevent breakage and minimize skin effect.
- The number of strands depends on the application, they may be 7, 19, 37, 61, 91 or more.
- If the Al and St strands are separated by a filler such as paper then this kind of ACSR is used in EHV lines and called expanded ACSR.
- Expanded ACSR has larger diameter and hence lower corona losses.

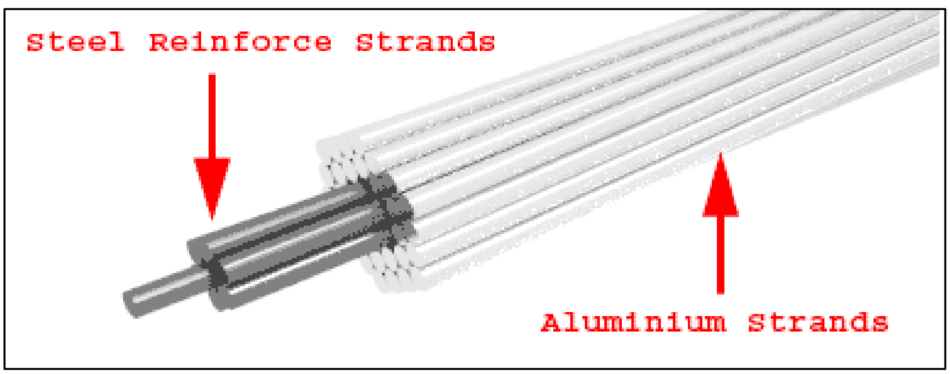


Figure 1-13.ACSR

1.5.3 Bundled Conductors

Transmission at extra high voltages (say above 220 kV) poses some problems such as significant corona loss and excessive interference with nearby communication lines when only one conductor per phase is used. This is because, at EHV level, the electric field gradient at the surface of a single conductor is high enough to ionize the surrounding air which causes corona loss and interference problems. The electric field gradient can be reduced significantly by employing two or more conductors per phase in close proximity. Two or more conductors per phase are connected at intervals by spacers and are called as bundled conductors. Number of conductors in a bundled conductor is greater for higher voltages.

1.5.4 Ground Wires/ OPGW

A ground conductor is a conductor that is usually grounded (earthed) at the top of the supporting structure to minimize the likelihood of direct lightning strikes to the phase conductors. The ground wire is also a parallel path with the earth for fault currents in earthed neutral circuit .These are either at the outermost ends of the highest cross beam, at two V-shaped mast points, or at a separate cross arm.

Ground wires on transmission lines may include optical fibers, used for communication and control of the power system.

M02 – TRANSMISSION TOWER

2.1 Objectives

Through this module participant will be able to;

- Identify the various types of towers in terms of their classifications, shapes, and designation.
- Explain the anatomy of a tower.
- State and explain the various types of loadings on a transmission tower.
- Explain the processes of the structural design of towers.

2.2 Introduction

Electricity is a versatile and convenient form of energy. Per capita consumption of energy is considered to be a yard stick the growth of the economy of countries. Power generation, transmission, and distribution is therefore growing exponentially all over the world.

In order to evacuate power from the generation centres to meet the ever increasing power demand, transmission grids are needed. The transmission tower forms a vital component of the power grid which enables bulk transmission of generated power over long distances to the load centres.

2.3 Definition

A transmission line tower is a structure set up to support an overhead power line for the purpose of transmitting and distributing electric power over long distances.

2.4 Tower Classifications

Transmission line towers can be classified according to the following:

- Functions
- Material
- Stability
- Phase configuration

2.4.1 Classification per Function

2.4.1.1 Suspension Towers

These towers are used on the lines for straight run or for small angle of deviation up to 2° or 5°or up to 15°(with inclined V strings). Conductor on suspension towers may be supported by means of I-Strings, V-Strings, Y-strings or a combination of I & V Strings.

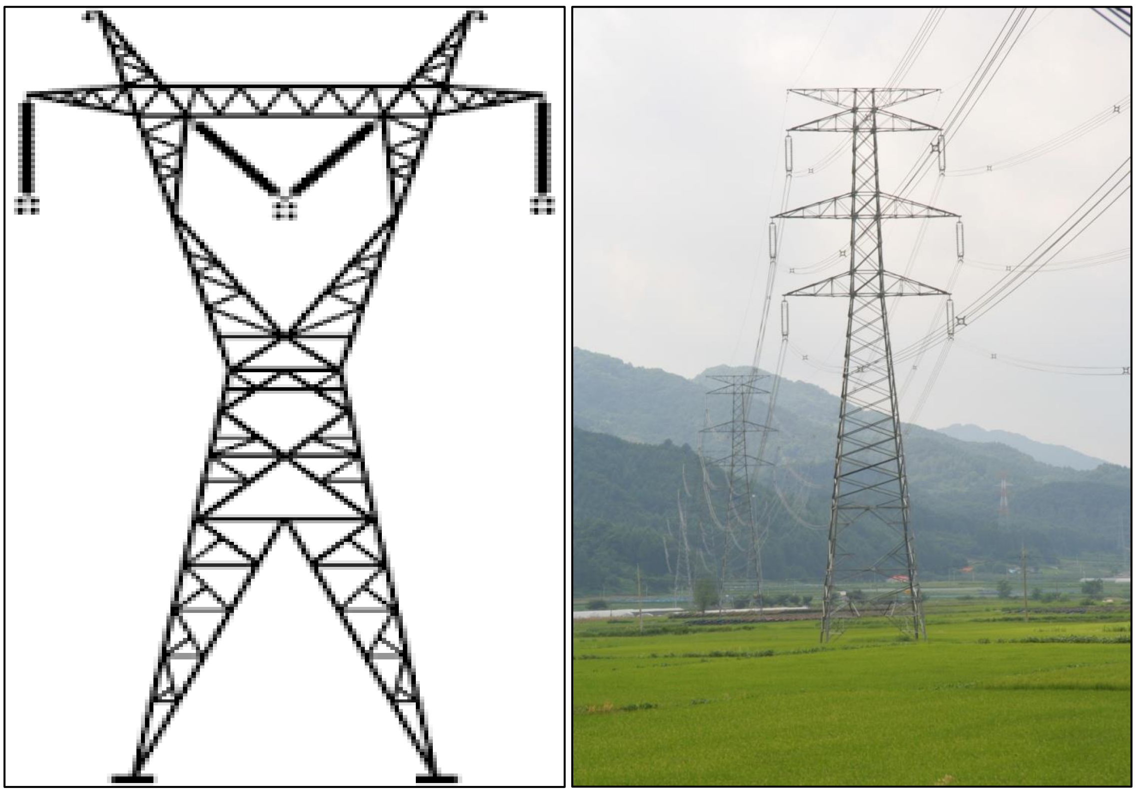


Figure 2-1. Suspension tower with I & V strings

2.4.1.2 Tension/Strain/Angle Towers

Tension towers, also known as angle towers, are used at locations where the angle of deviation exceeds that permissible on suspension towers and/or where the towers are subject to uplift loads. These towers are further classified as 2°/5°-15°, 15°-30°, 30° -60° /Dead end towers and are used according to the angle of deviation of line. In some countries, 90° angle tower are also used. One of the classes of angle towers depending on the site conditions is also designated Section Tower.

The Section Tower with 0° angle deviation is introduced in the line after a certain number of suspension towers or line length to avoid cascade failure. The number of suspension towers or line length required to install anti-cascading towers vary from country to country. The design of such towers is checked for adequacy both for angle location requirements as well as for arresting cascade failure

Figure 2-2. Tension Towers

2.4.1.3 Transposition Towers

Transposition towers are used to transpose the phase conductors in three sections in such a way that each phase by rotation occupies each of the three phase positions in a circuit. A typical transposition arrangement is shown in Figure 2-3 below. Generally, transposition of phases are required for the line length above 100 km or as per system study. While carrying out the transposition arrangements, availability of adequate electrical clearances should be ensured.

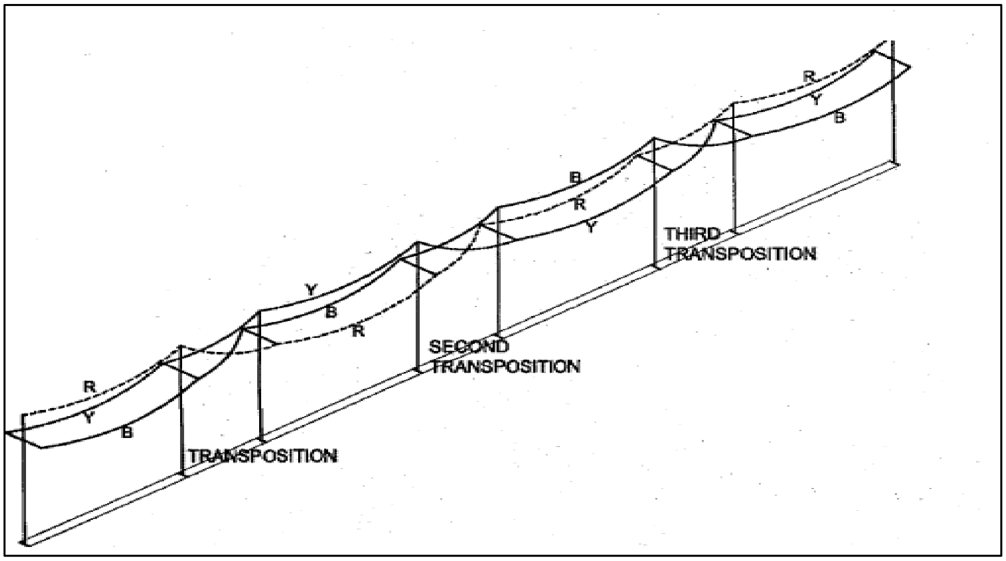


Figure 2-3. Transposition Arrangement

2.4.1.4 Special Towers

These towers are used at locations such as those involving long span river and valley crossings, creek crossings, cable termination towers etc. falling on the line route. These towers are specially designed to meet the site specific requirements.

2.4.2 Classification per Material

Towers are also classified according to the material the tower members are made of.

2.4.2.1 Wood

Mostly used in pole and H-frames as shown below.

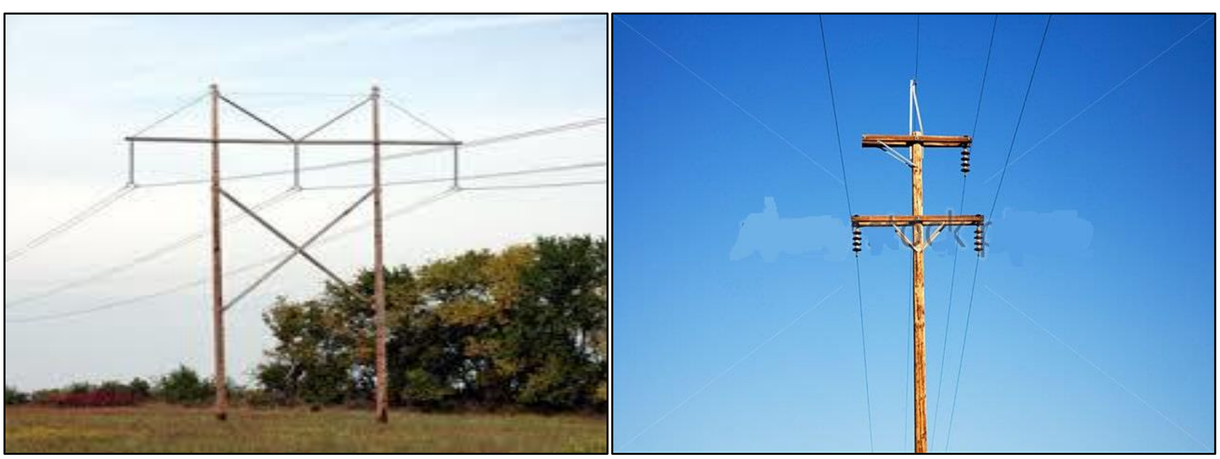


Figure 2-4. Wood Pole Lines

2.4.2.2 Metal

Mostly made of galvanized steel. Aluminum alloy is also used in some cases. Towers made of metal are either lattice or monopole towers.

Figure 2-5. Galvanized steel lattice & monopole towers

2.4.2.3 Concrete

Figure 2-6. Concrete Pole Tower

2.4.3 Classification per Stability

2.4.3.1 Self Supporting Towers

Self-supporting broad-based/narrow-based latticed steel towers are widely used in the world. Self-supporting towers usually have square/rectangular base and four separate footings. However narrow-based towers having combined monoblock footings may be used depending upon overall economy. Self-supporting towers as compared to guyed towers have higher steel consumption.

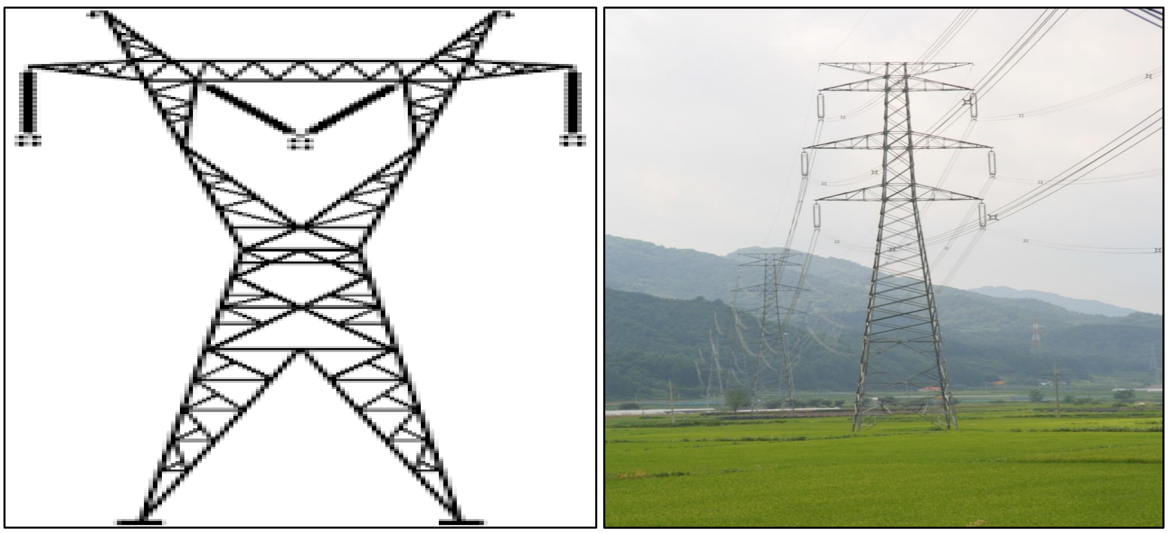


Figure 2-7. Self-Supporting Towers

2.4.3.2 Guyed Towers

These towers comprise portal structures fabricated in 'Y' and 'V shapes and have been used in some countries for EHV transmission lines up to 800kV. The guys may be internal or external. The guyed tower including guy anchors occupy much larger land as compared to self-supporting towers and as such this type of construction finds application in long unoccupied, waste land, bush tracts in Canada, Sweden, Brazil, Russia etc.

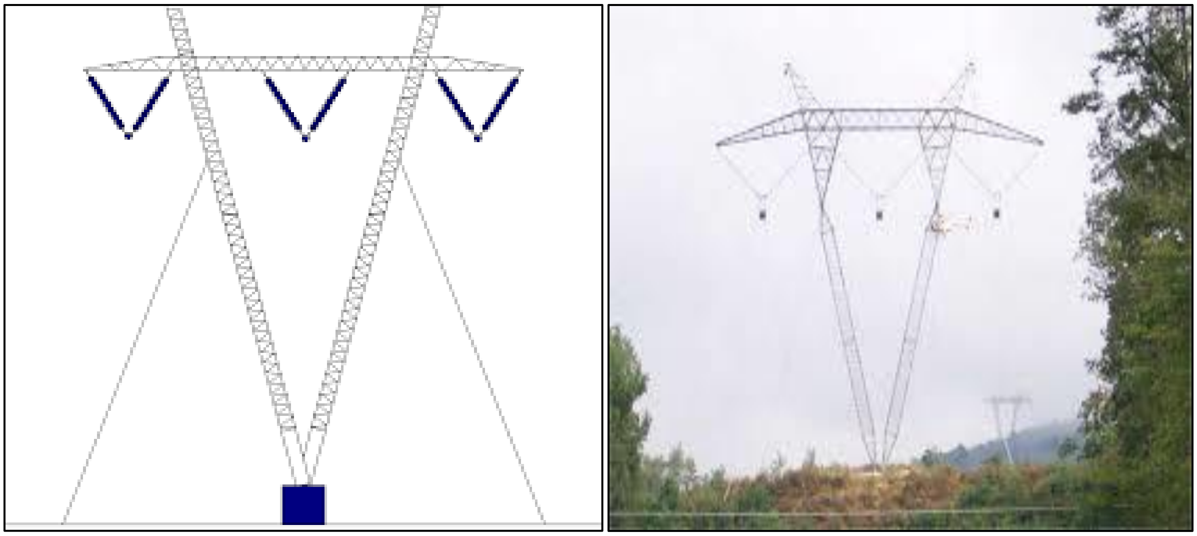


Figure 2-8. Guyed Tower

2.4.3.3 Chainette Guyed Towers

Chainette guyed tower is also known as cross rope suspension tower, and consists of two masts each of which is supported by two guys and a cross rope which is connected to the tops of two masts and supports the insulator strings and conductor bundles in horizontal formation.

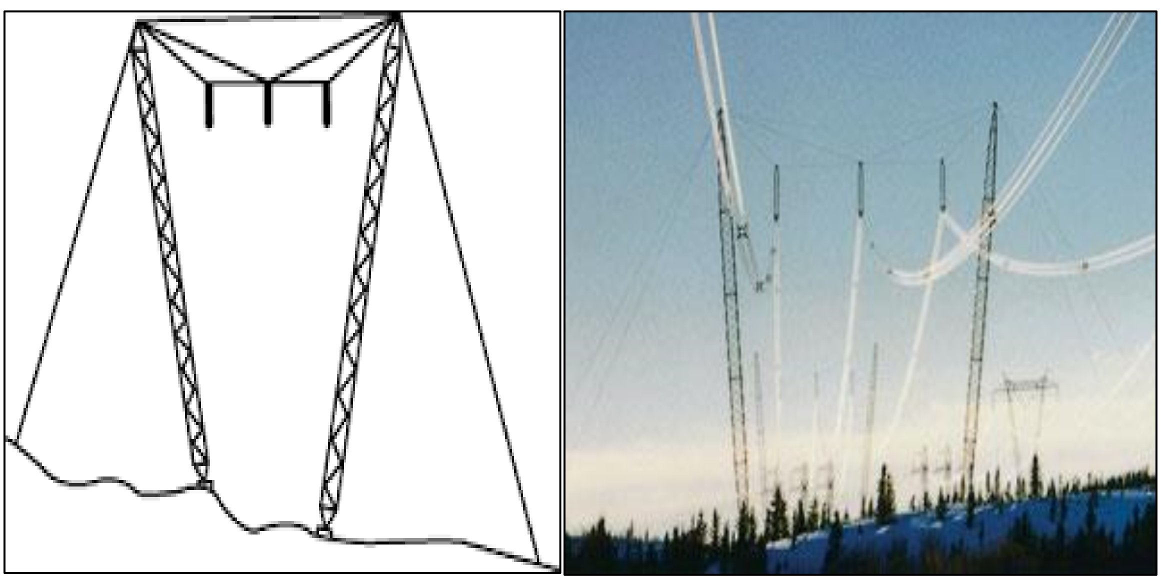


Figure 2-9. Chainette Guyed Tower

2.4.4 Classification per Phase Configuration

Phase classification is based on the arrangement of the phases in a circuit on a tower.

2.4.4.1 Horizontal Configuration

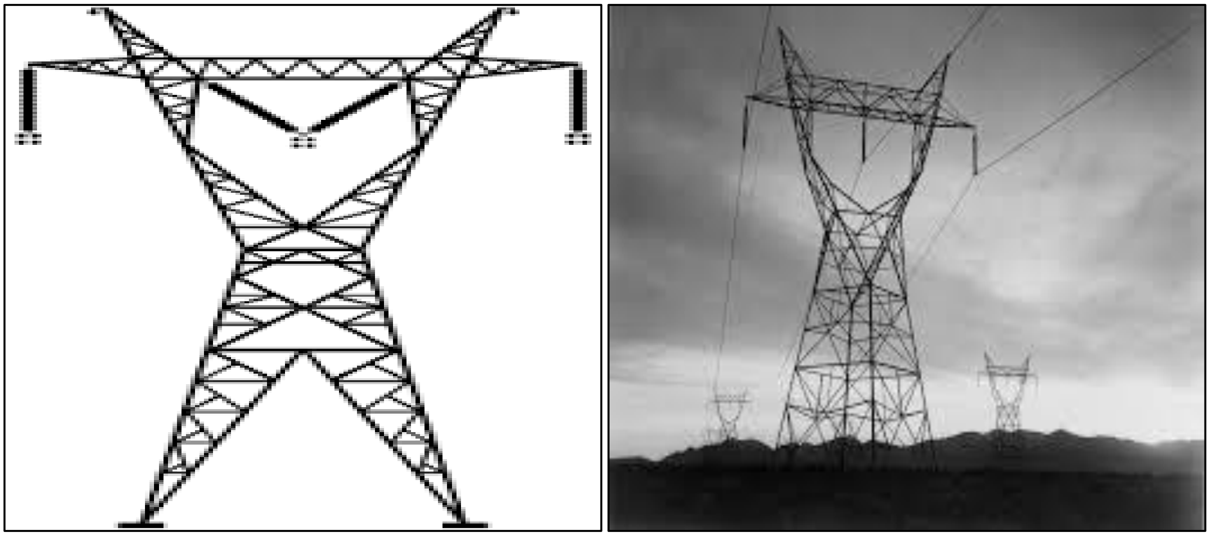


Figure 2-10. Horizontal Phase Configurations

2.4.4.2 Vertical Configuration

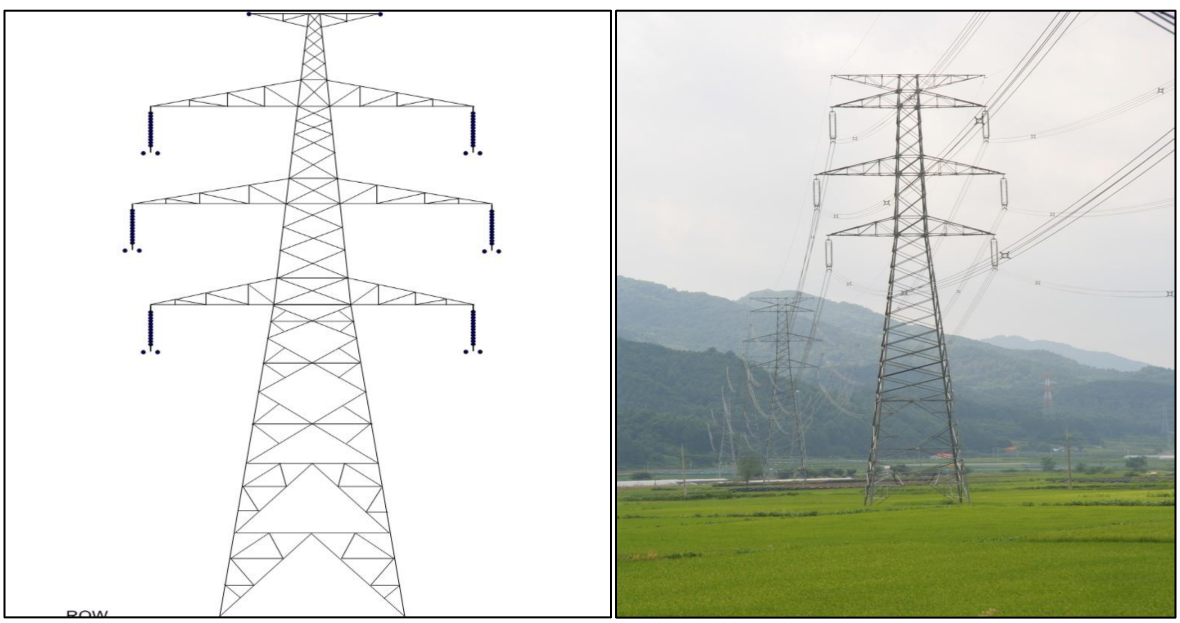


Figure 2-11. Vertical Phase Configuration

2.4.4.3 Delta Configuration


Figure 2-12. Delta Phase Configuration

2.5 Tower Shapes

The following shapes are in use:

2.5.1 Vertical/Barrel Type

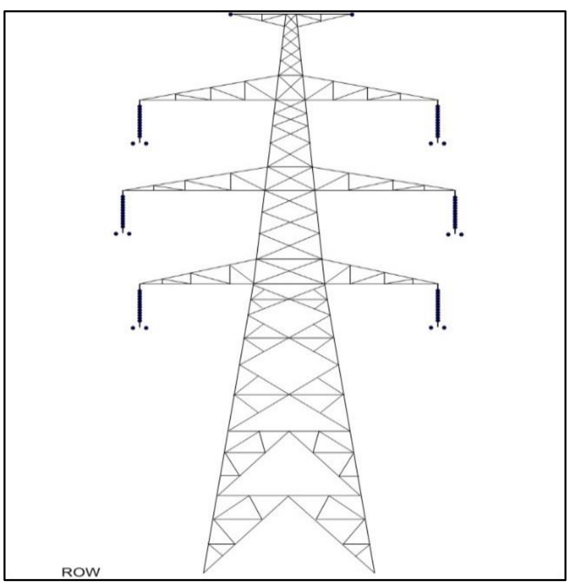


Figure 2-13. Vertical/Barrel Type Tower

2.5.2 Horizontal/Wasp Waist Type

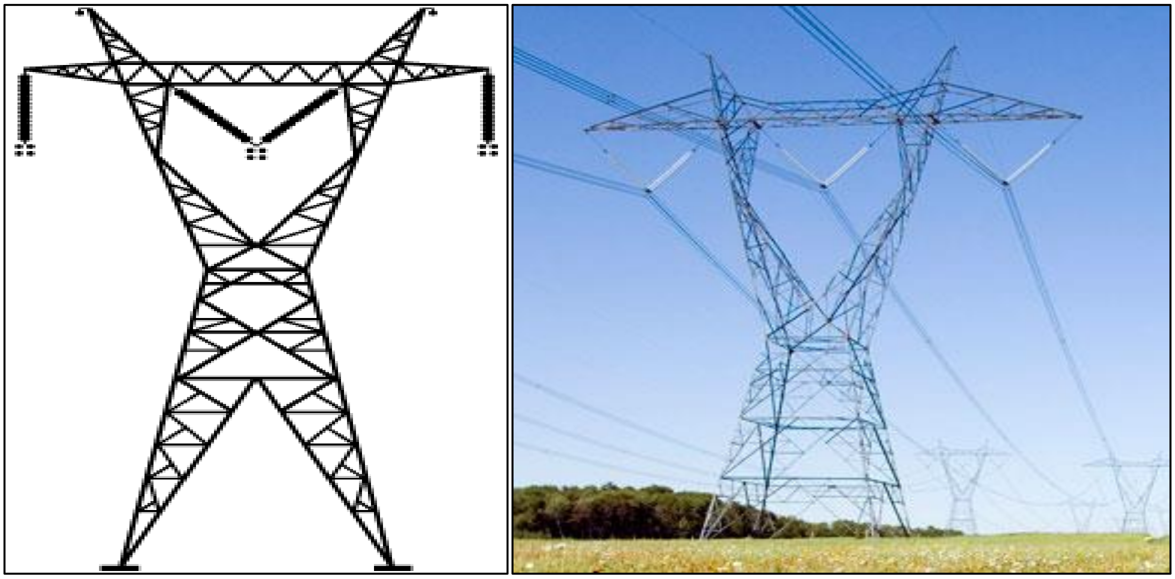


Figure 2-14. Horizontal/Wasp Waist Type Tower

2.5.3 Delta/Cat Type

Figure 2-15. Delta/Cat Type Tower

2.5.4 H-Structure Type

Figure 2-16. H-Structure Tower Type

2.5.5 Danube Configuration

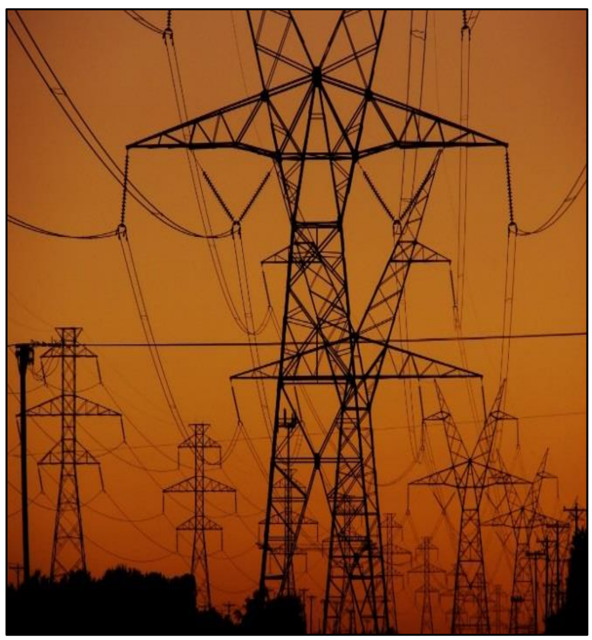


Figure 2-17. Danube Configuration Tower Type

he Danube configuration provides a compromise between the width of right-of-way, tower heights and investments. They are mostly used in Europe.

2.6 Tower Specification used in GRIDco

Designation	Position	Angle of Deviation or Line Entry	Type of Insulators
AO	Tangent towers; normal spans	0^0	Suspension
BO	Small angles and/or long spans	5^0	Suspension
CO	Intermediate angle	30^0	Tension
CO-Sp	Intermediate angle	5^0 - 15^0	Suspension
DO	Dead end or large angles	$0^0/60^0$	Tension

Table 2-1: GRIDCO's 161kV Single Circuit Towers

Designation	Position	Angle of Deviation or Line Entry	Type of Insulators
XX	Tangent towers; long spans	0^0	Suspension
YY	Intermediate angles	20^0	Tension
ZZ	Dead end or large angles	$0^0/60^0$	Tension

Table 2-2: GRIDCO's 161kV Double Circuit Towers

Designation	Position	Angle of Deviation or Line Entry	Type of Insulators
A3	Tangent towers; normal spans	0^0 - 2^0	Suspension
B3	Small angles and/or long spans	0^0 - 10^0	Suspension
C3	Intermediate angle,	0^0 - 30^0	Tension
	anticascading	0^0	
D3	Angle	30^0 - 60^0	Tension
	Dead end	0^0 - 15^0	
E3	Angle	60^0 - 90^0	Tension
	Dead end	15^0 - 45^0	

Table 2-3: GRIDCO's 330kV Single Circuit Towers

Designation	Position	Angle of Deviation or Line Entry	Type of Insulators
DA3	Tangent towers; normal spans	0^0 - 2^0	Suspension
DB3	Small angles and/or long spans	0^0 - 10^0	Suspension
DC3	Intermediate angle,	0^0 - 30^0	Tension
	anticascading	0^0	
DD3	Angle	30^0 - 60^0	Tension
	Dead end	0^0 - 15^0	
DE3	Angle	60^0 - 90^0	Tension
	Dead end	15^0 - 45^0	

Table 2-4: GRIDCO's 330kV Double Circuit Towers

2.7 Tower Anatomy

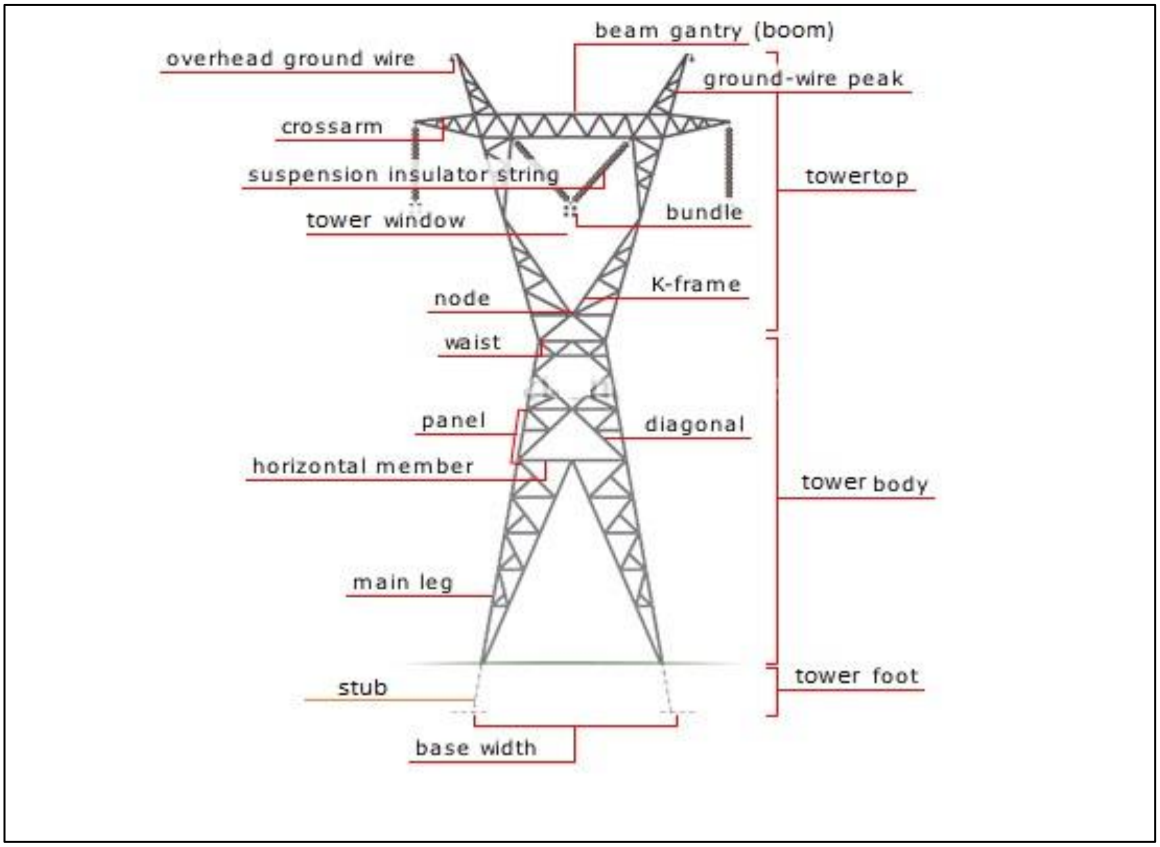


Figure 2-18. Tower Anatomy - Horizontal Type Tower

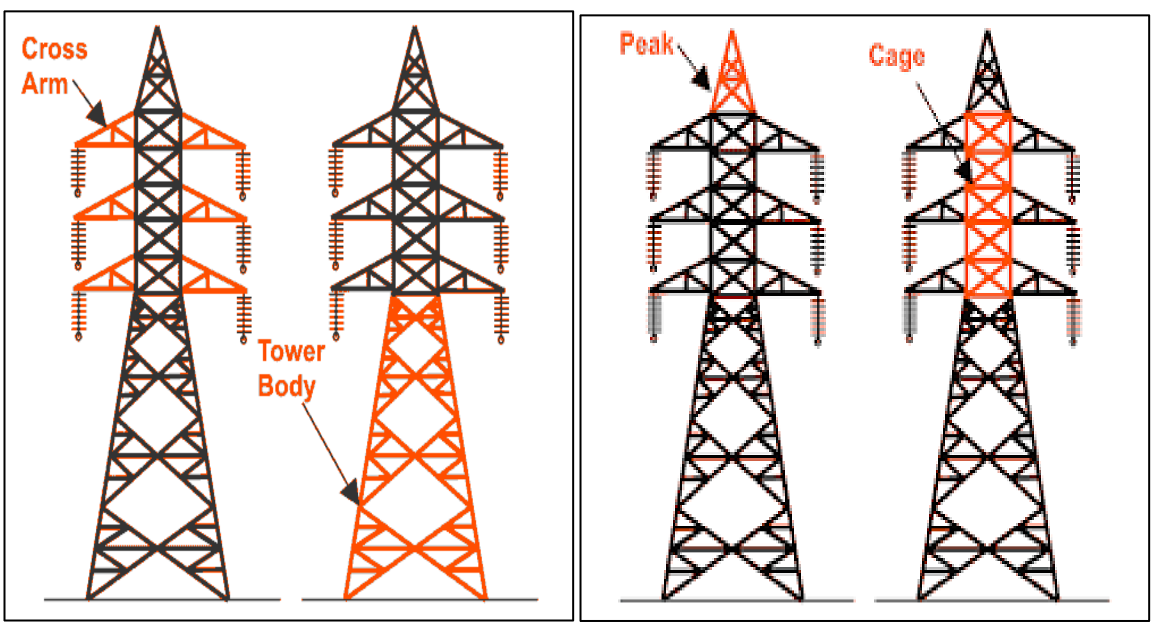


Figure 2-19. Tower Anatomy - Vertical Type Tower

A tower is constituted of the following components as shown in figures above:

- Peak
- Cross Arm
- Boom
- K – Frame
- Cage
- Tower Body
- Body Extension
- Leg Extension
- Stub/Anchor Bolts and Base Plate Assembly

A brief description of each component of the tower is given as under:

2.7.1 Peak

It is the portion of tower above the top cross arm in case of vertical configuration tower and above the boom in case of horizontal configuration tower. The function of the peak is to support the ground wire/OPGW in suspension clamp and tension clamp at suspension and angle tower locations respectively.

2.7.2 Cage

The portion between peak and tower body in vertical configuration towers in called Cage. The cross-section of cage is generally square and it may be uniform or tapered throughout its height depending upon loads.

In case of Special tower or tall tower, the dimension of cage shall be fixed taking into account provision of ladder for climbing up on the tower for maintenances purposes.

2.7.3 Cross-Arm

The function of a cross-arm in case of vertical configuration tower is to support conductor/ground wire/OPGW. The number of cross arms depends upon number of circuits, tower configuration and conductor/ ground wire/OPGW arrangement. The cross-arm for ground wires/OPGW consists of fabricated steel work and that for conductor may be insulated type or consist of fabricated steel work provided with insulator string. The dimensions of a cross-arm depend upon the line voltage, type and configuration of insulator string, minimum framing angle from the requirement of mechanical stress distribution, etc. At large angle line deviation, rectangular/ trapezoidal cross-arms with pilot string on outer side are used to maintain live conductor to grounded metal clearance.

2.7.4 Boom

It is generally a rectangular beam of uniform cross-section and forms part of horizontal configuration towers (self-supporting, guyed etc.). The boom is attached to the tower body and it supports power conductors.

2.7.5 K-Frame

It is a K-Shape frame twin in numbers and provided on transverse face between waist and boom level generally for horizontal configuration towers. The window in the center is meant for passing the middle phase conductor.

2.7.6 Tower Body

Tower body is the main portion of the tower for connecting cage/K-Frame to the tower foundation or body extension or leg extension. It comprises tower legs inter-connected by bracings and redundant members. It is generally square or rectangular in shape depending on the economics and behavior.

2.7.7 Body Extension

Body extensions are used to increase the height of tower to obtain the required minimum ground clearance and over road crossings, river crossings, ground obstacles etc.

concrete foundation, is called stub-cleat arrangement or simply "STUB". They project the tower body into the foundation.

2.7.8 Leg Extension

Leg extensions are widely used for any leg or any pair of transmission line tower legs locations where the footing of the towers are at different levels e.g. hilly terrain. They are also used to obtain the required minimum ground clearance.

2.7.9 Stubs

The anchoring arrangement of transmission tower legs consisting of inclined angle (in the same slope as that of the tower leg) with bearing cleats at the end, all embedded in the

2.8 Design of Transmission Towers

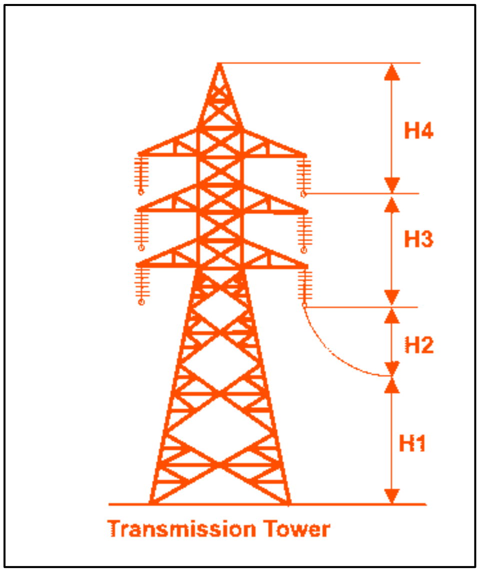


Figure 2-20 Image of Transmission Towers

During design of transmission tower, the following points have to be considered in mind:

- The minimum ground clearance of the lowest conductor point above the ground level.
- The length of the insulator string.
- The minimum clearance to be maintained between conductors and between conductor and tower.
- The location of ground wires with respect to outer most conductors.
- The mid span clearance required from considerations of the dynamic behavior of conductor and lightening protection of the line.

To determine the actual transmission tower height by considering the above points, we have divided the total height of tower in four parts,

- Minimum permissible ground clearance (H1)
- Maximum sag of the conductor (H2)
- Vertical spacing between top and bottom conductors (H3)
- Vertical clearance between ground wire and top conductor (H4)

2.9 Tower Loadings

Tower loading is one of the most vital input for tower design. Any mistake, omission or error in the load assessment will make the tower design erroneous and it will lead to severe financial impact to perform corrections / modifications at a later date. Various types of loads are to be calculated accurately depending upon the design parameters. Wind plays a vital role in the load calculations. The correct assessment of wind load will lead to proper load assessment and reliable design of tower structures.

2.9.1 Horizontal Loads

These are loads that act in the horizontal plane.

2.9.1.1 Transverse Loads

Transverse loads comprise:

- Wind load on tower structure
- Wind load on conductors,
- Wind load on ground-wire/OPGW
- Wind load on insulator strings
- Transverse component of mechanical tension of conductor and ground wire & OPGW

(a) Wind load on tower structure

In order to determine the wind load on tower, the tower is divided into different panels. These panels should normally be taken between connecting points of the legs and bracings. For square/rectangular lattice tower, the wind load for wind normal to the face of tower, on a panel height of 'h' is applied at the centre of gravity of the panel.

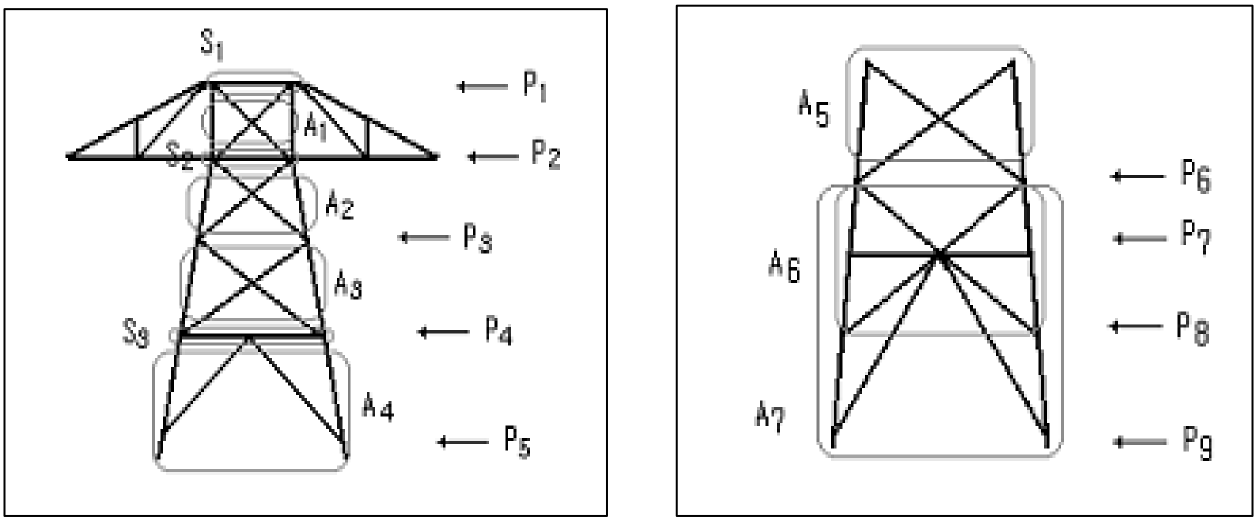


Figure 2-21. Wind loads on the tower structure

P_1= (A_1/2+S_1) x Equivalent wind load

P_2= {(A_1+A_2)/2+S_2} x Equivalent wind load

P_3= {(A_2+A_3)/2} x Equivalent wind load

P_4= {(A_3+A_4)/2+S_3} x Equivalent wind load

P_5= (A_4/2) x Equivalent wind load

P_6= (A_5+A_6)/2xEquivalent wind load

P_7= (A_7-A_6)/2xEquivalent wind load

P_8= (A_6/2) x Equivalent wind load

P_9= (A_7/2) x Equivalent wind load

(b) Wind load on conductors, ground wire & OPGW

The load due to wind on each conductor and ground-wire normal to the line applied at supporting point shall be determined by the following expression:

$$\mathbf{H_C = P_W * \boldsymbol{L_{ws}} * D}$$

Where H_C = wind load on conductor/ground wire/OPGW

P_W = design wind pressure (N/m²)

L_{ws} = wind span

D = diameter of conductor/ground wire/OPGW

The wind span is half the sum of adjacent span lengths as shown in Figure 22

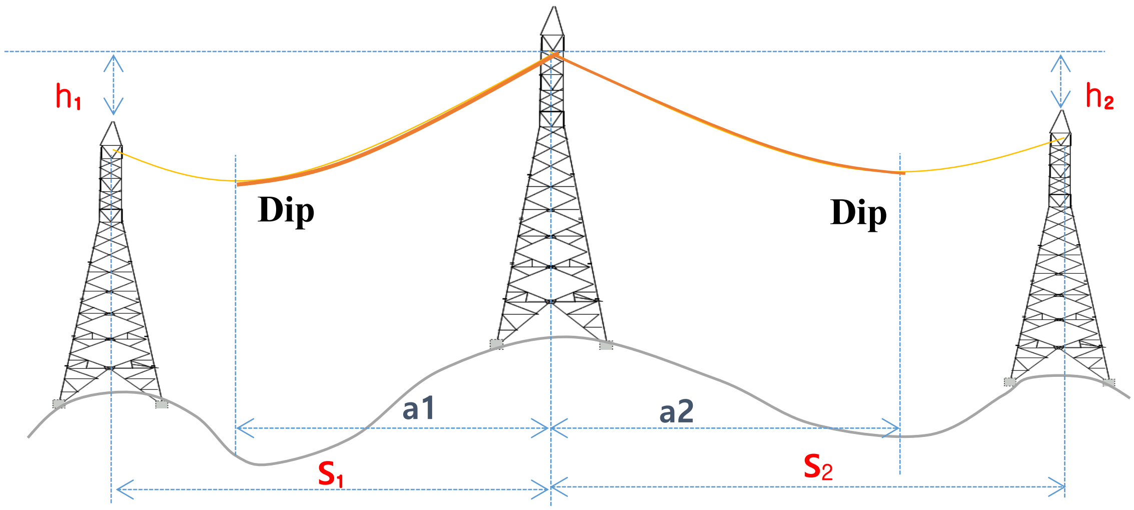


Figure 2-22. Wind Span

$$\textbf{Wind span} = L_{ws} = \frac{(S_1 + S_2)}{2}$$

(c) Wind load on insulator string

Wind load on insulator strings is the load on the insulator string due to the wind pressure. This shall be determined from the attachment point to the centre-line of the Conductor in case of suspension tower and up to the end of clamp in case of tension tower, in the direction of wind as follows:

$$H_i = P_W * A_i$$

Where H_i = wind load on insulator

P_W = design wind pressure (N/m²)

A_i = area of insulator string projected on a plane

$$A_i = 0.5 * d * h$$

d = diameter of insulator disc

h = height of insulator string

(d) Transverse load from mechanical tension of conductor/GW/OPGW due to line deviation

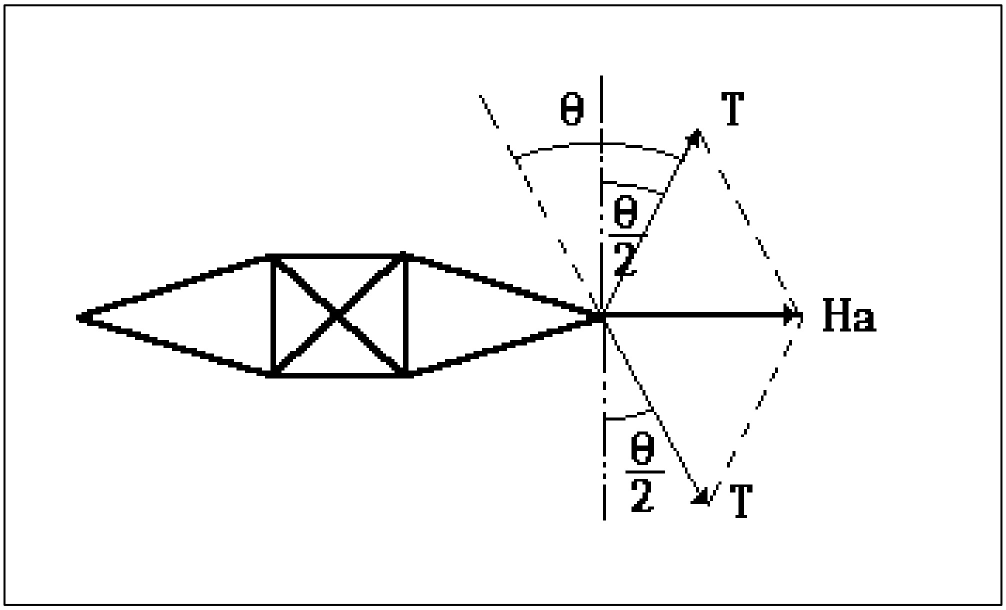


Figure 2-23. Transverse loads due to line deviation

This load acts on the tower where there is a line deviation and is due to the transverse component of the tension in the conductors/GW/OPGW.

$$\mathbf{H_a = 2T\,Sin\frac{\theta}{2}}$$

Where H_a = transverse load from conductor/ground wire/OPGW tension due to line deviation

T = conductor/ground wire/OPGW tension

θ = deviation angle

2.9.1.2 Longitudinal Loads

(a) Normal Condition

Longitudinal loads for Suspension and Tension towers due to Wind on Conductor/Ground wire/OPGW & Component of wire tension in the normal condition (i.e when all the conductors/ground wire/OPGW are unbroken) shall be taken as nil.

(b) Broken Wire Condition

When a wire gets broken, the balanced longitudinal loads on the tower becomes unbalanced. The unbroken wire on one side of the tower exerts a load equal to the tension in the wire in the longitudinal direction.

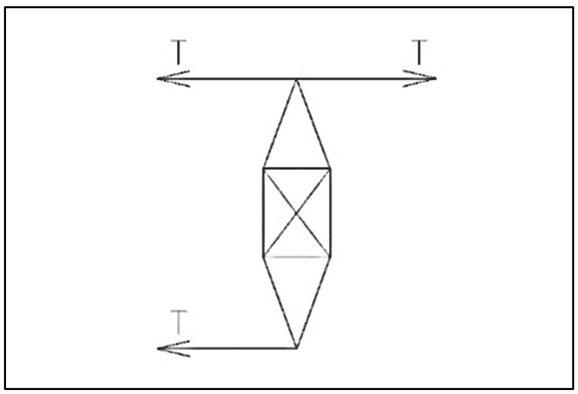


Figure 2-24. Unbalanced longitudinal load due to broken wire

A force T is applied on the tower as a result of the broken wire. This creates torsion on the tower.

(c) Dead End Towers Longitudinal Loads

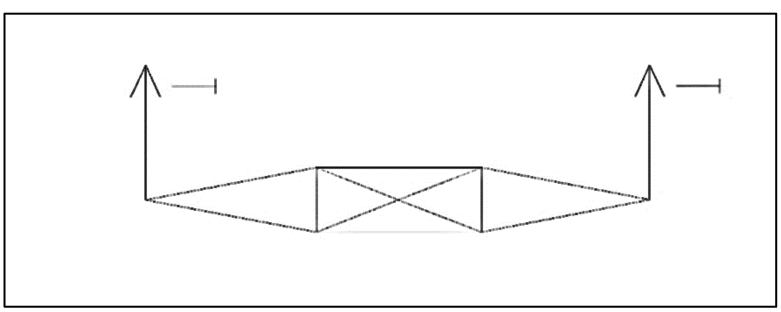


Figure 2-25. Dead end tower with longitudinal loads from all conductors/ground wire/OPGW on one side of the tower

In dead end towers, all the conductors/ground wire/OPGW on one side of the tower are slack and therefore exert no tension on the tower. This implies that longitudinal loads due to tension from all the conductors/ground wire/OPGW on the other side are applied on the tower as shown on the diagram.

2.9.1.3 Torsional Loads (q)

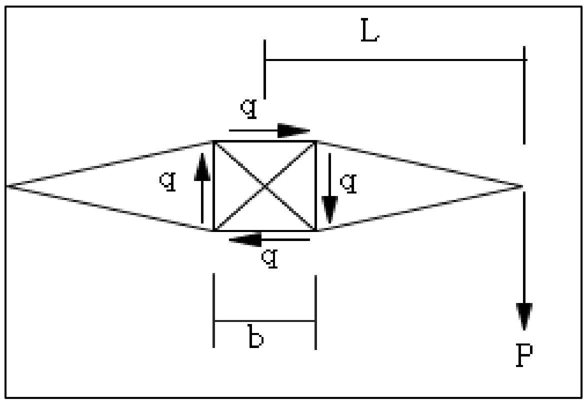


Figure 2-26. Torsional Loads

$$q = P \cdot \ell / 2 \cdot b$$

Torsional loads arise due to:

- Unbalanced tension of conductors
- Unbalanced tension due to conductor breakage
- Torsion by single line on a double/multiple circuit.

2.9.2 Vertical Loads

The vertical loads on a tower are made up of:

- Self-weight of the tower
- Weight of insulator strings and accessories
- Weight of each conductor, ground wire and OPGW based on the appropriate weight span
- Loads during construction and maintenance

The vertical load of one conductor or ground wire or OPGW is calculated as follows;

$$V_C = \omega * L_{wt}$$

Where V_C = vertical load of one conductor/ground wire/OPGW

ω = weight per length of conductor/ground wire/OPGW (kN/m)

L_{wt} = weight span (m)

The weight span is calculated as indicated in the diagram below:

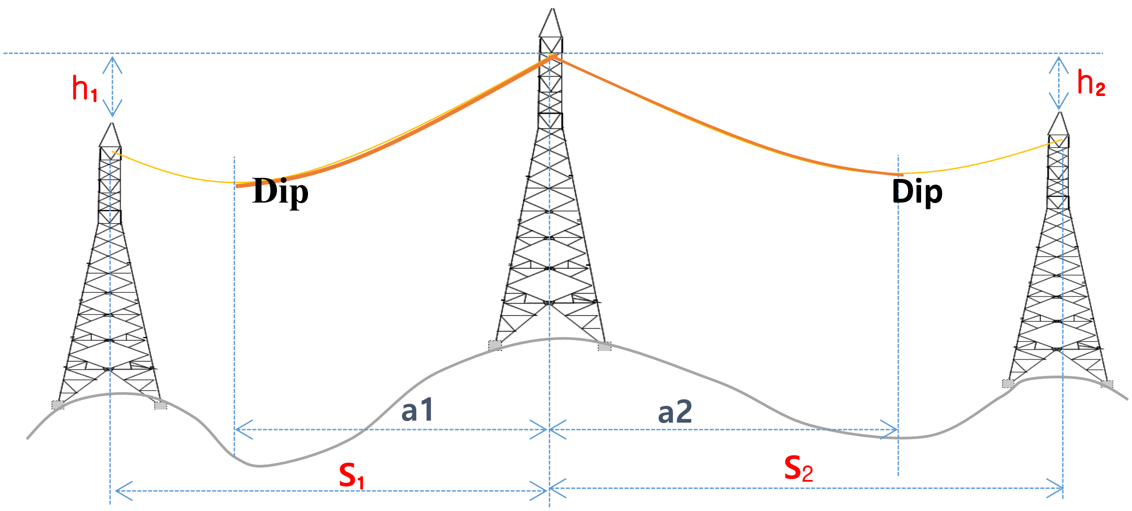


Figure 2-27. Weight Span

$$\mathbf{Weight\ Span = a_1 + a_2 = \frac{1}{2}(S_1 + S_2) + C(\frac{h_1}{S_1} + \frac{h_2}{S_2})}$$

Where,

C = parameter = $\frac{T}{W}$;

T = maximum allowable tension

W=weight of conductor per metre

The weight span is the distance between the lowest points on adjacent sag curves on either side of the tower as shown in Figure 2-27.

2.10 Stress analysis

The exact stress analysis of a transmission tower requires calculation of the total forces in each member of the towerr under action of combination of loads externally applied plus the dead weight of the structure.

Basically the stress analysis of any tower requires application of the laws of statics. As, a tower is a space frame, the solution becomes complex if all external loads are applied simultaneously. Different categories of loads are taken separately for calculation of stress in each member. Stresses so calculated, for different type loads are superimposed to arrive at overall stress in the member.

2.10.1 Methods of Stress Analysis

2.10.1.1 Graphical Method

Stress analysis by graphical method, i.e., stress diagram method is the easiest method of stress analysis but the accuracy of the calculated stress by graphical method depends upon the accuracy of the stress diagram drawn and measurement of stresses made on proportionate scale. Even the line thickness makes some difference in stress value. Further, for each load on each face, separate stress diagram is required. Sometimes, due to space limitation in a drawing sheet, each stress diagram bears a different scale and overall computation of the stresses become difficult. There is likelihood of some human error creeping in, while computing the stresses. Thus, the graphical method of drawing stress diagram has now become obsolete. The Maxwell Diagram and Cremona Diagram are two examples of stress analysis by the graphical method.

2.10.1.2 Analytical Method

Basically, all the assumptions which are made in stress analysis of Tower by Graphical Method, are also made while using Analytical Method. Examples are the method of joints and method of sections

2.10.1.3 Computer Aided Analysis

In the previously described methods of stress analysis, viz., Graphical Method as well as Analytical Method, a designer has limitations to try-out several permutation and combinations of tower geometry. To avoid mental stress due to numerous trials, one is inclined to restrict to few trials, based on One's experience, thus analytical designs were more or less personified ones.

With the advent of digital computer, now available as an aid to a designer, his capability is enhanced to try out number of iterations with several permutations and combinations, so as to achieve the optimum design and accurate stress analysis. Two different methods of stress analysis with the aid of computers are being practiced.

(a) Plane Truss Method or 2-Dimensional Analysis

This is an exact replica of the analytical method, covering all the steps as before but with unlimited scope of trials for variations in tower geometry of bracing systems. Various organizations have developed several computer programs suitable to use with particular computer system available with them.

Some computer programs are so elaborate that even optimum tower geometry is selected automatically by a computer. But most practical one is that computer software working on interactive mode, combines the experience of a designer to try a particular geometry along with capability of a computer to try numerous permutations and combinations. The main objective of such an elaborate aid from a computer is to achieve optimum design of a tower, which will withstand simultaneous application of worst loadings and achieve reliability as well as optimum strength of all tower members.

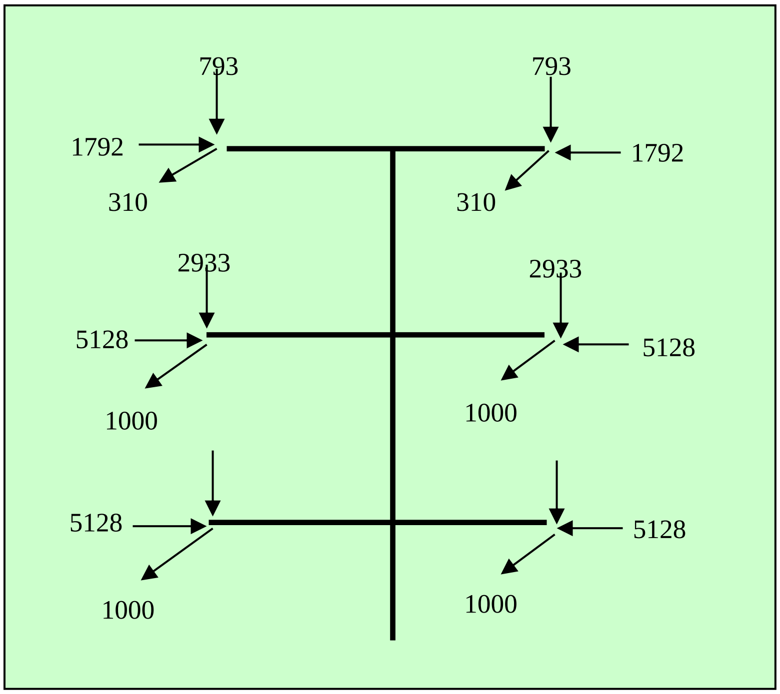


Figure 2-28. Example of a loading tree

The loads calculated are loaded on to the tower by drawing a loading tree as shown in Figure above.

(b) Space Truss Method or 3-Dimensional Analysis

The tower structure is basically a statically indeterminate structure. 3-dimensional analysis is not possible to do manually. Stiffness matrix analysis with the help of appropriate powerful computer is essential.

2.10.1.4 Comparison of Various Methods of Stress-Analysis

Comparison of stress analysis by graphical, analytical and computer method reveals, though it does not affect the practical stress design of tower much, the 3-D analysis by computer gives more insight into stress distribution in various members due to the various external loads. Whereas, in the case of graphical and analytical methods it is assumed that the transverse faces take care of transverse loads and members of longitudinal faces carry stresses due to longitudinal loads only, the 3-D stress analysis by computer shows the stress distribution in the members of all the four faces of the tower due to any type of external load applied to the structure. Similarly, while doing analysis by graphical and analytical method, stresses are only calculated in the members at the level of the externally applied load and below it, the 3-D analysis gives the magnitudes of stresses even in the members above the level of the externally applied load.

Again in the Cross-arm analysis we assume that the main members carry the transverse and longitudinal loads and a portion of vertical load, and the top inclined members carry the vertical loads, but the 3-D analysis indicates the top members share even the transverse and longitudinal loads. 3-D analysis, therefore, give more realistic picture of stress distribution in the Tower and can be used as an effective tool to arrive at the optimum design of Tower in minimum possible time.

2.11 Design of Members

The various members of the tower are selected based on the results of the stress analysis. The members are selected to withstand the maximum stresses that are expected to be imposed on the member.

M03 – CONDUCTORS

3.1 Objectives

Through this module participant will be able to;

- Identify the different types of overhead line conductors
- Understand characteristics of overhead line conductors
- Understand sag and tension design

3.2 Introduction

The transmission network comprises of a number of components including the conductors, insulators, towers and their associated foundations. The choice of an optimum sized conductor for a particular application is very important in that it is the main determining factor for the choice of the other components of the system and hence the cost of the transmission line system.

The knowledge of the characteristics of the different types of conductors available is very important. This will enable the transmission line design engineer to select the appropriate type of conductor, taking the necessary factors into consideration, for a particular application for a successful operation of the transmission line during its life time.

3.3 Overhead Transmission Line Conductors

Conductors used for transmission and distribution of electricity have undergone extensive change since the discovery of electricity some centuries ago. Copper was the first material used for overhead transmission line conductors in 1880s. Owing to the low mechanical strength of copper compared to its conductivity, the selection of the appropriate size of conductor was mainly based on the mechanical strength. As a result, larger sized conductors than actually required for power transmission were used. The low strength of copper conductors, coupled with its heavy weight made it possible for only short spans to be constructed thereby making the cost of transmission line high.

Aluminium and its alloys which have better strength–to-weight ratio were later introduced to reduce the cost of transmission lines. Aluminium has conductivity-to-weight ratio twice that of copper and strength-to-weight ratio 30% higher than copper. These properties made aluminium the most widely used material for overhead transmission line conductors.

The need for further improvement in the characteristics of OHTL conductors in order to reduce the cost of transmission lines led to the introduction of steel composite aluminium conductors. This type of conductor has the combined high conductivity of aluminium and the high tensile strength of galvanized steel. This conductor is referred to Aluminium Conductor Steel Reinforcement (ACSR).

Aluminium alloys which have improved electrical and mechanical properties than aluminium have in recent years been introduced into the industry as a material for OHTL conductors. These type of conductors, known as aluminium alloy and composite aluminium alloy cables, have been introduced to provide thermal stability, increased conductivity, vibration resistance, etc.

3.4 Characteristics of Overhead Transmission Line Conductors

The range of characteristics to be considered in the selection of OHTL conductors can be broadly described as follows:

- **High Conductivity**

This is required in order to provide adequate current carrying capacity and low voltage drop on the line. The conductivity of conductor materials are expressed as a percentage of the conductivity of the International Annealed Copper Standard (IACS).

- **High Strength**

This is necessary to enable ground clearances to be achieved in long spans and reduce the cost of transmission line.

- **Low Weight**

A low weight conductor material required in order to maintain good ground clearances in long spans. This will result in smaller tower structures and their associated foundations and hence a reduction in cost of the transmission line.

- **Flexibility**

This is required to ensure that vibration fatigue failure does not occur when the transmission line is in service.

- **Mechanical Stability**

Overhead conductors are subjected to a variety of loading conditions due to temperature changes during operation. The conductor should be able to withstand the changing of load conditions without failing.

- **Physical Stability**

The conductor is exposed to environmental conditions when in operation. It should be able to withstand these environmental conditions such as corrosion contaminants, wind pressure, etc.

- **Lifetime Stability**

The conductor should be able to maintain its physical, electrical and mechanical characteristics during its expected lifetime of about 40 – 50 years.

- **Economical**

The conductor material should have low cost in order to ensure low cost transmission lines.

3.4.1 Electrical Characteristics of Conductor

The main electrical characteristics of OHTL conductors in a power system are the current carrying capacity, DC and AC resistances.

The electrical resistance of a conductor may be defined as a measure of the difficulty encountered when passing an electric current through it. The SI unit of electrical resistance is the ohm (Ω). In an AC power system, both AC and DC resistances are encountered during transmission of power from one end to the other.

3.4.1.1 Current Carrying Capacity

The current carrying capacity of a conductor is defined as the maximum amount of current it can carry without sustaining immediate or progressive deterioration. Thus, the conductor remains within its temperature limits when current flowing through it is less than or equal to the rated current carrying capacity. Current carrying capacity is also described as Ampacity of a conductor. The unit of Ampacity is Amperes (A).

3.4.1.2 AC Resistance

When AC current flows through a conductor, the current produces a magnetic field across it which induces a voltage in a direction that opposes the flow of current through the conductor. This produces a resultant property of the conductor known as Inductance (L). The resultant resistance is also known Inductive Reactance (XL). The unit of inductive reactance is Ohm (Ω).

Inductive Reactance is calculated using the following formula:

$$XL = 2\pi fL$$

Where f = System frequency

L = Inductance of the conductor in Henry (H)

From the above equation, it is noted that the Inductive reactance of a conductor is directly proportional to the system frequency (f) and the inductance (L) of the conductor. The inductance of the conductor is also directly proportional to its length.

3.4.1.3 DC Resistance

This is the resistance encountered to the direct flow of current as a resultant of the conducting properties of the conductor material. The unit of DC resistance is Ohms (Ω).

The DC resistance of a conductor is calculated using the following formula (Figure 3-1:

$$R = \frac{\rho\, l}{A}$$

Where ρ = resistivity of the conductor material in Ohm-meter (Ω-m)

l = length of the conductor

A = cross-sectional area of the conductor.

Resistivity (ρ) is defined as the resistance measured across unit cube of the material. It is a constant value that depends on the conductor material. Hence the DC resistance of a conductor is directly proportional to the length of the conductor and inversely proportional to the area.

The conducting ability of a conductor can also be expressed as its Conductivity (σ) measured in Siemens per meter (Sm-1).

The resistivity and conductivity of a conductor are proportional constants and thereby depend only on the material of the conductor. Thus: $\rho = 1/\sigma$

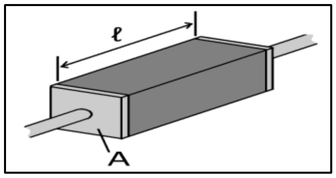


Figure 3-1 Measurement of DC Resistance

Other Electrical Characteristics of OHTL conductors related to the DC resistance include the following:

(a) International Annealed Copper Standard (IACS)

The conductivity of OHTL conductors are expressed with reference to the International Annealed Copper Standard (IACS). Thus, the IACS is the standard measure for comparing the conductivity of conductors. For example, the conductivity of All Aluminium Conductors (AAC) is stated as 61.2% of IACS and All Aluminium Alloy Conductors (AAAC) have conductivity of 52.5% of IACS.

(b) Effect of Temperature on DC Resistance

The DC resistance of a conductor is dependent on the temperature of the surrounding environment. As a result the resistance of conductors changes with change in the ambient temperature. DC resistance is usually quoted with respect to a reference temperature (usually room temperature of 20oC).

The resistance of a conductor at temperature T is calculated using the following formula:

$$R(T) = R_o [1+\alpha(T-T_o)]$$

Where	R(T)	=	final resistance value at temperature T
	Ro	=	Resistance value at reference temperature To
	To	=	Fixed reference temperature (usually 20oC)
	α	=	Temperature coefficient of resistance

(c) Effect of Frequency on DC Resistance – Skin Effect

Skin effect is a phenomenon that occurs in AC system whereby the DC resistance value of the conductor varies with the frequency of the current. The current tend to flow in the outer layers or skin of the conductor thereby causing the effective cross-sectional area of the conductor to reduce which in turn causes the effective resistance to increase. Generally, the effective cross-sectional area of the in AC power systems is about 37%.

3.4.1.4 AC Impedance (Z)

The transmission line impedance (Z) is the total resistance encountered to the flow of current in an AC circuit. It is the total effect of the AC and DC resistance of the conductor. The unit of Impedance is Ohm (Ω).

The total impedance of a conductor is expressed as:

$$\mathbf{Z = \sqrt{(XL^2 + R^2)}}$$

3.4.2 Mechanical Characteristics

Overhead transmission line conductors are strung between towers that support the conductor. In order to ensure that the required ground clearance (sag) are achieved and to prevent fatigue failure of the conductor from occurring during operation, it is necessary for the conductor to possess some mechanical properties to enable it withstand the mechanical forces that it will be subjected to when in service. The mechanical characteristics of the conductor to be considered include the following:

3.4.2.1 Maximum Working Tension

The maximum working tension of a conductor is the tension that the conductor has been designed to carry during its working life and not failing under normal conditions.

In order to understand this concept, it is worth understanding the general behavior of conductor materials when subjected to tensile load. The behaviour of materials under tensile is shown in Figure 3-2below:

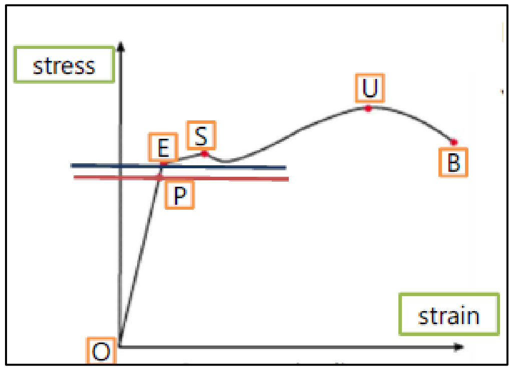


Figure 3-2. Stress – Strain Diagram

The various points on the Stress-Strain diagram are defined as follows:

Proportional Limit (P): It is the stress below which the strain is proportional to the applied stress. i.e. linear relation between the two. There is no deformation in the material.

Elastic Limit (E): It is the stress below which the material can regain its original shape if the forces are release, does not matter if the stress-strain relation is linear or not.

Yield Point (S): It is the stress at which the material deforms sharply even if the force is removed.

Ultimate Tensile Strength (UTS): It is the maximum stress that a material can withstand while being stretched or pulled.

Breaking Point (B): It is the stress at which the material fails while being stretched or pulled.

In order to prevent failure of the conductor due to fatigue, the working tension in the conductor is usually made lower than the Ultimate Tensile Strength. Usually a factor of safety is used to reduce the working tension to about 30 – 40% of the UTS of the conductor.

Example of calculating the maximum working tension is shown in the table 1 below:

Cross sectional Area	Weight Unit	Minimum Tensile Load	Maximum Working Tension	Safety Factor
(a)	(b)	(c)	(d)	(e)
$240mm^2$	1.673kg/m	10,210kgf	3,650kgf	2.797
$330mm^2$	1.32kg/m	10,930kgf	3,950kgf	2.767
$410mm^2$	1.673kg/m	13,890kgf	5,000kgf	2.778
$480mm^2$	1.673kg/m	11,800kgf	4,250kgf	1.776

Table 3-1: Example of calculating the maximum working tension(ACSR)

The Maximum working tension (column (d)) is calculated by dividing the Minimum Tensile load (column (c)) by the safety factor (column (e)).

3.4.2.2 Young's Modulus of Elasticity

It describes the tensile elasticity or the tendency of a material to deform along an axis when a force is applied along that axis. It is defined as the ratio of the tensile stress to tensile strain. The unit of Young's Modulus of Elasticity is Pascal and the symbol is λ.

This characteristics of the conducting material is used to ensure that the selected material remains within its elastic limits during its defined life span.

3.4.2.3 Elongation

This refers to the increase in length of the conductor due to the application of tensile load over a period of time. It is expressed as the ratio of the increase in length to the original length of the conductor.

Thus, Elongation **$(\epsilon) = (L-L_o)/L_o$**

Where L = Final length of the material

Lo = Original length of the material

Elongation of the conductor is not desirable because it causes the sag to increase and reduce the ground clearance. It can also lead to Creep thereby resulting in reduction of the conductor diameter and hence reduction of clamp grip power and in spacer dampers.

3.4.2.4 Coefficient of Thermal Expansion

Generally, conducting materials change in length when there is a change in the ambient temperature. The characteristics of the material that determines the extent to which it expands upon heating is called Coefficient of Thermal Expansion (α). The unit of coefficient of thermal expansion is $1/^{o}C$.

The temperature of OHTL conductors is increased when electric current is passed through and as such they experience some change in length. This change in length leads to change in the mechanical load (tensile) on the conductor. During hot seasons, the length of the conductor will increase with increase in temperature resulting from increased flow of current. This will result in increase of the sag and corresponding reduction in the ground clearance. The reverse happens during cold seasons. The length of the conductor reduces thereby increasing the tension in the conductor and this may lead to permanent deformation of the conductor and subsequent failure (breakage).

It is therefore important to know the coefficient of thermal expansion of conductors to enable a design engineer to select the appropriate conductor for a particular application. Thus, it helps in designing the sag for a transmission line in order to ensure safe operation and prevent failure in future.

3.4.2.5 Lay Ratio

Lay ratio is defined as the increased length over unit length of a wire (conductor) that is formed by twisted strands in helical strands.

Figure 3-3 below shows a sample twisted wire.

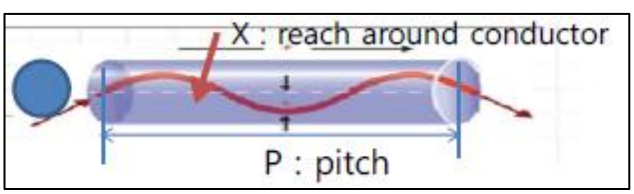


Figure 3-3. Sample Twisted Wire

Using the dimensions shown on the conductor, the definition of Lay Ratio (LR) can be expressed as follows:

$$\textbf{Lay Ratio (LR)} = \frac{\mathbf{X-P}}{\mathbf{p}} = \frac{\mathbf{X}}{\mathbf{p}} - \mathbf{1}$$

Actual length of conductor $\mathbf{X = P\ (LR + 1)}$

The lay ratio is used in determining the DC resistance of a conductor where the actual length of the wires that form the conductor are required for the computation. It is also used in conjunction with conductor strand density to calculate the actual weight of a conductor.

Example 1:

Calculate the DC resistance of a conductor having the following specifications.
Strand count/diameter/strand DC resistance/lay ratio:45/3.7/2.63/0.027.

Solution:

$R_{dc} = \frac{\mathrm{X.rdc}}{\mathrm{N}} = \frac{rdc(LR+1)}{\mathrm{N}}$

Where L_R = Actual length of conductor

rdc = DC Resistance of conductor

N = Number of strands

Therefore R_{dc} = 2.63 x (1+0.027)/45 = 0.0600Ω/km

3.4.2.6 Strand Density

It is the density of each strand of the conductor that indicates the mass of the strand per unit area. It provides an indication of the mass of the conductor material. The unit of strand density is g/cm^3. It is used in conjunction with the cross-sectional area of the conductor and the lay ratio to determine the mass of the conductor per unit length (kg/km).
In a composite conductor, the total mass of the conductor is the sum of the masses of the two materials that form the conductor.
Thus weight of a composite conductor = (Density of Al [g/cm3]) x (total cross sectional area of Al [mm2] x (layer ratio of Al +1) + (Density of St [g/cm3]) x (total cross sectional area of St [mm2] x (layer ratio of St +1).

Example:

Calculate the mass of an ACSR conductor with the following specifications:

Aluminium: Strand Density = 2.7g/cm3

Area= 483.84mm2

Lay ratio = 0.027

Steel: Strand Density = 7.8g/cm3

Area = 33.54mm2

Lay ratio= 0.005

Total mass = 2.7[g/cm3] x 483.84 [mm2] x 1.027 + 7.8 [g/cm3] x 33.54[mm2] x 1.005

= 1,605kg/km

3.5 Types of Transmission Line Conductors

Types of conductors used for transmission lines include the following:

- All Aluminium Conductors (AAC)
- All Aluminium Alloy Conductors (AAAC)
- Aluminium Conductor Steel Reinforcement (ACSR)
- High-Tensile Aluminium Stranded Conductor Steel Reinforcement (HACSR)
- Thermal-Resistance Aluminium Stranded Conductor Steel Reinforcement (TACSR)
- High-Tensile Thermal-Resistant Aluminium Stranded Conductor Steel Reinforcement (HTACSR)
- Super Thermal-resistant Aluminium-alloy Conductor, Invar-reinforced (STACIR)
- Aluminium stranded Conductor Aluminium-Clad Steel Reinforcement (ACSR/AW)
- High Tensile Aluminium stranded Conductor Aluminium-Clad Steel Reinforced (TACSR/AW)
- Super Thermal-resistant Aluminium-alloy Conductor, Invar-reinforced/Aluminium-Clad (STACIR/AW)
- High-Tensile, Super Thermal-resistant Aluminium-alloy Conductor, Aluminium-Clad Invar-reinforced (HSTACIR/AW)

3.5.1 Classification according to the purpose

- **Normal conductors**
  - ACSR, ACSR/AW : Aluminum stranded Conductor reinforced steel
  - HACSR, HACSR/AW : High-tension ACSR, HACSR/Aluminum Clad
- **Heat resistant conductors**
  - TACSR, TACSR/AW : Thermal resistant ACSR
  - HTACSR, HTACSR/AW : High tension Thermal resistant ACSR
- **Super heat resistant conductors**
  - STACIR, STACIR/AW: Super Thermal resistant Aluminum alloy conductor Invar reinforced
  - HSTACIR : High-tension STACIR
- **High Temperature Low Sag Overhead Conductors**
  - ACCC : Aluminum Conductor Composite Core

    Supporting line composite of Carbon and fiber

    Conductor of 63%IACS, structure of compression mold
  - Gap Wire

    Filled with grease between steel and Aluminum

    Stronger tensile than steel reinforced

    Allowable continuous temperature : 150℃
  - ACCR : Aluminum Conductor Composite Reinforced

    Supporting composite line alumina ceramic fiber and Al

    Conductor of 60%IACS, structure of compression mold

    Allowable continuous temperature : 210℃

3.6 Detailed Characteristics of OHTL Conductors And Applications

3.6.1 All Aluminum Conductor (AAC)

The main features of AAC conductor include the following:

- Good Conductivity -61.2% IACS
- Good Corrosion Resistance
- High Conductivity to Weight Ratio.
- Moderate Strength
- Low span applications
- Suitable for coastal line applications

Figure 3-4. Typical AAC

3.6.2 All Aluminum Alloy Conductor (AAAC)

The main features of AAC conductor include the following:

- Moderate Conductivity -52.5% IACS
- Superior Corrosion Resistance
- Better Strength to Weight Ratio
- Improved electrical characteristics compared to ACSR (lower losses)
- Good sag-tension characteristics
- Has limited use for transmission lines. Mostly used within substations and in corrosive environments.

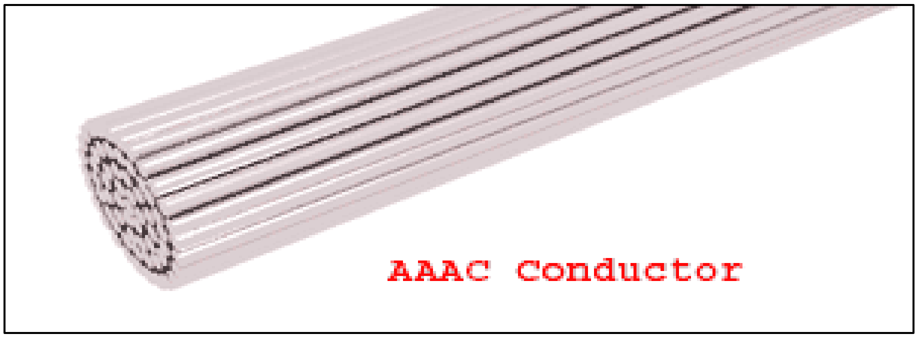


Figure 3-5. Typical AAAC

3.6.3 Aluminum Conductor Aluminium Alloy Reinforcement (ACAR)

Aluminum Conductor Alloy Reinforced (ACAR) is formed by concentrically stranded Wires of Aluminum on high strength Aluminum-Magnesium-Silicon (AlMgSi) Alloy core.

The main features of ACAR include the following:

- Excellent resistance to corrosion Specifications
- Balance of Mechanical & Electrical
- Excellent Corrosion Resistance
- Variable Strength to Weight Ratio
- Higher Conductivity than AAAC
- Custom Designed, diameter equivalent to ACSR most common.
- Typical applications include both transmission and distribution circuits.

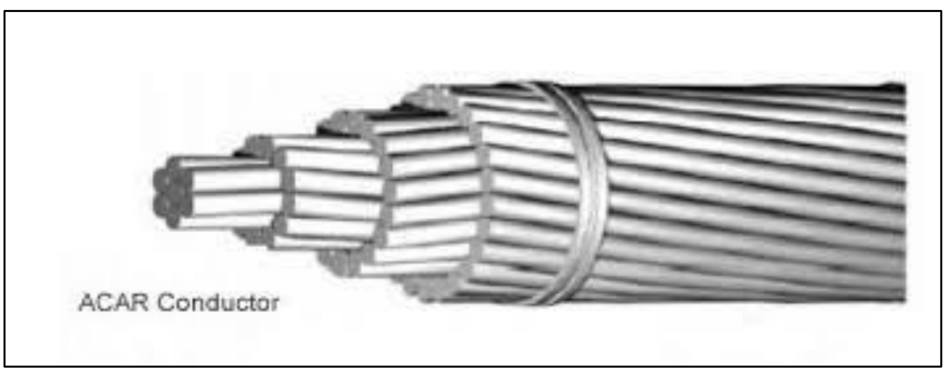


Figure 3-6. Typical ACAR

3.6.4 Aluminium Conductor Steel Reinforcement (ACSR)

3.5.4.1 Structure of ACSR Conductor

Typically ACSR and its variants are the main materials used for OHTL conductors. Figure 3-7 below shows the structure of a typical ACSR conductors.

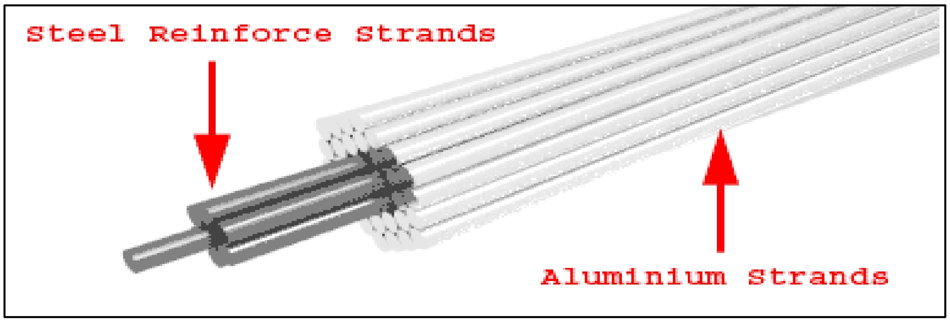


Figure 3-7. Cross section of ACSR Conductor

The ACSR conductor consists of a solid or stranded steel core with one or more layers of high quality aluminium – 1350 wires wrapped in spiral around the steel. In order to protect the steel from corrosion, the core may be coated with zinc (galvanized), aluminium coated (aluminized) or aluminium cladded. The steel content varies from 6 – 40% by weight depending on the application of the conductor.

The zinc coating is available in standard weight Class A, B or C, with Class B having the twice the weight of Class A coating and Class C having three times the weight of Class A.

3.5.4.2 Main Features of ACSR Conductor

- High Tensile strength
- Better sag properties
- Economic design
- Suitable for remote applications involving long spans
- Good Ampacity
- Good Thermal Characteristics
- High Strength to Weight Ratio
- Low sag
- High Tensile Strength
- Used for both transmission and distribution lines

3.5.4.3 Stranding of ACSR Conductor

The aluminium strands around the steel wire are wrapped in concentric circles as shown in Figure 3-8 below. In order to prevent loosening or distortion of the strands, the layers are stranded in different directions. The layer direction from the inner layer is S–Z-S-Z twisted in turns, where Z and S mean right left hand directions respectively.

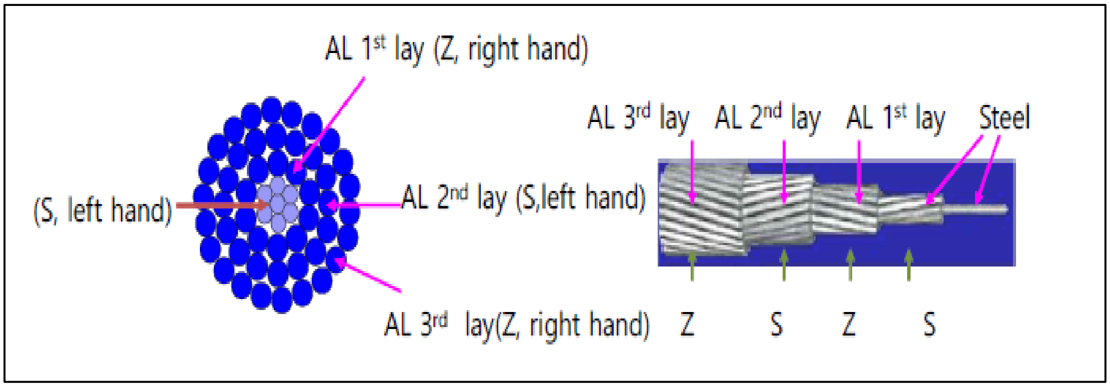


Figure 3-8. Typical ACSR Conductor Stranding

3.6.5 Different Types of ACSR Conductors

The different types of the ACSR conductors include the followings

3.6.5.1 ACSR/AW – Aluminum Conductor, Aluminum Clad Steel Reinforced

The main features of ACSR/AW:

- Good mechanical properties, better sag
- Improved electrical characteristics
- Excellent corrosion resistance
- Suitable for highly polluted environment

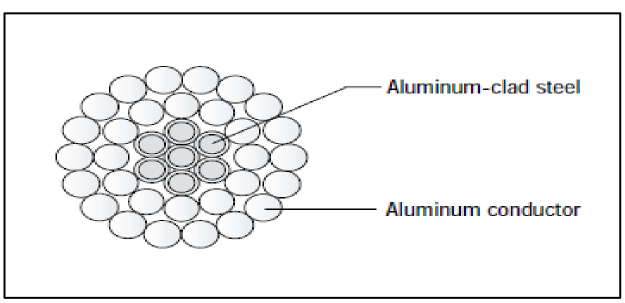


Figure 3-9.. Typical ACSR/AW

3.6.5.2 ACSR/TW – Trapezoidal Shaped Wire Aluminum Conductor, Steel-Reinforced

ACSR/TW is a concentrically stranded conductor with one or more layers of trapezoidal shaped hard drawn and annealed aluminum wires on a central core of steel. It can either be designed to have an equal aluminum cross sectional area as that of a standard ACSR which results in a smaller conductor diameter maintaining the same ampacity level but reduced wind loading parameters or with diameter equal to that of a standard ACSR which results in a significantly higher aluminum area, lower conductor resistance and increased current rating.

The main features of ACSR/TW include the following:

- High Tensile strength
- Better sag properties
- Reduced drag properties
- Low wind and ice loading parameters
- suitable for remote applications involving long spans

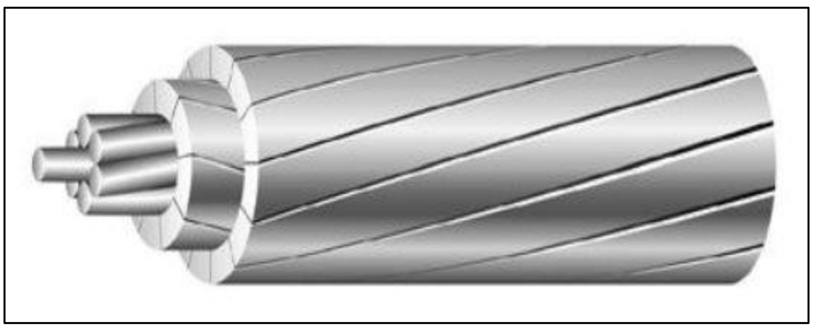


Figure 3-10. ACSR/TW Conductor

3.7 Types and Sizes Of AAC and ACSR Conductors Used in GRIDCo

Overhead transmission line conductors of different characteristics are designated using code names that depends on the jurisdiction in which it used. Annex A shows different types of conductors and the names given them in different parts of the world.

The following are some of the AAC and ACSR Conductors currently used in the GRIDCo transmission system.

Description	Nominal Area (mm^2)	No/Nominal Diameter (mm)	Approx. Overall Diameter (mm)	Approx. Weight (kg/km)	Nominal Breaking Load (kN)	Nominal DC Resistance Ω/km	Current Carrying Capacity (Amps)
Mistletoe	282.00	37/3.12	21.84	775.7	44.30	0.1018	490
Lilac	402.80	61/2.90	26.10	1110.0	63.80	0.0713	607
Hawthorn	604.20	61/3.55	31.95	1662.0	93.50	0.0476	771
Tern	403.77	45/3.38	27.03	1331.8	94.30	0.0715	610
Toucan	265	24/3.78	22.40	998	82.94	0.1094	475

Table 3-2: Standard Conductors used in GRIDCo

3.8 Sag and Tension Design

3.8.1 Sag in Overhead Lines

While erecting an overhead line, it is very important that conductors are under safe tension. If the conductors are too much stretched between supports in a bid to save conductor material, the stress in the conductor may reach unsafe value and in certain cases the conductor may break due to excessive tension. In order to permit safe tension in the conductors, they are not fully stretched but are allowed to have a dip or sag.

The difference in level between points of supports and the lowest point on the conductor is called sag.

Fig. 3-11. shows a conductor suspended between two equilevel supports A and B. The conductor is not fully stretched but is allowed to have a dip. The lowest point on the conductor is O and the sag is S. The following points may be noted :

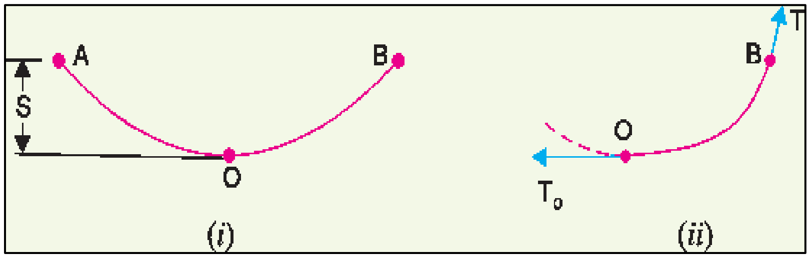


Figure 3-11. The Conductor suspend

(a) When the conductor is suspended between two supports at the same level, it takes the shape of a catenary. However, if the sag is very small compared with the span, then sag-span curve is like a parabola.

(b) The tension at any point on the conductor acts tangentially. Thus tension To at the lowest point O acts horizontally as shown in Fig. 3-11 (ii).

(c) The horizontal component of tension is constant throughout the length of the wire.

(d) The tension at supports is approximately equal to the horizontal tension acting at any point on the wire. Thus if T is the tension at the support B, then T = To .

3.8.2 Conductor sag and tension

This is an important consideration in the mechanical design of overhead lines. The conductor sag should be kept to a minimum in order to reduce the conductor material required and to avoid extra pole height for sufficient clearance above ground level. It is also desirable that tension in the conductor should be low to avoid the mechanical failure of conductor and permit the use of less strong supports. However, low conductor tension and minimum sag are not possible. It is because low sag means a tight wire and high tension, whereas a low tension means a loose wire and increased sag. Therefore, in actual practice, a compromise is made between the two.

3.8.3 Calculation of Sag

In an overhead line, the sag should be so adjusted that tension in the conductors is within safe limits. The tension is governed by conductor weight, effects of wind, ice loading and temperature variations. It is a standard practice to keep conductor tension less than 50% of its ultimate tensile strength i.e., minimum factor of safety in respect of conductor tension should be 2. We shall now calculate sag and tension of a conductor when (i) supports are at equal levels and (ii) supports are at unequal levels.

(a) When supports are at equal levels

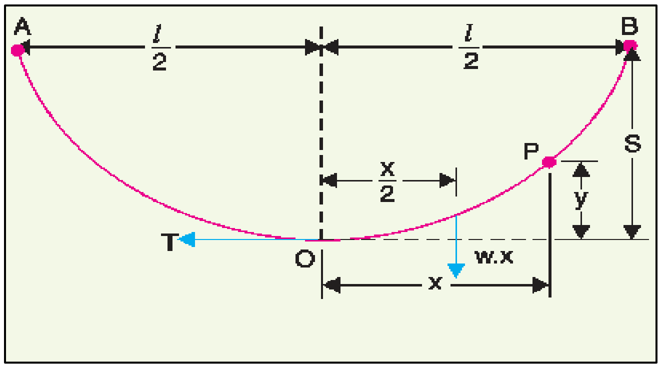


Figure 3-12. Dip between two equal level supports

Consider a conductor between two equal level supports A and B with O as the lowest point as shown in Fig. 3-12., it can be proved that lowest point will be at the mid-span.

Let

l = Length of span

w = Weight per unit length of conductor

T = Tension in the conductor.

Consider a point P on the conductor. Taking the lowest point O as the origin, let the co-ordinates point P be x and y. Assuming that the curvature is so small that curved length is equal to its horizontal projection (i.e., OP = x), the two forces acting on the portion OP of the conductor are:

(a) The weight wx of conductor acting at a distance x/2 from O.

(b) The tension T acting at O.

Equating the moments of above two forces about point O, we get,

$$Ty = w \times \frac{x}{2} \quad \text{or} \quad y = \frac{wx^2}{2T}$$

The maximum dip(sag) is represented by the value of y at either of the supports A and B.

At support A, x=l/2 and y=S

$$\text{Sag, S} = \frac{w(\frac{l}{2})^2}{2T} = \frac{wl^2}{8T}$$

(b) When supports are at unequal levels.

In hilly areas, we generally come across conductors suspended between supports at unequal levels. Fig 3-13 shows a conductor suspended between two supports A and B which are at different levels. The lowest point on the conductor is O.

Let

l = Span length

h = Difference in levels between two supports

x1 = Distance of support at lower level (i.e., A) from O

x2 = Distance of support at higher level (i.e. B) from O

T = Tension in the conductor

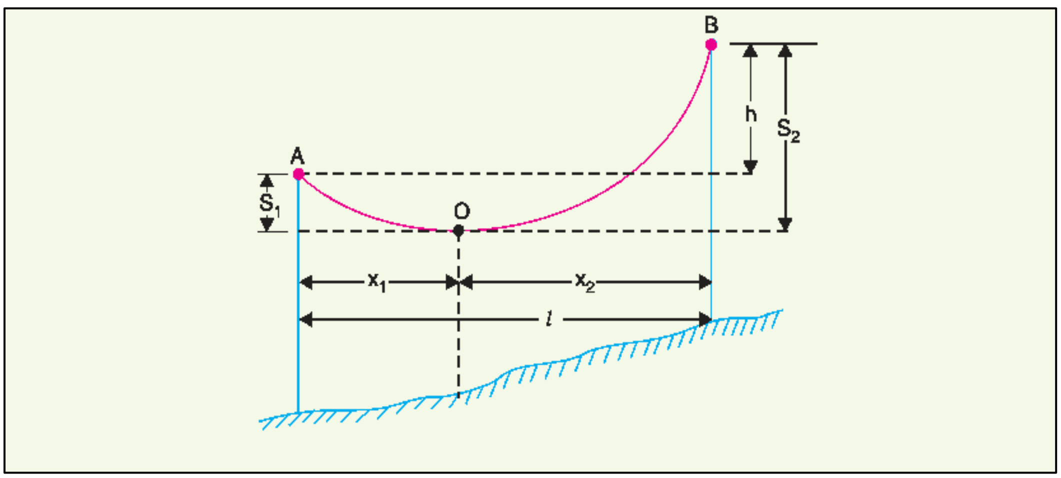


Figure 3-13. Dip between unequal level supports

If w is the weight per unit length of the conductor, then,

$$\text{Sag } S1 = \frac{wx1^2}{2T}$$

$$\text{Sag } S2 = \frac{wx2^2}{2T}$$

x1 + x2 = l ---------------------- (i)

S2-S1 = $\frac{w}{2T}(x2^2 - x1^2) = \frac{w}{2T}(x2 + x1)(x2 - x1)$

$$S1 - S2 = \frac{wl}{2T}(x2 - x1)$$

S2-S1=h

$$h = \frac{wl}{2T}(x2 - x1)$$

$x2 - x1 = \frac{2Th}{wl}$ --------------- (ii)

Solving exps. (i) and (ii), we get,

$$x1 = \frac{l}{2} - \frac{Th}{2wl}$$

$$x2 = \frac{l}{2} + \frac{Th}{2wl}$$

Having found x1 and x2, values of S1 and S2 can be easily calculated.

3.8.4 Effect of wind and ice loading

The above formulae for sag are true only in still air and at normal temperature when the conductor is acted by its weight only. However, in actual practice, a conductor may have ice coating and simultaneously subjected to wind pressure. The weight of ice acts vertically downwards i.e., in the same direction as the weight of conductor. The force due to the wind is assumed to act horizontally i.e., at right angle to the projected surface of the conductor. Hence, the total force on the conductor is the vector sum of horizontal and vertical forces as shown in Fig. 3-15.

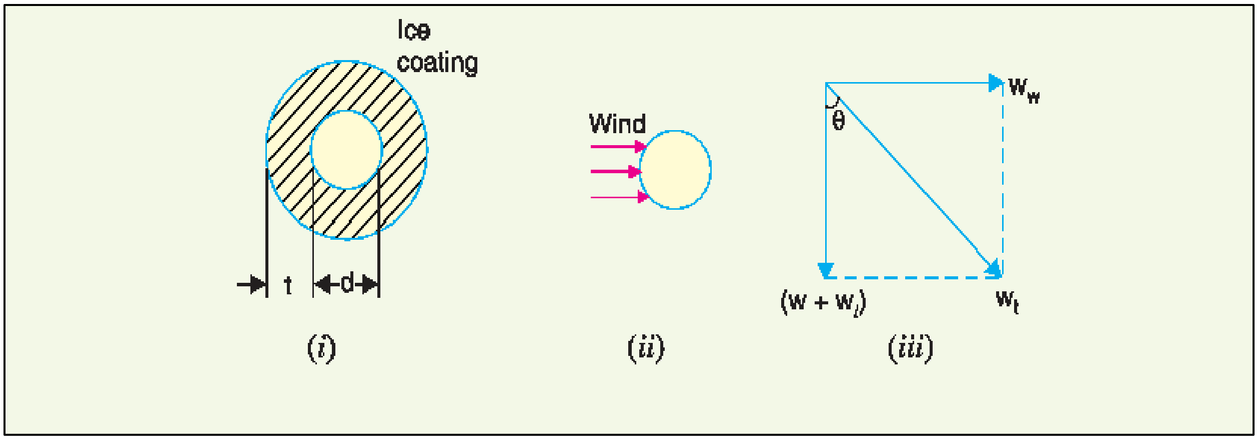


Figure 3-15. Effect of wind and ice loading

Total weight of conductor per unit length is

$$Wt = \sqrt{(W + Wi)^2 + (Ww)^2}$$

Where W = weight of conductor per unit length

= conductor material density × volume per unit length

Wi = weight of ice per unit length

= density of ice × volume of ice per unit length

= density of ice $\times \frac{\pi}{4}[(d+2t)^2 - d^2] \times l$

Ww = wind force per unit length

= wind pressure per unit area × projected area per unit length

= wind pressure × [(d+2t) × l]

When the conductor has wind and ice loading also, the following points may be noted:

(i) The conductor sets itself in a plane at an angle θ to the vertical where

$$\text{Tan } \theta = \frac{Ww}{W+Wi}$$

(ii) The sag in the conductor is given by:

$$S = \frac{Wtl^2}{2T}$$

(iii) Hence S represents the slant sag in a direction making an angle θ to the vertical. If no specific mention is made in the problem, then slant sag is calculated by using the above formula.

$$\text{The vertical sag} = S \times \cos\theta$$

3.8.5 Additional Considerations

Mechanical factors of safety to be used in transmission line design should depend to some extent on the importance of continuity of operation in the line under consideration. In general, the strength of the line should be such as to provide against the worst probable weather conditions. We now discuss some important points in the mechanical design of overhead transmission lines.

(a) Tower height

Tower height depends upon the length of span. With long spans, relatively few towers are required but they must be tall and correspondingly costly. It is not usually possible to determine the tower height and span length on the basis of direct construction costs because the lightning hazards increase greatly as the height of the conductors above ground is increased. This is one reason that horizontal spacing is favoured despite of the wider right of way required.

(b) Conductor clearance to ground

The conductor clearance to ground at the time of greatest sag should not be less than some specified distance (usually between 6 and 12 m), depending on the voltage, on the nature of the country and on the local laws. The greatest sag may occur on the hottest day of summer on account of the expansion of the wire or it may occur in winter owing to the formation of a heavy coating of ice on the wires. Special provisions must be made for melting ice from the power lines.

(c) Sag and tension

When laying overhead transmission lines, it is necessary to allow a reasonable factor of safety in respect of the tension to which the conductor is subjected. The tension is governed by the effects of wind, ice loading and temperature variations. The relationship between tension and sag is dependent on the loading conditions and temperature variations. For example, the tension increases when the temperature decreases and there is a corresponding decrease in the sag. Icing-up of the line and wind loading will cause stretching of the conductor by an amount dependent on the line tension. In planning the sag, tension and clearance to ground of a given span, a maximum stress is selected. It is then aimed to have this stress developed at the worst probable weather conditions (i.e. minimum expected temperature, maximum ice loading and maximum wind). Wind loading increases the sag in the direction of resultant loading but decreases the vertical component. Therefore, in clearance calculations, the effect of wind should not be included unless horizontal clearance is important.

M04 – INSULATION

4.1 Objectives

Through this module participant will be able to;

- Explain the required characteristics of a good insulating material.
- Identify the different types of insulators used in overhead transmission lines.
- Understand the different types of overvoltages in power system.
- Understand procedure of insulation design

4.2 Introduction

In overhead transmission systems the towers and poles that carry the conductor are usually grounded. There is therefore the need for the provision of an insulation between the live conductor and the supporting structures to prevent unwanted flow of electric current to earth through the supporting points. A failure of the insulation will result in a short circuit between the live conductor and the grounded supporting structure which will result in outages. Insulators are therefore a very critical part of the transmission system on which the reliability of the system relies.

4.3 Electrical Insulation

An insulator is a material that presents a very high resistive path through which practically no current flows. Electrical insulation can be expressed as the dielectric of the insulating material which serves to preserve the electrical integrity of the power system. They can be described as “internal” or “external” insulations.

Internal insulation include solid, liquid, or gaseous materials, which are protected from the effects of atmospheric conditions. They are used for applications such as transformer windings, cables, gas-insulated substations, oil circuit breakers, etc.

This type of insulation may also be described as non-self restoration insulation in that the insulation characteristics cannot be restored after the overvoltage is applied and discharged.

External insulation is provided by air and as such it is exposed to atmospheric conditions. It is used in conjunction with solid insulating materials for applications such as bushings, bus support insulators, disconnect switches, line insulators, air itself (phase spacing, etc.).

This type of insulation may also be described as self-restoration insulation in that the insulation characteristics are fully restored after the overvoltage is applied and discharged. Overhead transmission lines make use of the external type of electrical insulation to preserve the electrical integrity of the power system.

4.4 Characteristics of Insulating Material

A good insulating material for overhead transmission line system should possess the following characteristics in order to have a reliable system.

- Good mechanical strength to withstand tensile load in the conductor as well as the weight of the conductor.
- High dielectric strength to withstand the voltage stresses in High Voltage system.
- High Insulation Resistance to prevent leakage current to the earth through the supporting structures.
- Free from unwanted impurities.
- Non porous.
- Nonabsorbent moisture so that moisture or gases cannot enter in it.
- The mechanical and electrical properties must be less affected by temperature changes.
- Economical

4.5 Types of Insulator Materials

There are basically three (3) types of materials used for producing insulators that are used for transmission lines. They are:

- Porcelain
- Toughen Glass
- Polymers

4.5.1 Porcelain

Porcelain is the most commonly used material for overhead insulators. It possesses most of the desired characteristics of a good insulating material as outlined in Subsection 4.4. It is made of aluminium silicate mixed with plastic kaolin, feldspar and quartz. The final product is glazed such that water cannot trace on it. The properties of porcelain insulator are presented below:

Property	Value(Approximate)
Dielectric Strength	60 kV / cm
Compressive Strength	70,000 Kg/cm^2
Tensile Strength	500 Kg/cm^2

Figure 4-1. Porcelain Disc Insulator

(a) Advantages

- It can be designed and used for all voltage levels
- Moisture does not condense on the surface of porcelain
- Environmentally friendly. At disposal, porcelain insulator is not a dangerous waste material.
- It has high resistant to degradation of the surface.
- The ceramic material is resistant to rodents, termites, birds and other animals capable of compromising the integrity of polymer insulators.
- It can withstand extreme hot/cold changes in the environment.
- The design can be modified to suit the environment.
-

(b) Disadvantages

- Impurities and air bubbles cannot be easily detected.
- Absorbs heat from sunlight and heats up. This may lead to shattering of the insulators under severe weather conditions.
- More susceptible to vandalism
- Very fragile. Packaging and transportation needs care

4.5.2 Glass Insulator

The use of toughened glass for insulators in transmission systems is gaining popularity in recent days. The mechanical and insulating properties of toughened glass are better than that of porcelain.

The properties of glass insulator are presented below:

Property	Value(Approximate)
Dielectric Strength	140 kV/cm
Compressive Strength	10,000 Kg / cm^2
Tensile Strength	35,000 Kg / cm^2

Figure 4-2. Glass Insulator Disc

(a) Advantages

- It has very high dielectric strength compared to porcelain.
- Its resistivity is also very high.

- It has low coefficient of thermal expansion.
- It has higher tensile strength compared to porcelain insulator.
- As it is transparent in nature it is not heated up in sunlight as porcelain.
- The impurities and air bubble can be easily detected inside the glass insulator body because of its transparency.
- Its mechanical and electrical properties are not affected by ageing. It therefore has very long service life.
- Cheaper than porcelain.

(b) Disadvantages

- Moisture can easily condensed on glass surface and hence air dust will be deposited on the wet glass surface which will provide path to the leakage current of the system.
- For higher voltage glass cannot be cast in irregular shapes since due to irregular cooling internal cooling internal strains are caused.
- Susceptible to vandalism
- Very fragile. Packaging and transportation needs care

4.5.3 Polymer Insulator

The polymer insulator has two main parts, one is glass fiber reinforced epoxy resin rod shaped core and other is silicone rubber or EPDM (Ethylene Propylene Diene Monomer) made weather sheds. Rod shaped core is covered by weather sheds. Weather sheds protect the insulator core from outside environment. As it is made of two parts, core and weather sheds, polymer insulator is also called composite insulator. The rod shaped core is fixed with Hop dip galvanized cast steel made end fittings in both sides.

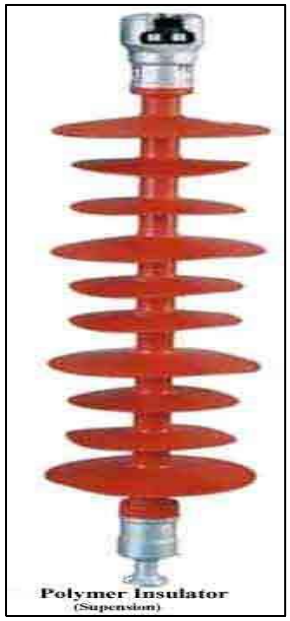


Figure 4-3. Polymer Insulator

(a) Advantages

- It is very light weight compared to porcelain and glass insulator, easy to install and transport.
- As the composite insulator is flexible the chance of breakage becomes minimum.
- Because of lighter in weight and smaller in size, this insulator has lower installation cost.
- It has higher tensile strength compared to porcelain insulator.
- Its performance is better particularly in polluted areas.
- Due to lighter weight polymer insulator imposes less load to the supporting structure.
- Less cleaning is required due to hydrophobic nature of the insulator.
- Good resistance to soiling and flashover
- Good shock resistance

(b) Disadvantages

- Moisture may enter in the core if there is any unwanted gap between core and weather sheds. This may cause electrical failure of the insulator.
- Over crimping of the end fittings may produce cracks in the core which leads to mechanical failure of polymer insulator.
- Shorter lifespan compared to porcelain

- Challenges associated with the disposal of polymeric materials.
- Susceptible to damage by rodents, termites, birds and other animals. Special care is required for its storage.

4.6 Types of Insulators Usage

There are basically two types of insulators used in overhead transmission system. The suspension type and the strain type insulators.

4.6.1 Suspension Insulator

Suspension type insulator consists of insulator discs connected in series to form a string of insulator and the line conductor is carried by the bottom most insulator. The individual insulators are described as disc insulator because of their shape. Figure 4 below shows a suspension type insulator string.

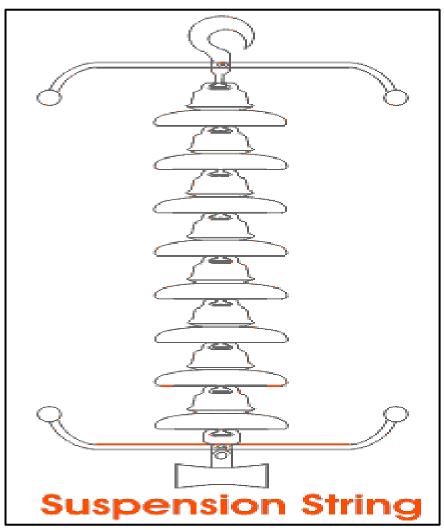


Figure 4-4. Suspension Insulator String

4.6.2 Strain (Tension) Insulator

Strain insulator is similar to the suspension type insulator except that it is used for anchoring the conductor to the tower at dead ends or where there is a large angle in the transmission line. They are designed to be able to withstand the tensile load of the conductor and as such they have considerable mechanical strength in addition to their electrical insulating properties. Figure 5 below shows a typical Strain Insulator.

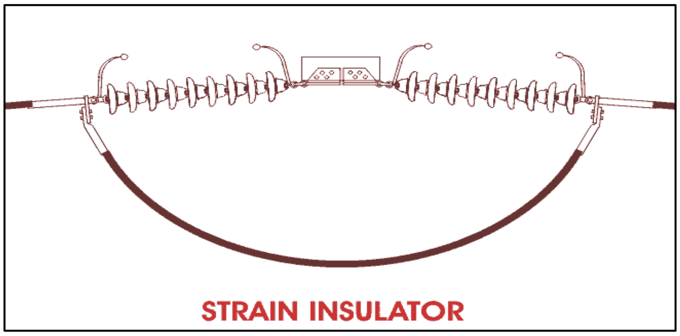


Figure 4-5. Strain Insulator

4.6.3 Characteristics of String Type Insulators

The general characteristics of string type insulators include the following:

- Each suspension disc is designed for normal voltage rating of about 11kV. A number of disc insulators can be connected in series to achieve a string that is suitable for any target voltage level.
- A failed insulator disc in the string can easily be replaced.
- There is less mechanical stresses on the suspension insulator since the line hanged on a flexible suspension string.
- Suspension string requires more height of supporting structure in order to maintain ground clearance of current conductor.
- The amplitude of free swing of conductors is larger in suspension insulator system, hence, more spacing between conductors should be provided.

4.6.4 Insulator Strings

Suspension and strain type insulators used in overhead transmission system are made of disc insulators connected in series that form the string. Most widely used insulator disc design is the ball-and-socket type. It is also referred to as “cap-and-pin”. The cross section of a ball-and-socket type insulator disc is shown in Figure 4-6 below.

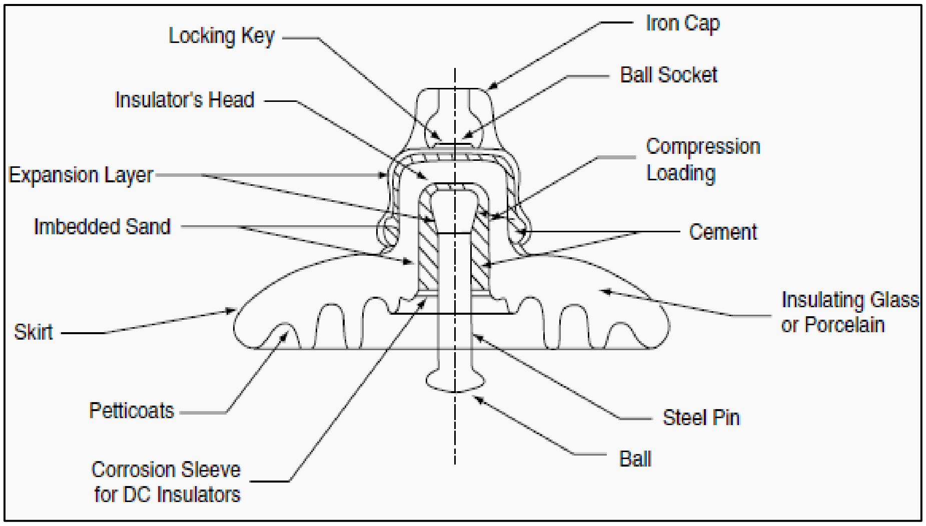


Figure 4-6. Cross-section of a standard ball-and-socket insulator

There are two types of disc insulators, standard and fog type. The fog type are also described as long leakage distance insulators and they are used in polluted areas, close to the ocean, or in industrial environments. Figure 4-7 below shows the standard and fog type insulators.

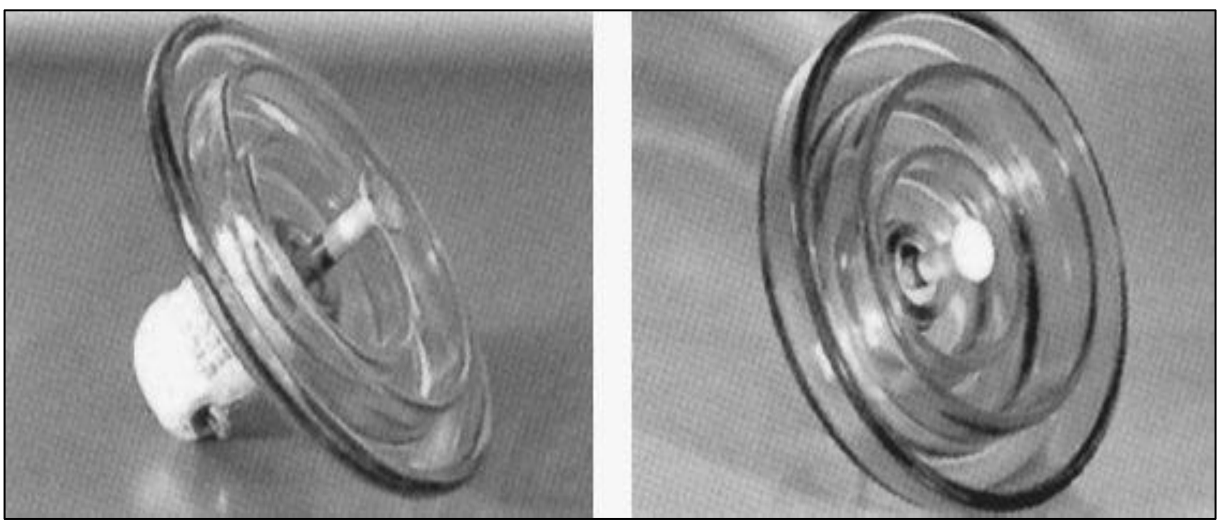


Figure 4-7. Standard and Fog Type Disc Insulators

4.7 Insulation Design

The transmission network traverses different terrains of different environmental characteristics and at the mercy of the atmospheric conditions such as wind, ice, thunder storms, etc. which may cause system condition to change thereby resulting in arcing and disruption of power supply. There is therefore the need to design the system insulation such that it can withstand the normal system voltages as well as overvoltages that may occur during its operation. This is to ensure an optimized system that is safe and reliable.

A power system can be designed to withstand all the expected overvoltages but such a system will be very expensive. Thus to reduce the breakdown of the system, the more money have to be spent and hence the higher the cost of the system. This relationship is shown in Figure 4-8 below. Transmission line components are therefore designed to have some acceptable level of failure or breakdown in order to have an optimized system.

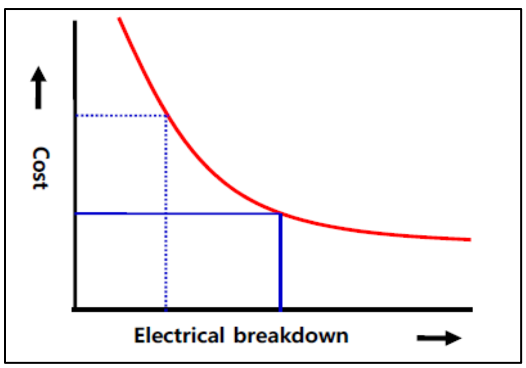


Figure 4-8. Insulator – Electrical Breakdown Relationship

There are various causes of overvoltages in the power system. This include the following.

4.7.1 Temporary Overvoltages (Power Frequency Overvoltage)

In normal operating conditions, network voltage may present short duration power frequency overvoltages the amplitude of which is usually less than 2p.u. These overvoltages are extremely destructive due to their relatively long duration.

The causes of temporary overvoltage may be classified as follows:

- Line to ground fault
- Rapid change of load

- Ferranti Effect
- Low frequency oscillation (line & reactor)
- Ferro-resonance (transformer, voltage transformer)
- Disconnection of line conductor

4.7.2 Switching Overvoltage

The power system is made of resistive, capacitive and inductive components which have different characteristics. During normal system operations such as pening and closing of circuit breakers, there is transfer of energy among these components giving rise to switching overvoltages of a high frequency wave that is aperiodic or oscillating in nature with rapid damping. This may cause overvoltage between phase-to-groung and phase–to–phase on the power system.

The duration of this overvoltage lasts for tens-hundreds micro-second (10ms) and amplitued of between 2 – 4 p.u.

The causes of the overvoltage may be classified as follows:

- Line energization and re-closing
- Fault Initiation
- Fault Clearing
- On/Off of capacitive current (capacitor banks)
- On/Off of reactive current (transformers, reactors)

4.7.3 Lightning Overvoltages

Lightning is a natural phenomenon well known to mankind, which is both spectacular and dangerous. Overhead transmission networks are the most affected by lightning strikes due to their heights. They have fast rising front characteristics of 1.2/50 μs as sown in Figure 4-9 below.

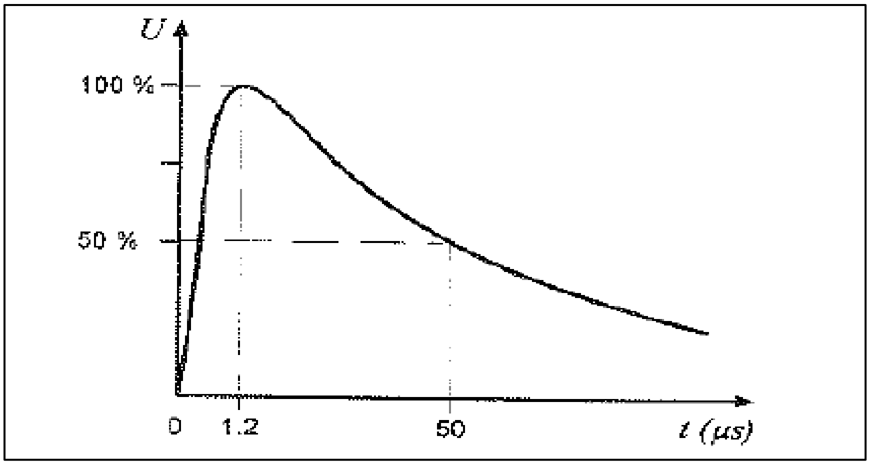


Figure 4-9. Characteristics of Lightning Wave

Lightning causes overvoltages on the transmission network to occur in two ways as follows.

4.7.3.1 Direct Lightning Stroke

When lighting strikes the transmission line conductors directly, it is called **Direct Lighting Stroke**. When direct lightning stroke occurs, it causes an injection of a current wave of magnitude of kA range in the line which is propagated on either side of the point of impact resulting in an increase in the system voltage. The voltage rise U given by the formula:

$$U = \frac{Zc \times I}{2}$$

Where I = Value of the injected current

Zc = Line zero sequence impedance (300-1000Ω)

The value of U can rise to a level that the insulation level of the transmission line cannot withstand. Thus, the value of U may increase to a level where clearance breakdown occurs (insulator string). This is known as **Shielding Failure.**

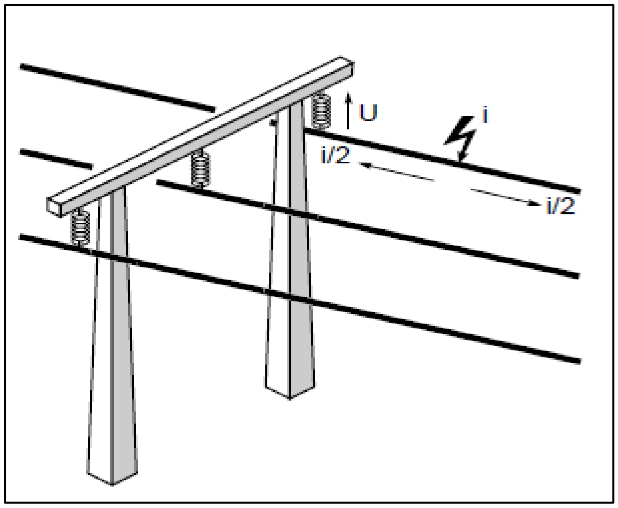


Figure 4-10. Direct Lightning Strike

4.7.3.2 Indirect Lightning Stroke

When the lightning strikes falls on the support (tower) or shield wire(ground wire) high overvoltages are generated in the network. Indirect strokes are equally dangerous to the transmission network. The lightning induced current flows through the tower body to ground and causes a rise in the tower potential with respect to earth. The corresponding overvoltage U may reach several hundred of kV.

The rise in the potential U is calculated using the formula

$$U = \frac{RI}{2} + \frac{L\,di}{dt} \quad \text{----------------} \ (1)$$

Where R	=	Tower footing resistance in Ω
I	=	Lightning current in A
L	=	Inductance of the tower in Henry
di/dt	=	Rate of rise of the current.

The inductance of the tower is usually relatively small and hence negligible. The rise in the tower potential can therefore be approximated to

$$U = \frac{RI}{2} \quad \text{………………..} \; (2)$$

From equation (2) above, it is noted that the value of the potential rise of the tower is dependent on the tower footing resistance and the magnitude of the lightning current. The tower footing resistance is the only variable that is within the control of the transmission line designer. The magnitude of the lightning depends solely on the lightning phenomenon. When the value U reaches the breakdown voltage of the air clearance of the insulator string, arcing occurs from the tower to the live conductor. This is known as **Back Flashover.**

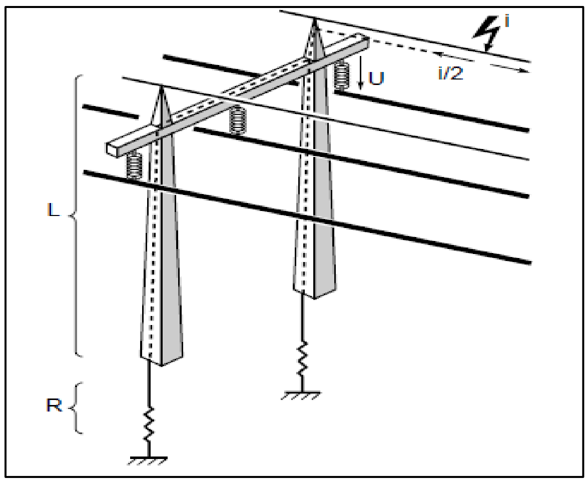


Figure 4-11. Indirect Lightning Strike

4.7.4 Methods of Controlling Overvoltages

Overvoltages in power system can be controlled using one of the following methods.

- Application of surge protective devices – surge arresters and arcing horns/gaps.
- Switching device insertion resistors and controlled closing.
- Shunt reactors
- Application of shield wires(ground wires) on towers
- Improved grounding (reduce tower footing resistance).

4.7.5 Consequences of Overvoltage

Overvoltages in electrical network cause equipment degradation, a drop in service continuity and are a hazard to the safety of persons.

The consequences vary depending on the type of overvoltages, their magnitude and their duration. The effects are summed up as follows:

- Breakdown in the insulating dielectric of equipment in the case where the overvoltage exceeds the specified withstand voltage.
- Degradation of equipment through ageing, caused by non-destructive but repetitive overvoltages.
- Loss of power supply caused by the destruction of network elements
- Disturbance of control, monitoring and communication circuits by conduction or electromagnetic radiation.
- Electrodynamic stress (destruction or deformation of equipment) and thermal stress (elements melting, fire, explosion) essentially caused by lightning impulses.
- Hazard to man and animals following rises in potential and occurrence of step and touch voltages.

4.7.6 Insulation Coordination

All the insulating materials that constitute the insulation system of the power system have finite strength. The strength of the insulating item depends on the magnitude and duration of the maximum electric field strength (stress) that is applied to it. The stresses are caused by overvoltages that occur on the power system. For the system to be able to operate reliably, it is important that the strength of the insulation is coordinated with stresses that may occur on the power system.

The IEC defines Insulation Coordination as follows:

"Insulation Coordination comprises the selection of the electrical strength of equipment and its application, in relation to the voltages which can appear on the system for which the equipment is intended and taking into account the characteristics of available protection devices, so as to reduce to an economically and operationally acceptable level of reliability that the resulting voltage stresses imposed on the equipment will cause damage to the equipment insulation or effective continuity of service”.

IEEE also defines Insulation Coordination as:

“The selection of insulation strength consistent with expected overvoltages to obtain an acceptable risk of failure. The procedure for insulation coordination consists of (a) determination of the voltage stresses and (b) selection of the insulation strength to achieve the desired probability of failure. The voltage stresses can be reduced by the application of surge protective devices, switching device insertion resistors and controlled closing, shield wires, improved grounding, etc. ”

In practice, it means that an insulation level is determined for each voltage level to which the equipment is designed and tested. At the same time the system overvoltages are kept low by design efforts, such as proper grounding and shielding. Finally, the overvoltages are limited to the desired level by the application of protective devices such as lightning arresters or surge diverters.

In order to understand the concept of insulation coordination, we have to understand first, some basic terminologies of the electrical power system.

4.7.6.1 Definition of Terminologies

- **Nominal System Voltage**

This is the phase to phase voltage of the system for which the system is normally designed. Typical nominal system voltage for transmission systems 100kV, 132 KV, 154kV, 161kV, 220KV, 225kV, 330kV, 345kV, 400kV, 765kV, etc.

- **Maximum System Voltage**

This is the maximum allowable power frequency voltage which can occur, may be for long time during no load or low load condition of the power system. It is also measured in phase to phase manner. Generally, the maximum system voltage is 110% of the corresponding nominal system voltage. For systems with nominal system voltage of 400kV and above, the maximum system voltage is limited 105% of the corresponding nominal system voltage.

- **Rated System Voltage**

This defines the voltage class for which the component or equipment has been designed to operate within. It also outlines the withstand voltage levels that an equipment is expected to have according to the standards. Table 1 below shows the rated voltages for some transmission nominal system voltages.

Nominal System Voltage	154kV	161kV	330kV	345kV	765kV
Rated System Voltage Um (kV)	170	170	362	362	800

Table 4-1: Typical Rated Voltage of Power Systems

- **Overvoltage Withstand**

This is the maximum value of an impulse voltage (lightning or switching) of the prescribed form that an insulating medium is capable of withstanding without failure.
It is influenced by external factors such as;

- Ageing
- Environmental conditions (humidity, pollution)
- Variation in air or insulating gas pressure

- **Withstand Voltage (Insulation Level)**

The components of the transmission system experience abnormal transient overvoltage situation at different times during its total service life period due to lightning, switching operations or short duration power frequency overvoltages. Depending upon the maximum level of impulse voltages and short duration power frequency over voltages that one power system component can withstand, the insulation level of high voltage power system is determined. During the determination of the insulation level of systems rated less than 300kV, the lightning impulse withstand voltage and short duration power frequency withstand voltage are considered. For equipment rated more or equal 300kV, switching impulse withstand voltage and short duration power frequency withstand voltage are considered.

Electrical equipment is characterized by it's withstand voltage to different types of overvoltages. The withstand voltage rating of equipment corresponding to rated system voltage provided by the relevant standards. Table 2 below shows the withstand voltage for equipment.

AC Voltage (kV) Nominal/Rated System Voltage	Power Frequency Withstand Voltage (kV rms)	Lightning Impulse Level (kV peak)	Switching Impulse Level(kV peak)
69/72.5	140	325	-
132/145	275	650	-
154/170	325	750	-
161/170	325	750	-
220/245	460	1050	-
400/420	680	1550	1050
765/800	830	2400	1550

Table 4-2. Typical Standard Insulation Levels provided by (IEC)

4.7.6.2 Electrical Clearance (Air and Creepage Distance)

The two types of electrical clearances considered in insulation design are air clearance and creepage distance.

- **Air Clearance**

This is defined as the shortest path between two conductive parts. Clearance distance helps prevent dielectric breakdown of the air insulation between the two conducting parts caused by the ionization of air. The dielectric breakdown level is influnced by relative humidity, temperature, and degree of pollution in the environment.

There are different types of air clearances that have to be considered in transmission line design. These are:

- Ground clearance
- Phase to ground metal clearance (live-metal clearance)

- Phase to phase clearance
- Clearance between power conductor and ground/ground wire/OPGW
- Clearance of power lines crossing over water bodies
- Clearance between power lines crossing each other
- Clearance of power lines crossing railway tracks (Electrified/Non Electrified)
- Clearance of lines crossing telecommuncation lines

For the purposes of insulation coordination, only the phase to ground metal clearance (live-metal clearance) will be considered.

- **Creepage Distance**

It is the shortest path between two conductors but following the outer surface of the solid insulators. A proper and adequate creepage distance protects against tracking, a process that produces a partially conducting path of localized deterioration of the surface of and insulating material as a result of the electric discharges on or close to an insulation surface.

Tracking that damages the insulating material normally occurs because of the one or more of the following reasons:

- Humidity in the atmosphere
- Presence of contamination
- Corrosive chemicals
- Altitude at which equipment is to be operated.

In designing insulation for a power system, contaminations caused by the environment has to be taken into consideration. Generally, different environmental conditions are classified and the target insulation level of the insulators determined accordingly. The level of pollution is generally expressed in terms of Equivalent Salt Deposit Density (ESDD) on the insulators which are measured from the existing line and/or field testing station. Tables 4-3 and Table 4-4 below shows typical pollution level values and their corresponding target withstand voltage. Note that the target withstand voltage reduces as the pollution level increases. This will result in increased number of insulator discs required in order to take care of the contaminations in the environment.

Clean	A	B	C	D
x≤0.03	0.03<x≤0.063	0.063<x≤0.125	0.125<x≤0.25	0.25<x≤0.5
x≤0.03	0.03<x≤0.063	0.063<x≤0.125	0.125<x≤0.25	0.25<x≤0.5

Table 4-3: Pollution Level

Description		Clean	A	B	C	D
210kN Suspension (Normal)	Target Withstand Voltage [kV/EA]	11.3	9.7	8.4	7.2	6.4
210kN Suspension (Fog)	Target Withstand Voltage [kV/EA]	41.7	12.6	10.9	9.4	8.3
210kN Tension (Normal)	Target Withstand Voltage [kV/EA]	11.3	9.7	8.4	7.2	6.4

Table 4-4: Withstand Voltage

Air clearance and creepage distance of a typical insulator is shown in Figure 4-12 below.

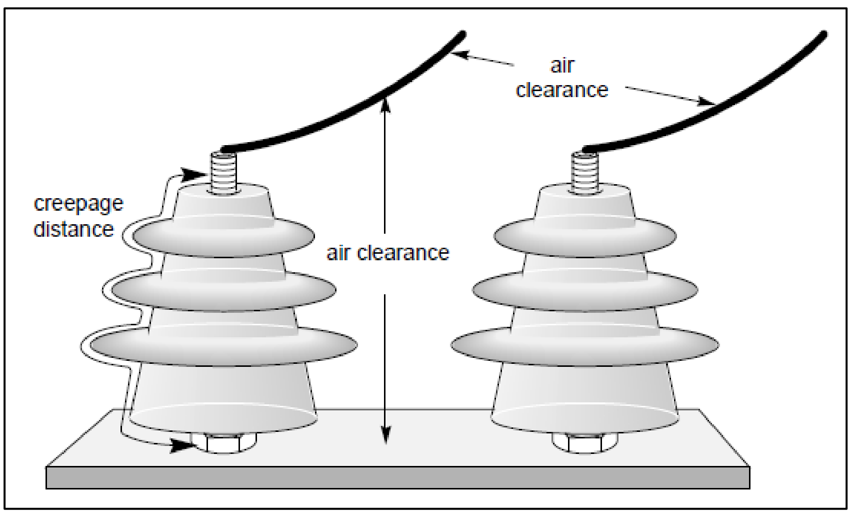


Figure 4-12. Air Clearance and Creepage Distance

4.7.6.3 Procedure for Insulation Coordination

Having defined what Insulation Coordination is and the related terminologies, we can now discuss the concept of insulation design for transmission lines using the insulation coordination principles.

The procedure for insulation coordination consists of

(a) determination of the voltage stresses (overvoltages) and

(b) selection of the insulation strength to achieve the desired probability of failure.

There are basically two methods of applying the concept of insulation coordination.

(a) Deterministic Method

As noted above the overvoltage expected in a power system can be limited by using protective devices like lightning arresters or surge arresters. If the insulation level of the transmission system is maintained above the protective level of the protective device, then ideally there will be no chance of breakdown of insulation of any component of the system. This method is depicted in Figure 4-13 below.

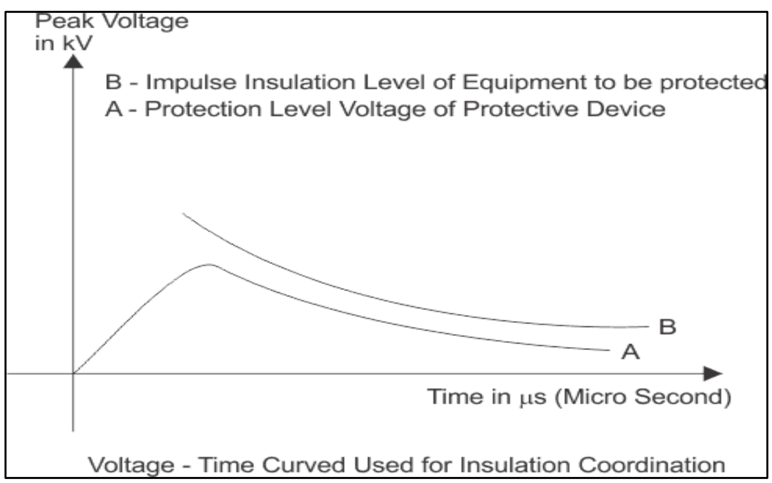


Figure 4-13. Deterministic Method of Insulation Coordination

(b) Statistical Method

In this method the overvoltage stress is given as a statistical distribution function (d.f) with the withstand strength a cumulative distribution function (c.d.f). The area of the product of the functions can be shown to constitute the risk of flashover. Reducing the magnitude of the overvoltages (by design or the application of protective devices) would move the overvoltage curve to the left. Similarly, an increase of the withstand capability of the insulator would move the strength curve to the right. A smaller risk of flashover would therefore result. This method is the modern approach and can be based on actual test data, simulations and experience.

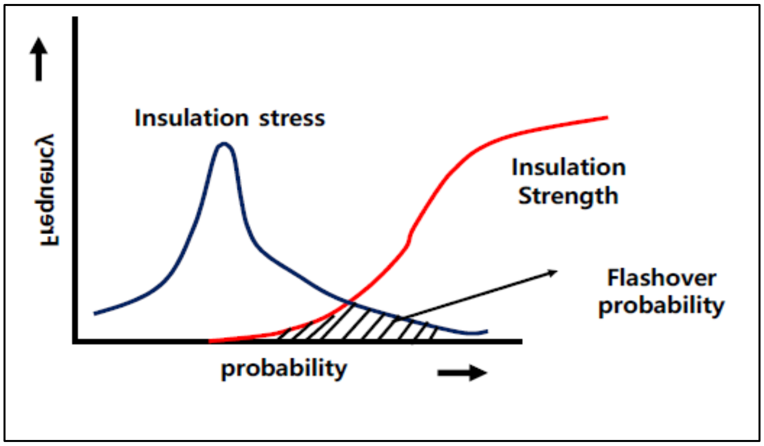


Figure 4-14. Deterministic Method of Insulation Coordination

4.7.6.4 Application of Insulation Coordination

Insulation design for transmission lines using the insulation coordination concept is used for the following:

- Creepage Distance Design (Contamination Design)
- Air Clearance Design
- Lightning Protection Design

(a) Creepage Distance Design (Contamination Design)

This process involves determining the number of insulators needed to provide the required creepage distance to withstand the rated system voltage of the system. The number of insulators is selected taken into account the level of contamination in the environment.

The process is as follows:

- Determine the maximum rated voltage of the sytems [Um]. This value is usually a phase –to- phase voltage.
- Determine the target withstand voltage of the system [Ut]. It is a phase value and is determined by dividing Um by √3. Thus Ut = Um/√3
- Determine the pollution level based on studies performed in the area.
- Select the target withstand voltage (Ud) of the disc insulator based on the pollution level.

The number of insulator discs can then be determined using the following formula:

$$\text{Number of Insulator Discs N} = \frac{Ut}{Ud}$$

Example:

Determine the number of insulator strings to be used in the different environment for a 161kV transmission system as shown below.

Solution

For a 161kV transmission system, the rated voltage is 170kV. Therefore,

The maximum target voltage $U_T = Um/\sqrt{3} = 170/\sqrt{3} \approx 99\text{kV}$

$$\text{Number of insulator discs N} = \frac{Ut}{Ud}$$

The number of insulator discs for the various pollution levels are computed as indicated in the tables.

Clean	A	B	C	D
x≤0.03	0.03<x≤0.063	0.063<x≤0.125	0.125<x≤0.25	0.25<x≤0.5
x≤0.03	0.03<x≤0.063	0.063<x≤0.125	0.125<x≤0.25	0.25<x≤0.5

Table 4-5. Pollution Level

Description		Clean I	A	B	C	D
210kN Suspension (Normal)	Target Withstand Voltage [kV/EA]	11.3	9.7	8.4	7.2	6.4
	Required Number of Insulators [N]	10	11	12	14	16
210kN Suspension (Fog)	Target Withstand Voltage [kV/EA]	41.7	12.6	10.9	9.4	8.3
	Required Number of Insulators [N]	-	-	10	11	12
210kN Tension (Normal)	Target Withstand Voltage [kV/EA]	11.3	9.7	8.4	7.2	6.4
	Required Number of Insulators[N]	10	11	12	14	16

Table 4-6. Target Withstand Voltages

(b) Air Clearance Design

In order to determine the air clearance required (length of insulator string), overvoltage analysis is performed using Electro- Magnetic Transient Program (EMTP) to determine the maximum switching and temporary overvoltages that can occur on the transmission system. The result of the EMTP becomes the basis for determining the required air clearance to withstand the overvoltages. The air clearances corresponding to the estimated impulse overvoltages are provided by the relevant standards – IEEE and IEC.

Note that where the withstand voltage determined from the EMTP is high and the air clearance required very large, the voltage stress can be reduced by the application of surge protective devices, arcing gaps, switching device insertion resistors and controlled closing, shield wire, improved grounding.

(c) Air Clearance Diagram

Overhead conductor supported by suspension insulator can take up different positions relative to the tower depending on the velocity of winds blowing against it. The zero swing angle is the stationary position of the conductor and this corresponds to the maximum insulation strength of the gap between the conductor and the tower. This is shown as the length (A) in Figure 4-15 below.

The maximum swing angle of the insulator string is the position where the insulation strength of the gap between the conductor and the tower reduces to its minimum. This is shown as the distance (D).

The minimum electrical clearance to be kept across air gaps between the conductor and tower depends upon the magnitude of the expected overvoltages. This rarely occurs during the operational life of the transmission line. The specific swing angles and corresponding clearances are unique to each transmission line tower. The swing angle and live metal clearances are therefore to be optimized/decided based on prudent utility practices, applicable standards and codes and keeping in view electrical system parameter and service requirements, physical location, climatic conditions, etc.

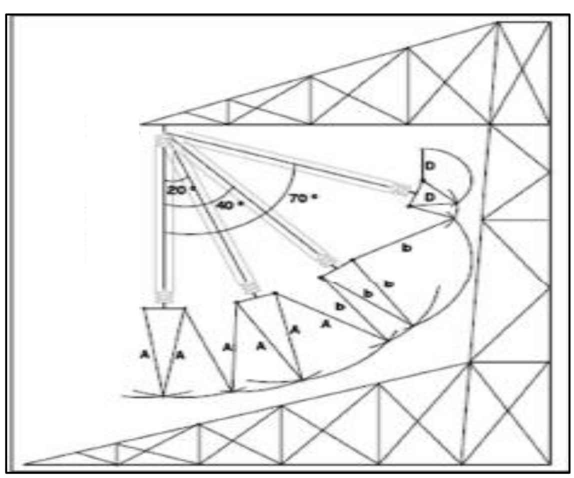


Figure 4-15. Example of Air Clearance Diagram

(d) Surge Protection Devices

As explained in the preceding sections, some overvoltages are expected to occur in the transmission system due to either lightning or switching operations. Therefore some measures have to be put in place to control the size of these overvoltages. Switching overvoltages can be controlled by having circuit breakers that incorporate closing and tripping resistors and other methods. The magnitude of lightning impulse on the hand depends on the lightning discharge current which cannot be controlled.

The effect of lightning on the transmission lines are minimized by proper shielding of the system from direct lightning strikes and ensuring low tower footing resistance to reduce the incidence of back-flashover. Figure 4-16 shows lightning protection scheme using the Shieldwire or Ground wire. In practice, shielding angles of 30^o have been used successfully for towers with height up to 24m. Higher towers experienced a poor lightning performance and this has led to the modification of the tower to have two shieldwires instead of one.

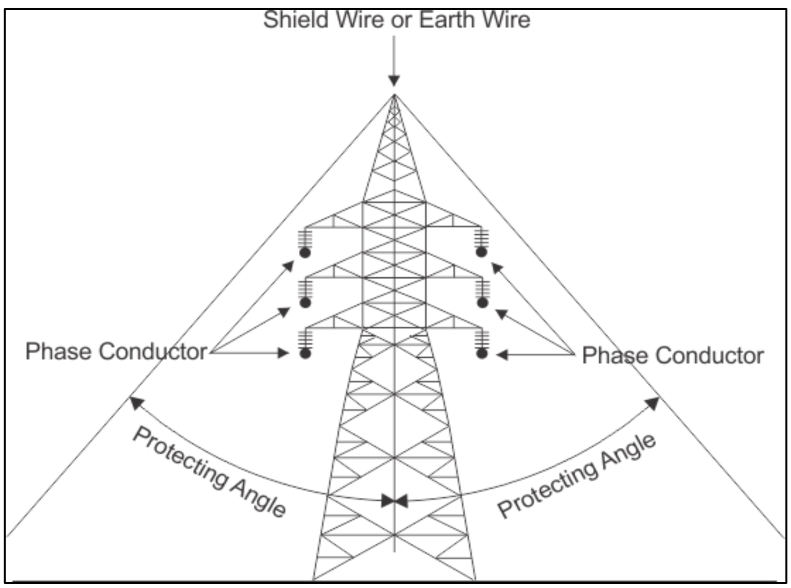


Figure 4-16. Shieldwire Protection of Transmission Lines

After the provision of shieldwire and ensuring low tower footing resistance, the transmission line is further protected against surges using different types of devices.

- **Protective Gaps**

These take the form of rod or horn gaps across the insulators, one connected to the conductor and the other connected to earth. They limit the surge potential to values lower than insulation flashover while providing a path to ground to divert the overvoltage. The gap therefore enables the adjustment of the protection level provided by the device. Arcing horns function by bypassing the high voltage across the insulator using air as a conductive medium. The small gap between the horns ensures that the air between them breaks down resulting in a flashover and conducts the voltage surge rather than cause damage to the insulator. The horns are constructed in pair so that one horn is on the line side and the other is on the ground side. The main disadvantage of this device is that it results in an earth fault in the system during its operation that has to be cleared by the protection relays. Figure 4-17 below shows a typical arcing horn arrangement.

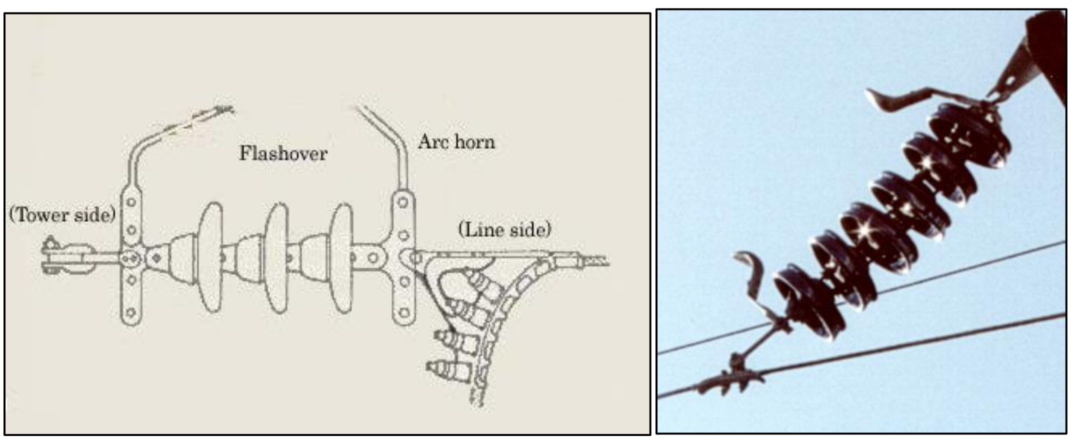


Figure 4-17. Air Gap or Arcing Horn

- **Surge Arresters**

Surge arresters (or lightning arresters or surge diverters) are installed on transmission lines between phase and earth in order to improve the lightning performance and reduce the failure rate. Surge arresters are semiconductors with nonlinear resistance from a few ohms to several ohms.

Several different types of arresters are available (e.g. gapped silicon carbide, gapped or non-gapped metal-oxide) and all perform in a similar manner. They function as high impedances at normal operating voltages and become low impedances during surge conditions.

Even though a great number of arresters which are gapped arresters with resistors made of silicon-carbide (SiC) are still in use, the arresters installed today are almost of metal-oxide (MO) type without gaps, which means arresters with resistors made of metal-oxide.

An ideal lightning arrester should:

- conduct electric current at a certain voltage above the rated voltage
- hold the voltage with little change for the duration of overvoltage
- substantially cease conduction at very nearly the same voltage at which conduction started

The main characteristics of a surge arrester are:

- Maximum Continuous Operating Voltage(MCOV) which must be greater than the maximum network operating voltage with a safety margin of 5 percentage of the rated voltage, which must be1.25 x MCOV
- Protection level
- Capacity to withstand the energy of transient over voltages.

The advantage of the arresters is that they do not cause system outage when they operate. Line surge arresters have been introduced in recent times to improve the performance of transmission lines with respect to lightning. Figure 4-18 below shows a typical line arrester.

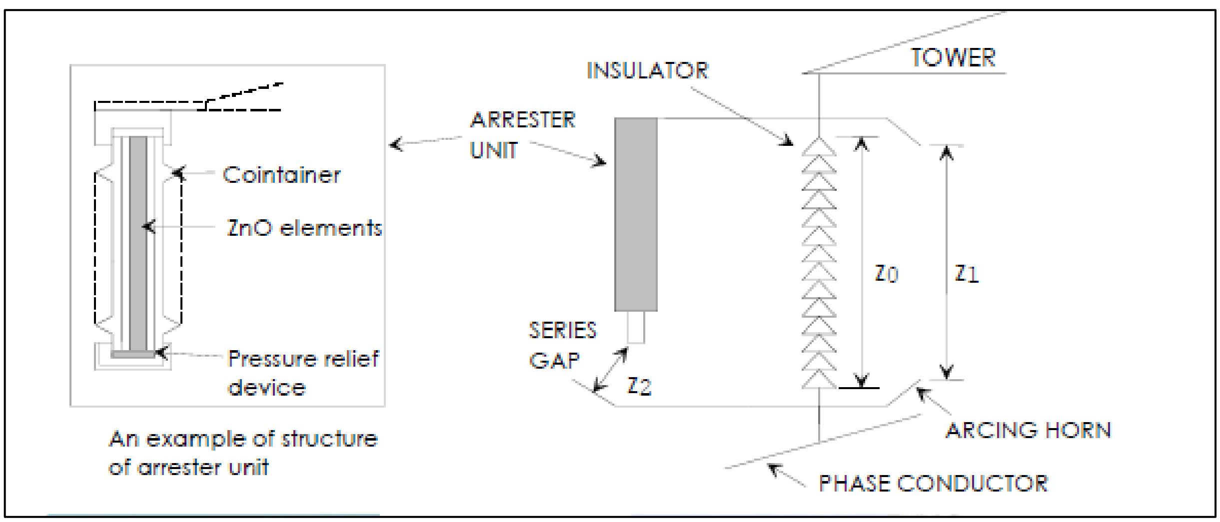


Figure 4-18-1. Transmission Line Arrester

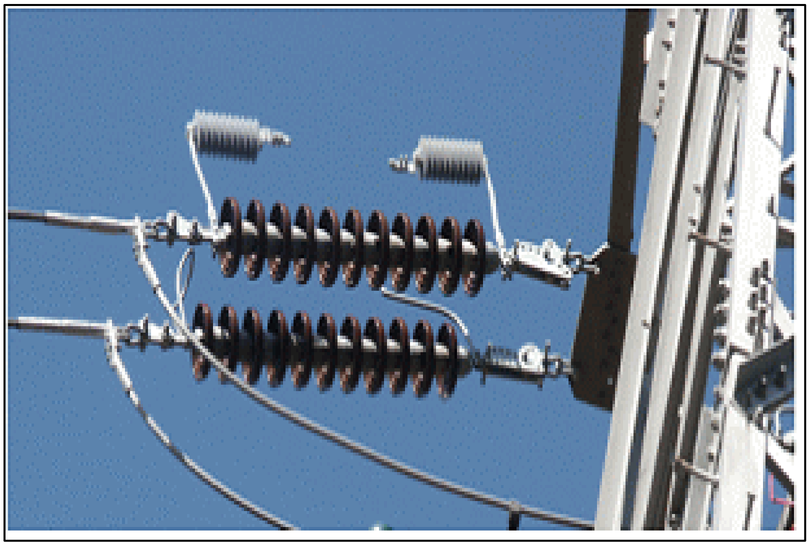


Figure 4-18-2. Transmission Line Arrester

M05 – TOWER FOUNDATION AND GROUNDING

5.1 Objectives

The participant at the end of this module should be able to;

- Explain what the foundation of a structure is.
- State and explain the classifications of foundations.
- State and explain the characteristics of each type of tower foundations.

5.2 Introduction

Foundation of any structure plays an important role in reliability, security & safety and satisfactory performance of the structure as it transmits the loads from structure to earth. Without having a sound and safe foundation, a structure cannot perform the functions for which it has been designed. Therefore, the importance of foundation need not be over-emphasized.

The sizes of transmission line towers and transmission line network are increasing because of the present day extra-high and ultra-high voltage transmission, resulting in heavier loads and number of towers and as such requiring more number & bigger and heavier foundations. A large number of foundations are normally required in any transmission line project. Thus, the total cost of foundations in a transmission line project becomes quite substantial. Apart from the financial aspects, past records show that failure of tower foundations has also been responsible for collapse of towers. These failures have usually been associated with certain deficiencies either in the design or classification or construction of foundations. Many times, foundations cast are over-safe because of inappropriate classification, resulting in wastage of resources.

5.2.1 Definition

- The foundation of a structure is that element of the structure that connects it to the ground and transfers loads from the structure to the ground.
- The tower foundation is the name given to the system which transfers to the ground the various dead and live loads developed by the transmission tower and conductors.

5.3 Basic Considerations for Design

To meet the varying needs in respect of soil conditions and loading quantum, several types of tower foundations have been used for the transmission line towers. Design philosophy of tower foundation should be closely related to the principles adopted for the design of the tower which the foundation has to support. A weak or unsound foundation can make a good tower design useless while a very strong foundation for a weak tower means a wasteful expenditure. Functionally, the foundation should be strong and stable. It should take care of all the loads such as dead loads, live loads, wind loads, seismic loads, and erection loads etc. causing vertical thrust, uplift as well as horizontal reactions. For satisfactory performance, it should be stable and structurally adequate and be able to transmit these forces to the soil such that the limit soil bearing capacities are not exceeded.

5.3.1 Types of Loads on Foundations

The foundations of towers are normally subjected to three types of forces. These are:

(a) The compression or downward thrust;

(b) The tension or uplift; and

(c) The lateral forces or side thrusts in both transverse and longitudinal directions.

- The compression or downward thrust is due to the weight of line material, self-weight of tower, tension of conductor & wind action on line material & the towers & broken wire condition.
- The tension or uplift is due to the action of wind on line material & on the broken wire condition.
- Lateral forces or side thrust in the longitudinal directions due to the wind action and the broken wire condition.

5.3.2 Resistances for Designing Foundations

As discussed above, the foundations of transmission line towers are subjected to three types of loads viz. the downward thrust (compression), the uplift (tension) and the side thrust (horizontal shear).

The soil resistances available for transferring the above forces to earth are described below:

(a) Uplift Resistance

The soil surrounding a tower foundation has to resist a considerable amount of upward force (tension). In the case of self-supporting towers, the available uplift resistance of the soil becomes the most decisive factor for selection of the type of footing for a particular location. It is generally considered that the resistance to uplift is provided by the shear strength of the surrounding soil and the weight of the foundation.

The uplift resistance is estimated by computing the weight of the earth contained in an inverted frustum of cone whose sides make an angle with the vertical equal to the angle of earth frustum.

It should, however, be noted that effective uplift resistance, apart from being a function of the properties of soil like angle of internal friction (Ø) and cohesion (C) is greatly affected by the degree of compaction and the ground water table. When the back fill is less consolidated with non-cohesive material, the effective uplift resistance will be greatly reduced. In case of foundation under water table, the buoyant weights of concrete and back fill are only considered to be effective.

The uplift resistance of footing with undercut projections within undisturbed soils in firm none cohesive soils and fissured/soft rock shall generally be larger than that of conventional footings.

The Figure below shows the soil resisting uplift pressures.

Total weight of soil resisting uplift = $W_1 + W_2 + W_3$

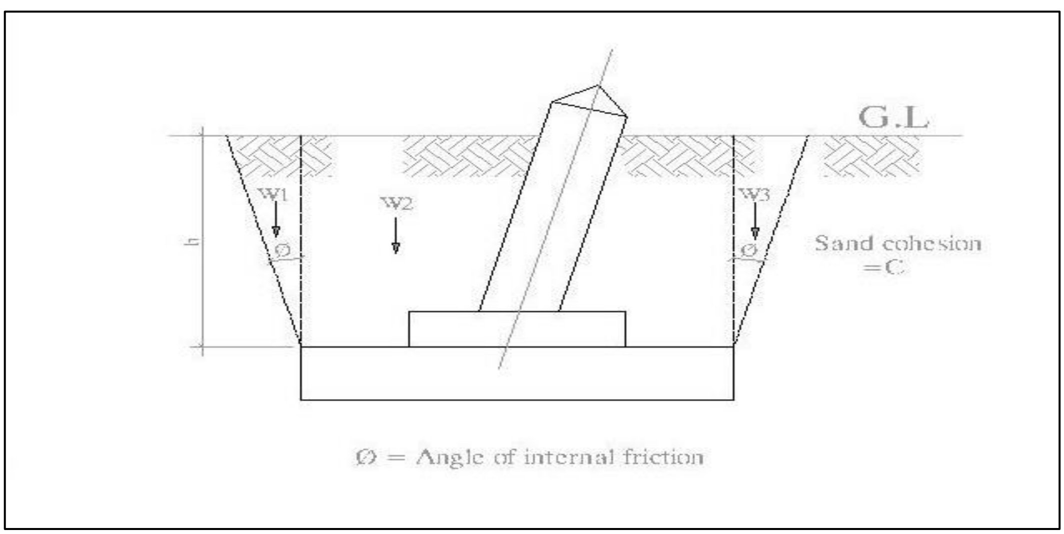


Figure 5-1: Total weight of soil resisting uplift

(b) Lateral Soil Resistance

While designing towers, the side thrusts (horizontal shears) on the foundation are considered to be resisted by the passive earth pressure mobilized in the adjoining soils due to rotation of the footing. Passive pressure/resistance of soil is calculated based on Rankine's formula for frictional soils and unconfined compressive strength for cohesive soils. Unbalanced horizontal shear is transferred from the foundation to earth through bearing capacity.

(c) Bearing Capacity

The downward compressive loads acting on the foundation including moments due to horizontal shears and/or eccentricities, wherever existing, are transferred from the foundation to earth through bearing. The limit bearing capacity of soil is the maximum downward intensity of load which the soil can resist without shear failure or excessive settlement.

5.3.3 Soil and Rock Condition

5.3.3.1 Types of Soil

(a) Non-cohesive Soils

These are soils in which the particles lie side by side without sticking/bonding together. This group of soils includes gravel and sands which are composed mainly of larger sized grains resulting from weathering of rocks. In non-cohesive soils, increasing the loads on the soil results in squeezing out its water content and this can lead to the settlement of a structure. The following types of soils come under this category:

- Sandy Soils which have no clay/silt or have very little clay/silt.
- Soft and hard laterite. These can be excavated using normal tools and these get disintegrated into pieces.

(b) Cohesive Soils

These comprise clays, silts and soft shales, etc. having comparatively fine grain size particles. The strength of this group of soils is derived primarily from cohesion between their particles.

The most important characteristic of cohesive soils from engineering point of view is their susceptibility for slow volume changes due to their low permeability. When this type of soils is subjected to loads, the contained water in the voids is expelled very slowly with consequent diminution of volume resulting in consolidationn settlement. Unlike settlement in non-cohesive soils which is immediate, the settlement in cohesive soils may take many years to reach its final value.

The following soils come under this category.

- Normal soil having mixture of silt and clay (clay not exceeding 15%). When this type of soil is made wet and rolled between the palms, only short threads can be made.
- Clayey soils having high percentage of clay (more than 15%) e.g. Black Cotton Soil (yellow in colour). When this type of soil is made wet and rolled between the palms, long threads can be made.
- Marshy soil having mud (marine soil) which is very sticky in nature.

5.3.3.2 Types of Rock

Rocks derive their strength from permanent bond of cohesive forces among their particles. They are usually classified as hard, and soft. Rocks have high bearing capacity except when decomposed, heavily shattered or stratified. Tower foundations are usually built on the upper area of the rock formations which are often found to be weathered and disintegrated. The rocks are broadly classified as follows:

(a) Soft Rock/Fissured Rock

The rocks which can be excavated using normal tools without blasting are classified as soft rock. These include decomposed or fissured rock, hard gravel, lime stone, laterite or any other soil of similar nature.

(b) Hard Rock

The rocks which cannot be excavated using normal tools and require chiseling, drilling and blasting are classified as Hard Rock. These include hard sand stone, quartzite, granite, basalt, hard marble, etc.

5.3.3.3 Soil Parameters

For designing the foundations, the following soil parameters are required:

(a) Limit bearing capacity of Soil;

(b) Unit Weight (Density) of soil; and

(c) Angle of Earth frustum (angle of internal friction).

These soil properties are normally obtained either by conducting in-situ or laboratory tests on soil samples collected from the field during Soil Investigation or from available testing record of the area. The importance of above soil parameters in foundation design is discussed below in brief.

(a) Limit Bearing Capacity

The bearing capacity of soil is the maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil. The limit bearing capacity is vital from the point of view of establishing the stability of foundation against shear failure of soil and excessive settlement of foundation when foundation is subjected to total downward loads and moments due to horizontal shears and/or eccentricities as applicable.

(b) Density of Soil

The unit weight (density) is the weight (mass) per unit volume of a material. This parameter is required to calculate the uplift resistance of foundations as well as to calculate differential weight of soil and concrete below ground level far checking the bearing pressure under foundation.

(c) Angle of Earth Frustum (angle of internal friction)

This parameter is required for finding out the uplift resistance of the foundation.

5.4 Types of Foundations

The following type of foundations are normally provided for transmission line towers depending on soil conditions, magnitude of loads, type of tower i.e. special or normal:

- Shallow Spread Foundations
- Deep Foundations

5.4.1 Shallow Spread Foundations

Shallow foundations are generally where the founding depth is less than 3m. Shallow foundations are used where the surface soils are sufficiently strong and stiff to support the imposed loads. They are unsuitable for generally weak or highly compressible soils, such as poorly compacted fill and peat.

5.4.1.1 Shallow Foundations (based on ground water table and type of soil and rock)

Depending upon the ground water table and type of soil and rock, shallow foundations are classified as follows:-

(a) Normal Dry Soil Foundations

When the water table is below foundation level and when soil is cohesive and homogeneous up to the full depth having clay content of 10-15%.

(b) Wet Soil Foundations

When the water table is above foundation level and up to 1.5 m below ground level. Also the foundations in the soils which have standing surface water with water penetration not exceeding 1.0 m below ground level (e.g. paddy fields) are also classified as wet foundations.

(c) Partially Submerged Foundations

When the water table is at a depth between 1.5 m and 0.75 m below ground level and when the soil is normal and cohesive.

(d) Fully Submerged Foundations

When water table is within 0.75m below ground and the soil is normal and cohesive.

(e) Black Cotton Soil Foundations

When the soil is cohesive having inorganic clay exceeding 15% and characterised by high shrinkage and swelling property (need not be always black in colour).

(f) Partial Black Cotton Foundations

When the top layer of soil up to 1.5 m is Black Cotton and thereafter it is normal dry cohesive soil.

(g) Soft Rock/Fissured Rock Foundations

When decomposed or fissured rock, hard gravel or any other soil of similar nature is met which can be executed without blasting. Under cut foundation is to be used at these locations.

(h) Hard Rock Foundations

Where chiseling, drilling and blasting is required for excavation.

(i) Sandy Soil Foundations

Soil with negligible cohesion because of it is low clay content (0-10%).

The above categorization of foundations has been done for economizing the foundations, as uplift resistance of foundation is a critical design factor which is greatly affected by the location of water table and the soil surrounding the foundation.

5.4.1.2 Shallow Type Foundations (based on structural arrangements)

Based on structural arrangement of foundations, various types of foundations are possible. The necessity of erecting towers on a variety of soils has made it possible and necessary for the designers to adopt new innovations and techniques. As a result, several types of tower foundations have been devised and successfully used. Some of the more, common types of foundations are described below:

(a) Reinforced Concrete Spread Foundation

Typical types of reinforced concrete spread foundation are shown in Figs 5-2(a) and 5-2(b). It consists of a reinforced concrete base slab or mat and a square chimney. They can be either single step type or multiple step type and/or chamfered step type.

This type of footing can be suitably designed for variety of soil conditions. Reinforced concrete spread foundations in some situations may be higher in cost although structurally these are most suitable, stable & safe.

When cast in contact with inner surface of excavated soil it offers higher uplift resistance as compared to the footing having 150 mm side clearance as shown in Fig 5-2(b)

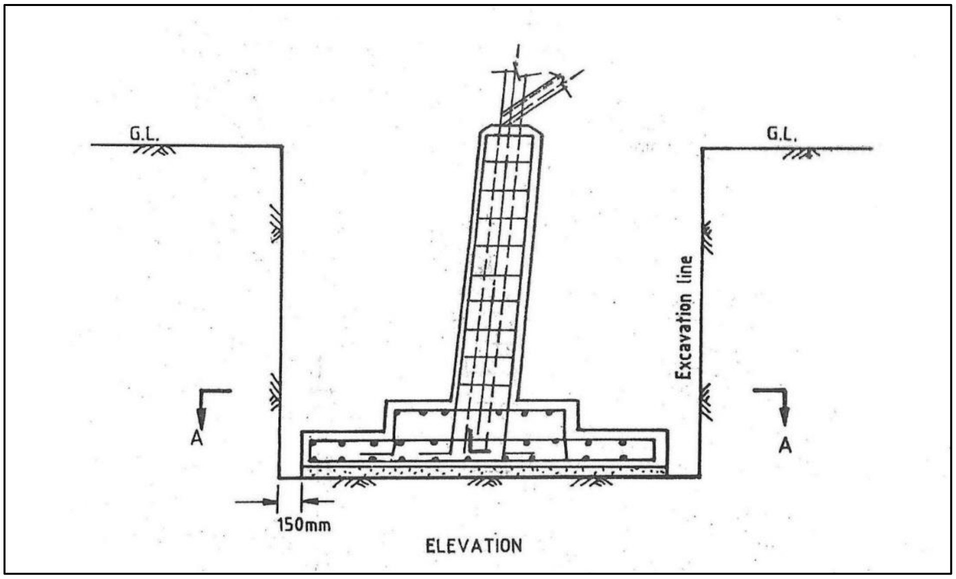


Figure5-2(a): Reinforced Concrete Spread Foundation with working clearance

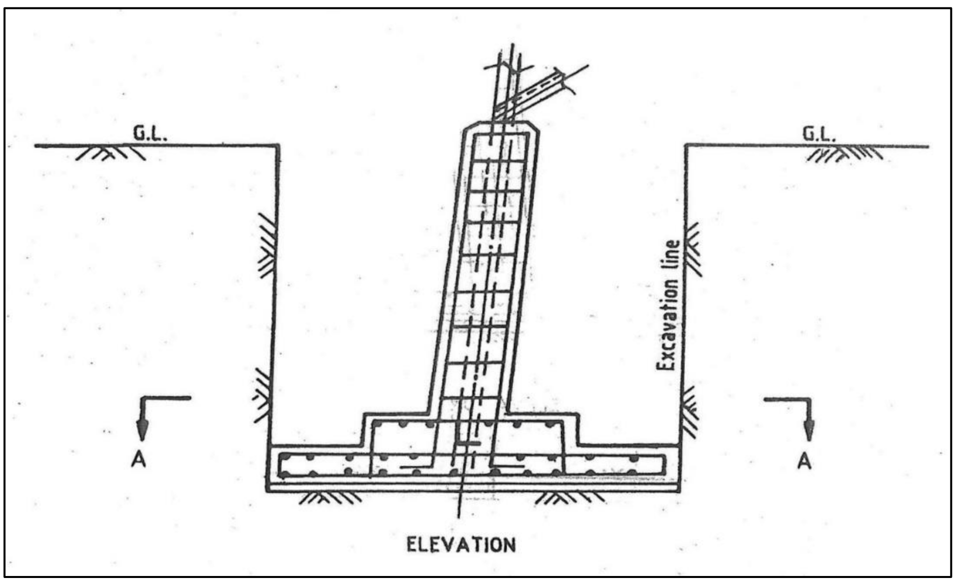


Figure 5-2(b): Reinforced Concrete Foundation without working clearance

(b) Block Foundation

This type of foundation is usually provided where soft rock and hard rock strata are encountered at the tower location. This type of foundation is shown in Fig. 5-3(a) and 5-3(b). It consists of a chimney and block of concrete. In this type of foundation, concrete is poured in direct contact with the inner surfaces of the excavated rock so that concrete develops bond with rock. The uplift resistance in this type of footing is provided by the bond between concrete and rock. The thickness and size of the block is decided based on uplift resistance of foundation for resisting uplift loads and bearing area required for down thrust.

Block type foundations are being provided by some power utilities for soft and hard rock strata. However, under cut type of foundations for soft rock and anchor type of foundations for hard rock are sometimes preferred by some power utilities because of their soundness even though these may be more costly in comparison with block type foundations.

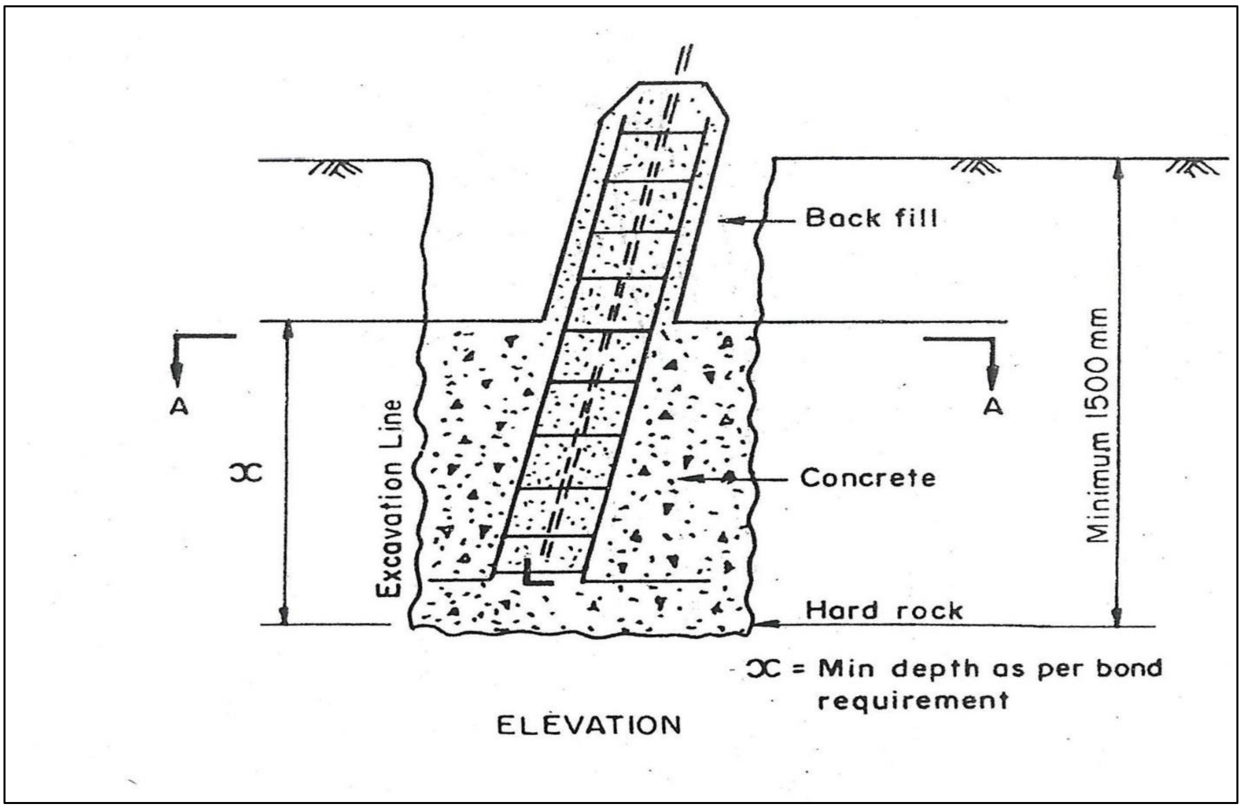


Figure 5-3(a): Block Type Foundation (Hard Rock Type)

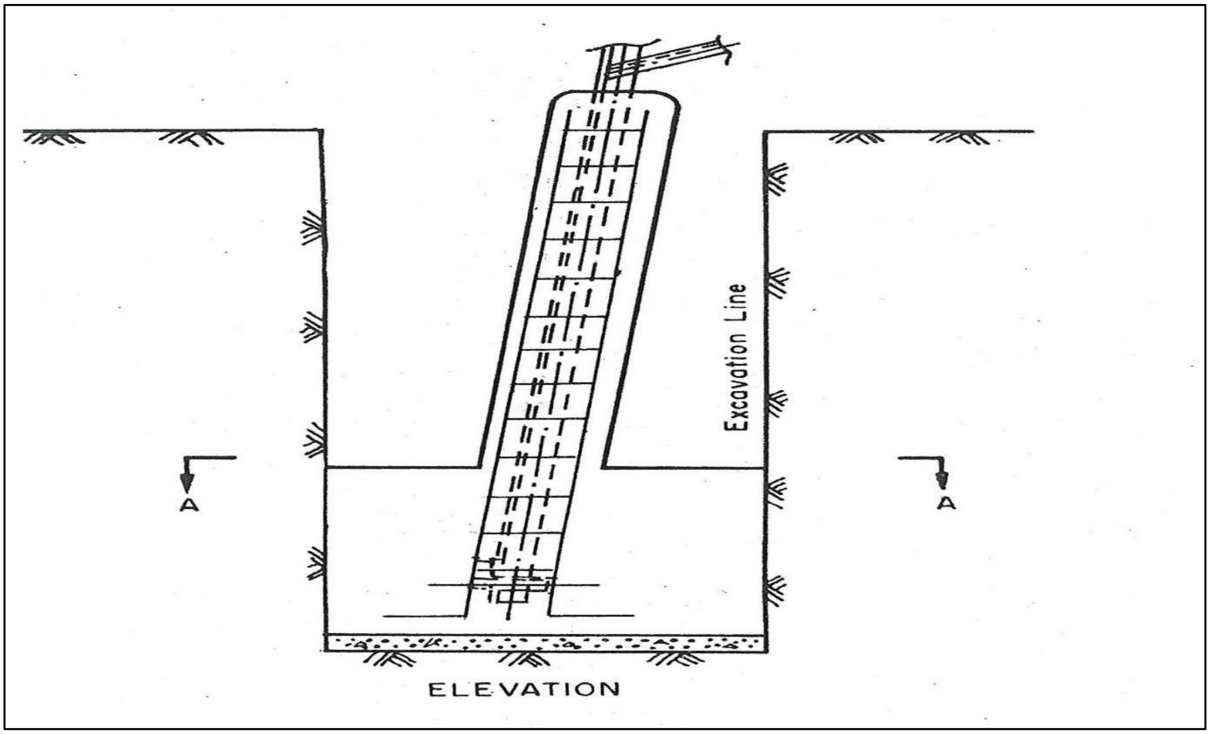


Figure 5-3(b): Block Type Foundation (Friction Type)

(c) Under-Cut Foundation

These types of foundations are shown in Figs 5-4(a) & (b). These are constructed by making undercut in soil/rock at foundation level. This type of foundation is very useful in normal dry cohesive soil, fissured/soft rock, soils mixed with clinker, where soil is not collapsible type i.e., it can stand by itself. A footing with an under-cut generally develops higher uplift resistance as compared to that of an identical footing without under-cut. This is due to the anchorage in undisturbed virgin soil. The size of under-cut shall not be less than 150 mm. At the discretion of power Utility and based on the cohesiveness of the normal dry soil, the owner may permit undercut type of foundation for normal dry cohesive soil.

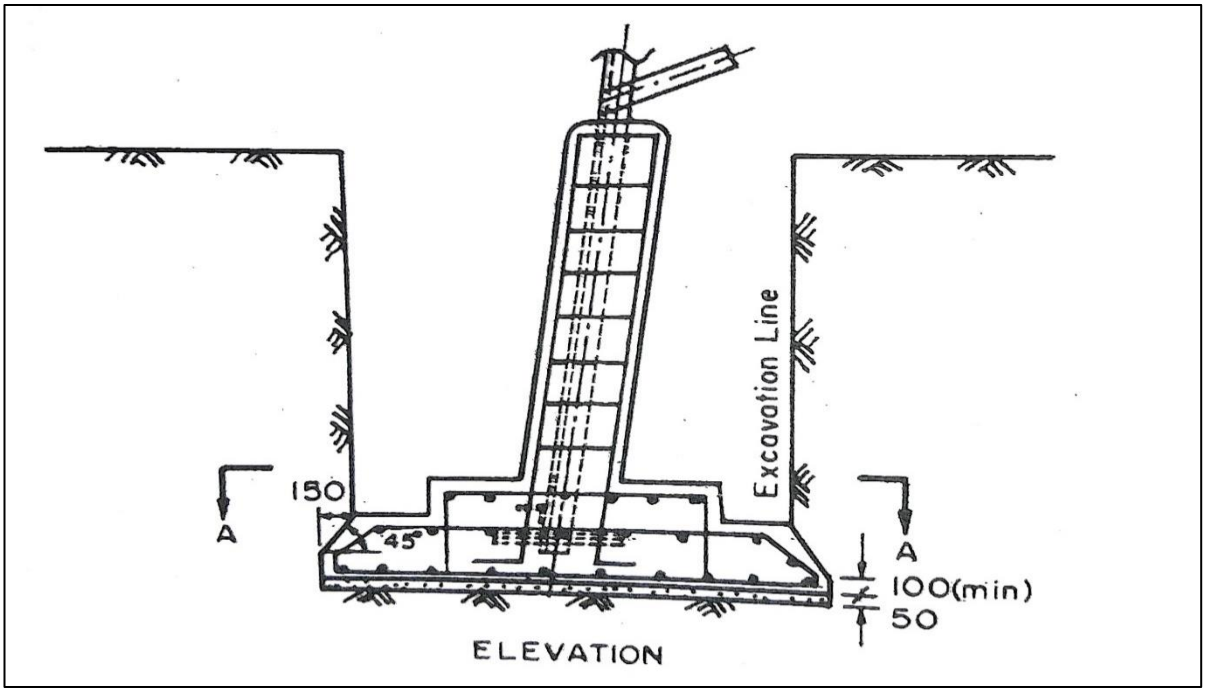


Figure5-4(a): Reinforced Concrete Spread Foundation (Under-cut Type)

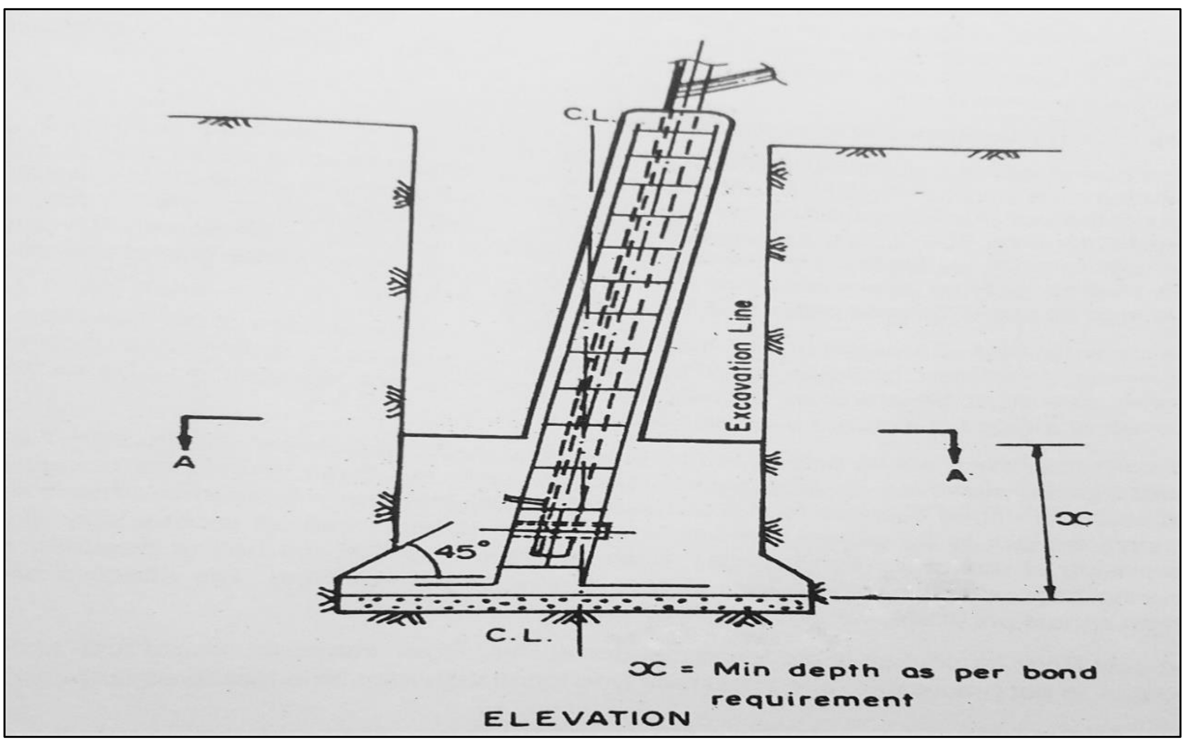


Figure 5-4(b): Block Foundation (Under-cut Type)

(d) Grouted Rock and Rock Anchor Foundation (Hard Rock Foundation)

This type of footing is suitable when the rock is very hard. Typical Grouted Rock and Rock Anchor type footing is shown in Fig 5-5. It consists of two parts viz. block of small depth followed by anchor bars embedded in the Grouted Anchor Holes. The top part of the bar is embedded in the concrete of the shallow block. The depth of embedment, diameter and number of anchor bars will depend upon the uplift force on the footing.

The determination of whether a rock formation is suitable for installation of rock anchors is an engineering judgement based on rock quality. Since, the bearing capacity, of rock is usually much greater, care must be exercised in designing for uplift. The rock surfaces may be roughened, grooved, or shaped to increase the uplift capacity. The uplift resistance will be determined by considering the bond between reinforcement bar and grout/concrete. Anchor strength can be substantially increased by provision of mechanical anchorages. Such as use of eye-bolt, fox bolt or threaded rods as anchoring bars or use of keying rods in case of stub angle anchoring.

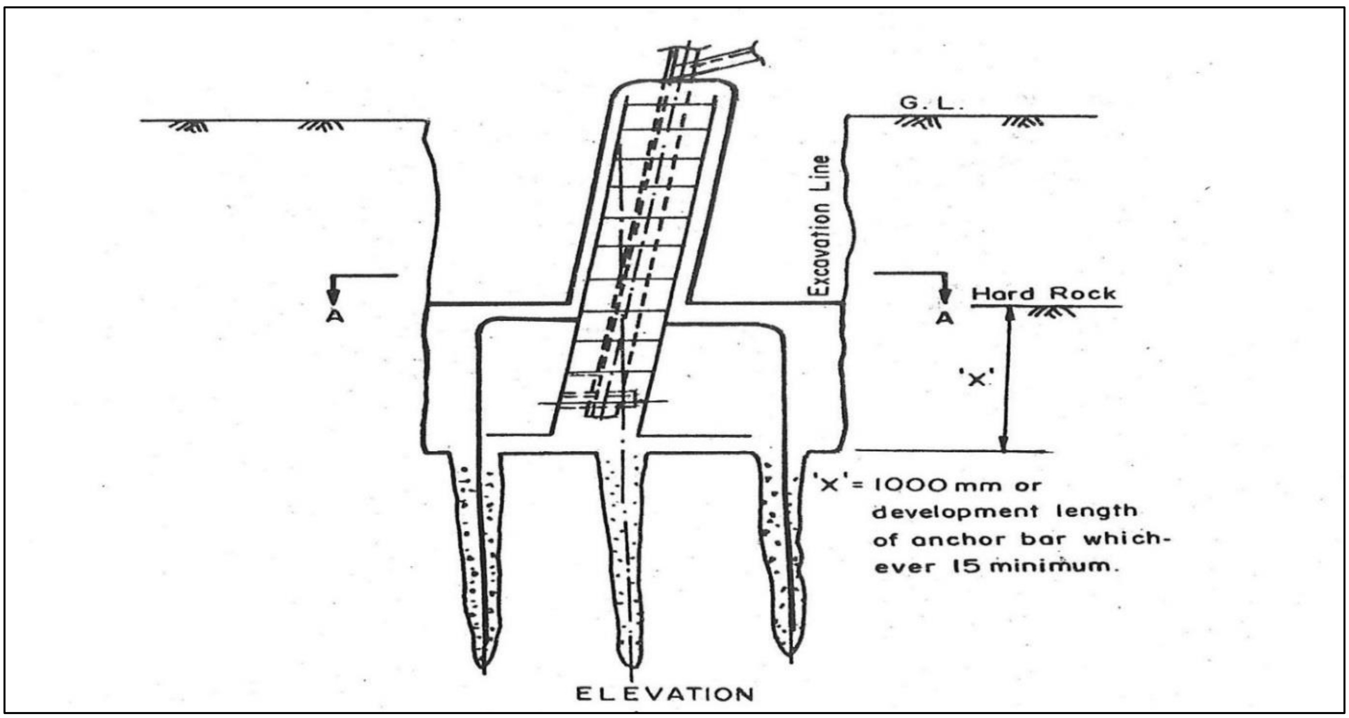


Figure 5-5: Grouted Rock/Anchor Type Foundation (Hard Rock Foundation)

(e) Raft Foundation

These types of foundation are shown in Fig. 5-6 and involves supporting all the four legs of tower on a single concrete footing instead of having individual footing under each leg of tower. The raft type of foundation can be adopted for soil having poor bearing capacity, for towers where individual footing overlap with each other and for tower with narrow base where footing for each leg may not be possible on account of small leg to leg distance of tower.

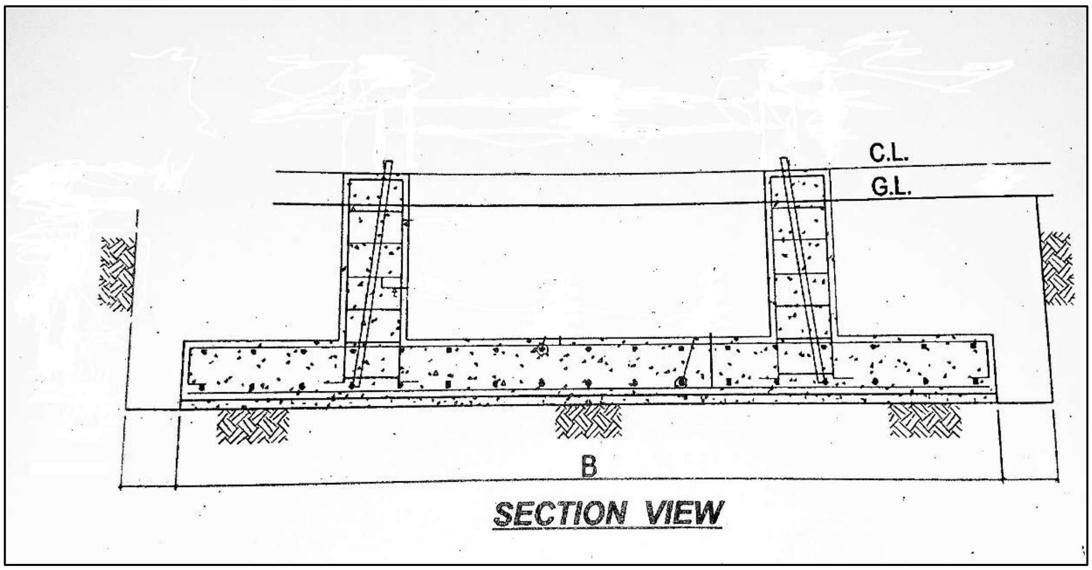


Figure 5-6: Raft Foundation

(f) Steel Grillage Foundation

These types of foundation are shown in Fig. 5-7. These are made of structural steel sections. Steel grillages can be of various designs. Generally, it consists of a layer of steel beams as pad for the bearing area. In this type of foundations, there is no solid slab as compared to concrete foundations. As a precaution against corrosion, a coat of bituminous paint is usually applied to the footing.

Grillage footings require much more steel than a comparable concrete footing, but erection cost is small in comparison to that of the concrete footing resulting in often economical and always quicker construction. Other advantages include their simplicity in construction, procurement of complete foundation with tower parts from the manufacturer of towers and elimination of concrete work at site. These foundations are also very helpful in restoring the collapsed transmission lines because of quicker construction.

The disadvantage of this type of foundation is that these foundations have to be designed before any soil borings are made and may have to be enlarged and require a concrete base if actual soil conditions are not as good as those assumed in the original design.

These types of foundation are generally provided in case of firm soils and are, usually, adopted for locations where concreting is not possible and head loading is difficult.

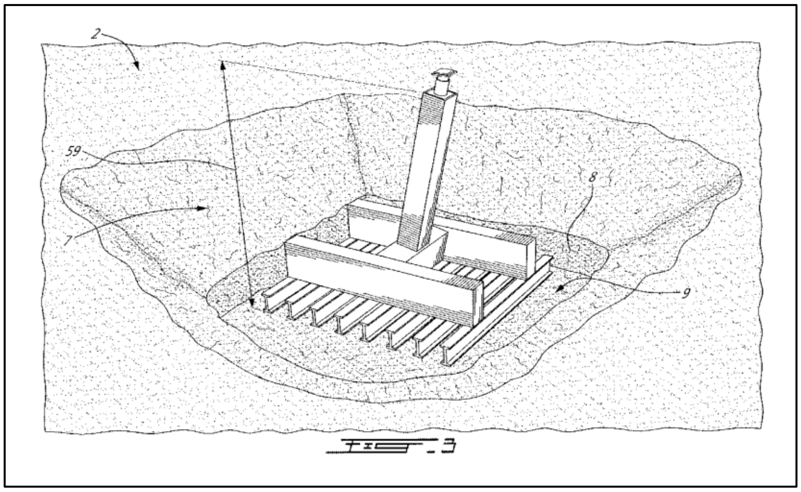


Figure 5-7: Steel Grillage Type Foundation

5.4.2 Deep Foundations

Deep foundations are those with depths greater than 3m below finished ground level. The depth of foundations is very large compared to its width (generally with a foundation depth to width ratio exceeding 5).

Deep foundations are used to transfer the loading to a deeper, more competent strata at depth if unsuitable soils are present near the surface.

Two types of deep foundations are considered here.

(a) Auger Type Foundations

Typical types of foundation are shown in Fig 5-8. The cast-in-situ reinforced concrete augured
footings have been extensively used in some western countries like USA, Canada. Usually a truck mounted power augur is utilised to drill a circular hole of required diameter, the lower portion of this may be belled, if required, to a larger diameter to increase the uplift resistance of the footing. Holes can be driven up to one metre in diameter and six metre deep. Since the excavated hole has to stand for some time before reinforcing bars and cage can be placed in position and concrete poured, all kinds of soils are not suitable for augured footing. Usually, stiff clays and dense sands are capable of being drilled and standing up sufficiently long for concreting works and installation of stub angle or anchor bolts, whereas loose granular materials may give trouble during construction of these footings. Bentonite slurry or similar material is used to stabilise drilled holes in loose granular material. In soft soils, a steel casing can also be lowered into the hole as the excavation proceeds, to hold the hole open.
Uplift resistance of augured footing without be is provided by the friction along the surface of the shaft alone and hence its capacity to resist uplift is limited. The primary benefits derived from this type of foundations are the saving in time and man-power.

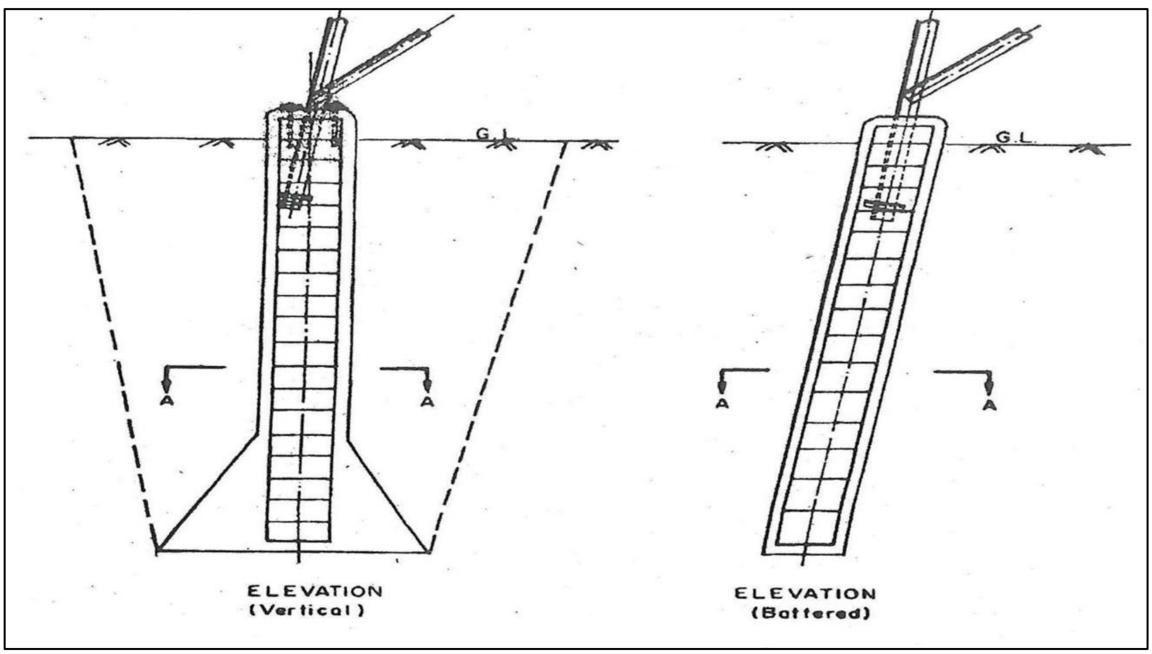


Figure 5-8: Auger Type Foundation

(b) Pile Foundations

A typical pile type foundation is shown in Fig 5-9. This type of foundation is usually adopted when soil is very weak and has very poor bearing capacity or foundation has to be located in filled-up soil or sea mud to a large depth or where tower location falls within river bed and creek bed which are likely to get scoured during floods.

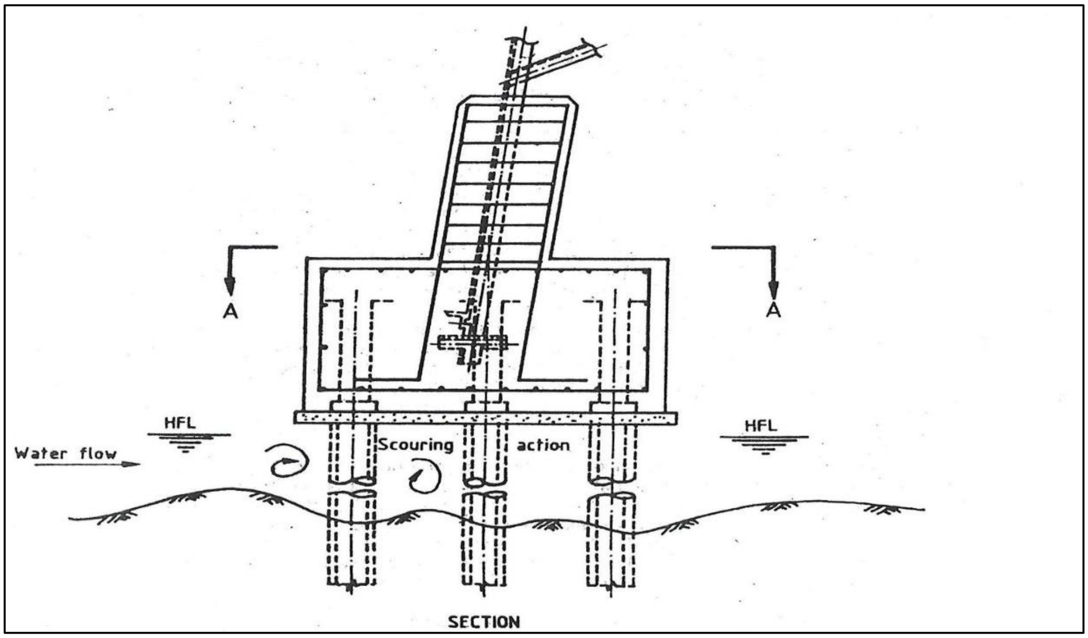


Figure 5-9: Pile Foundation

Pile foundation usually costs more and may be adopted only after detailed examination of the site conditions and soil data. The downward vertical load on the foundation is carried by the piles through skin friction or by point bearing or both; while the uplift is resisted by the dead weight of the concrete in piles and pile caps and frictional resistance between pile and soil surrounding the pile. However in case of filled up soil, especially in clayey soil, the settlement of soil is slow. Because of the slow settlement, there may be negative skin friction which may be considered while designing the pile foundation.

Two types of piles are normally used viz. driven pile or bored piles. The driven piles in turn are of two types namely pre-cast driven piles and cast in-situ driven pile.

Pile foundations require heavy machinery for their construction and as such are used only when other types of foundations are not techno-economically feasible or for special towers like river crossing etc. Mostly, cast-in-situ concrete bored piles are provided in transmission line projects since they do not require heavy machinery for their construction.

5.5 Tower Grounding Systems

The transmission line systems are exposed to the adverse effect of the environment such as lightning storms. During lightning strike, the system is subjected to large amount of discharge current with a fast rising time front. This can produce high voltages that can cause the insulation of the components of the transmission line system to fail resulting in disruption to power supply. The overvoltages also can produce earth potential rise in the surrounding soil near the towers which can endanger people who happened to be in that vicinity at that moment. There is therefore the need for transmission lines to be protected against lightning due to the following reasons:

- Limit voltage gradient in order to protect personnel and power system equipment from danger and damage.
- Limit electromagnetic interference to other infrastructures such telecommunication and television networks
- Flashovers resulting from direct or indirection lightning strikes to power lines

Transmission lines are protected against direct lightning strikes by overhead ground wires or shield wires. These are simply elevated ground wires, paralleling the line conductor and supported at higher level. The spacing is designed so that the shield wire takes the lightning stroke instead of the conductor. The wires are connected to earth at each supporting tower.

5.5.1 Tower Footing Resistance

A fundamental factor that determines the effectiveness of protection provided against lightning phenomenon is the connection of the tower to earth (grounding). The tower footing itself, being in contact with soil, provides some amount of grounding, but this alone is generally not sufficient to conduct the lightning current to earth. Grounding rods are driven to appropriate depths around the base of the tower to provide an effective grounding system. Figure 5-10 below shows a typical tower foundation and grounding.

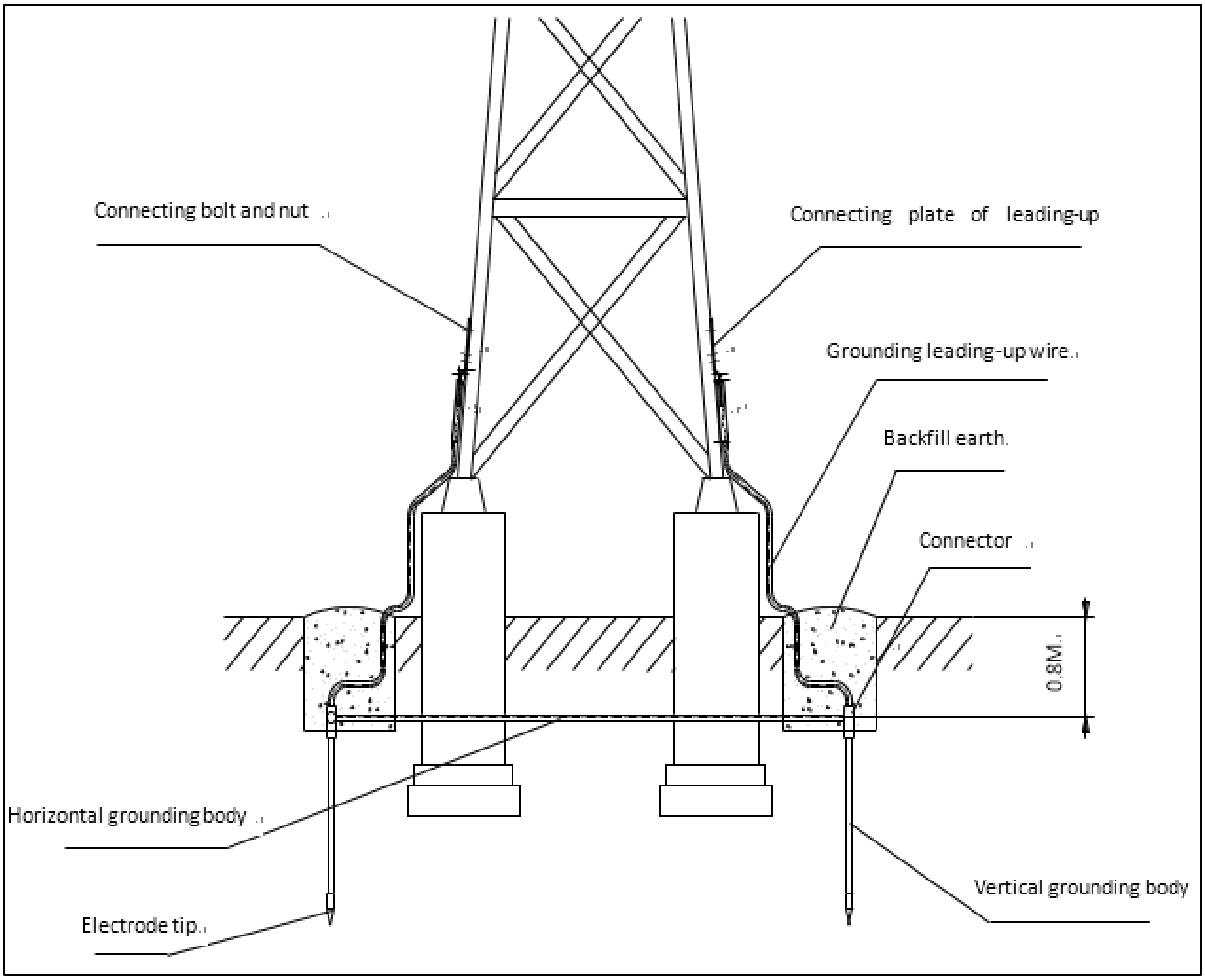


Figure 5-10: Typical tower foundation and grounding

The ground resistance is dependent on the soil resistivity. Soil resistivity is expressed in Ohm-meters (Ωm). This corresponds to the theoretical resistance in ohms of a cylinder of earth with a cross-sectional area of $1m^2$ and a length of 1m. It provides an indication of how well the soil conducts electric currents. So the lower the resistivity, the lower the resistance of the earth. Resistivity varies according to the region and the type of soil because it depends on various characteristics such as moisture, salt content, temperature and the type of soil. The soil resistivity also varies with the depth from ground level.

The higher the soil resistivity, the higher the ground resistance. Typically, the tower footing resistance for the 161kV network being operated by GRIDCo is 20Ω or below. This resistance is composed of the following three parts:

(a) Resistance of grounding conductor including bonding conductor and connector;

(b) Contact resistance between the surface of grounding conductor and the contacting soil;

(c) Dispersed resistance of soil around grounding conductor.

5.5.2 Counterpoise Grounding

In more demanding environments, where sufficient use of driven grounding rods are hampered, counterpoise are used instead to improve the grounding system. Counterpoise grounding is a system of bare conductors buried at shallow depths and extending from the tower in two or more directions. The counterpoise, in addition to providing conductivity to earth, also acts to rapidly transfer the surge from the top of the tower harmlessly to earth. The time required to transfer the surge current to earth is related to the length of the counterpoise. The level of protection is improved if the total length of the wire is spread in several wires radiating from the tower rather than a single stretch. Greater separation improves efficiency up to four wires. Due to land ownership, the counterpoise are run along the right-of-way.

The diameter of the wire and material used are not of significance in counterpoise construction. Typically, steel wires are used for this purpose.

5.5.3 Types of Grounding Systems Used in GRIDCo

There are different types of tower footing grounding methods used in GRIDCo. These are shown in Figures 5-11 and 5-12 below.

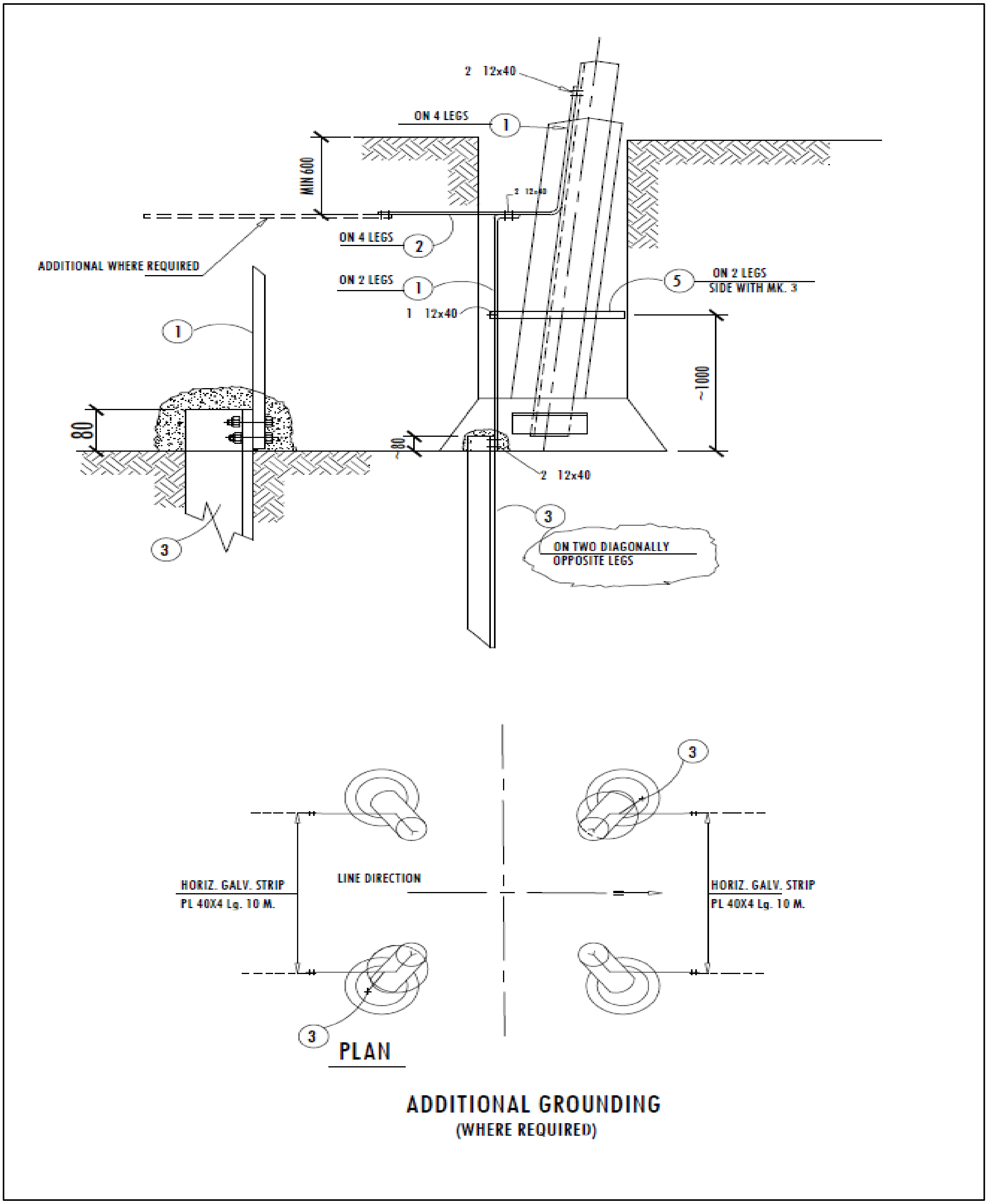


Figure 5-11: Combined Grounding & Counterpoise Grounding

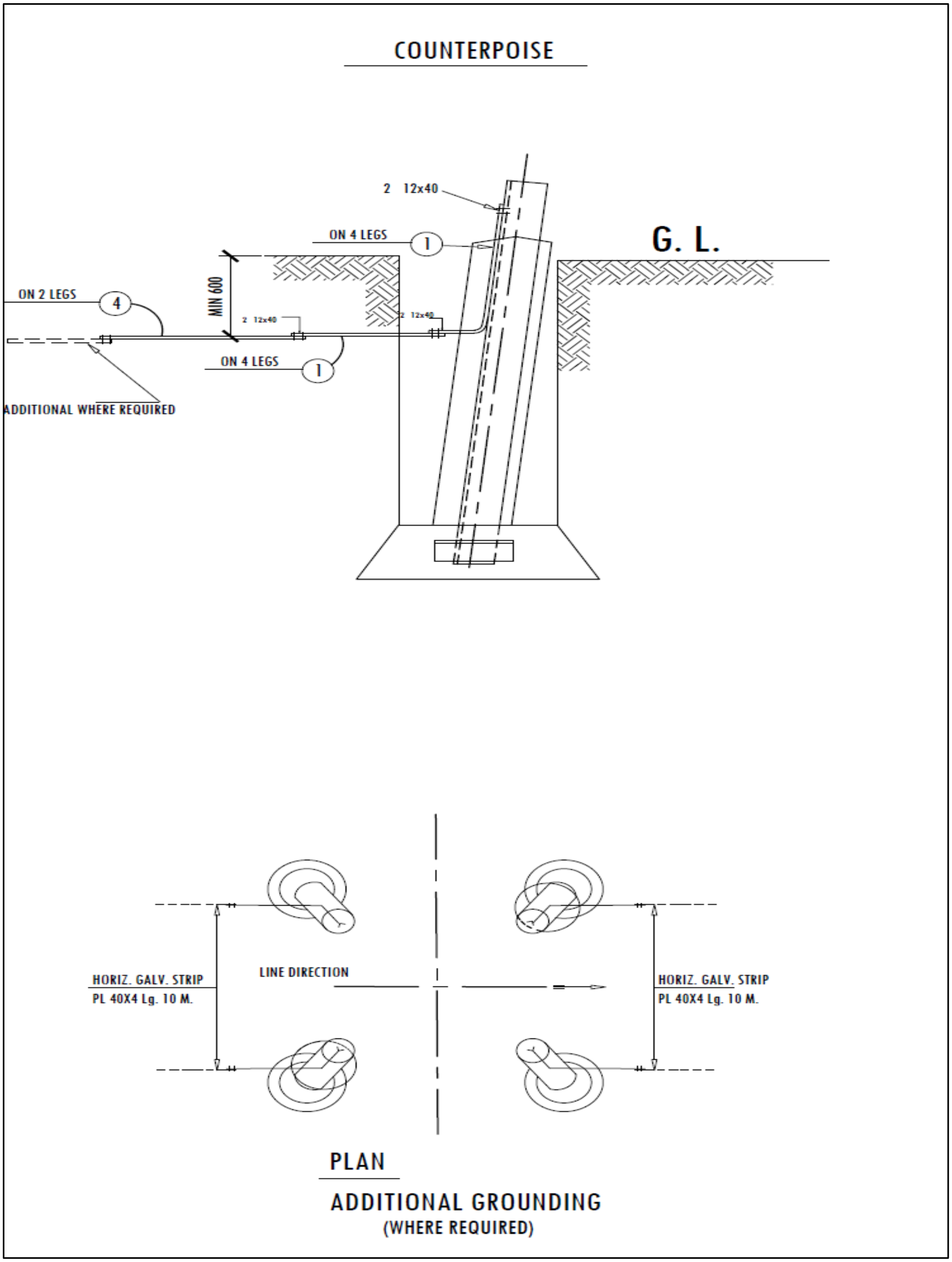


Figure 5-12: Counterpoise Grounding

From Figures 5-11 and 5-12 above, it is noted that the connection between the grounding systems to the tower is done outside the tower foundation. This is to allow for periodic inspection of the connection point in order to ensure its effectiveness. The cable between the buried grounding system and the tower may be made of copper or steel. The cable may also be insulated or non-insulated.

M06 – SHIELD WIRES AND OPGW

6.1 Objectives

At the end of this module participants should be able to:

- Describe the basic concepts of lightning and the hazards it poses to power grid.
- List various components to put in place to mitigate the effects of lightning.
- Differentiate between Shield wire and OPGW.

6.2 Introduction

The electric power transmission system is made up of components that transmit electrical energy from the generating station to consumers.

The components are:-

- Transmission Towers
- Conductors
- Insulators
- Shield Wire / OPGW

The components of the transmission grid are connected in such a way as to safely convey electric power from the generating station to the consumers. Figure 1 below shows a simplified Transmission Line System.

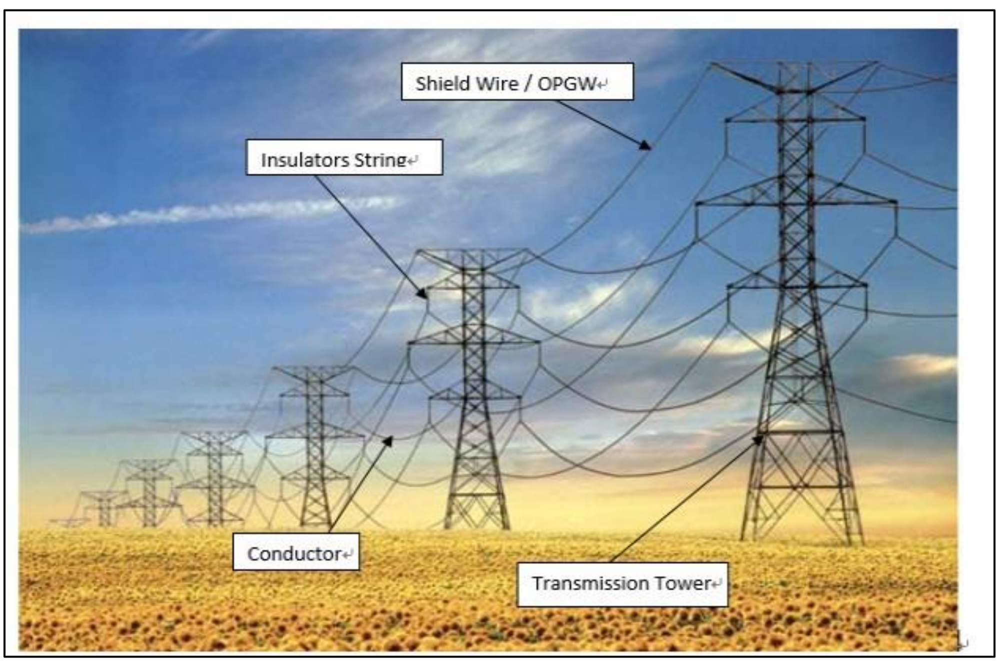


Figure 6-1. Typical Transmission Line System

Lightning strikes on transmission grids, and equipment, have since the early days of the power industry been one of the major causes of power interruptions. With the growing importance of electric power to both industrial and residential consumers, attention was increasingly concentrated on protective systems and devices to improve, and also ensure service continuity. Thunder cloud, was detected to be one of the sources of over-voltages, hence the installation of ground conductors, usually above the power conductors to divert some of the induced charges. The growing importance of service continuity led to differing philosophies of protection which were developed along with improved definition of the indices of service reliability. It is now generally agreed that both the frequency and duration of service interruptions are such indices, with their relative importance varying with the size and nature of the load. Improvement methods may be classified as those intended to prevent the occurrences of the system faults and those intended to mitigate the effect of the fault on the sound portions of the system.

Accordingly, modern philosophies of transmission lines protection may be grouped as follows:-

- Prevention of flashover of the line insulation.
- Acceptance of insulation flashover, clearing the fault as rapidly as possible, and reclosing the circuit after a short delay to permit deionization of the path.
- Provision of multiple supply paths to permit the temporary loss of any one section of the transmission network without loss of service to any load in case of multiple supply paths such as double circuit line. It is worthy of note that the reliability of such lines is not equivalent to that of two well designed single- circuit lines because of the possibility of a double circuit outage from a single lightening stroke.

6.3 Lightning

Lightning is one of the main causes of electric power system failure. The entire power system comprises power plants, substations, transmission lines, distribution feeders and power consumers that are electrically connected as a system. Generally, the Power Grid or Transmission Line Network is that part of the electric power system that transports power from the power plants (generating stations) to the main load centres (consumers). The system frequency, voltage, tie-line flows, line currents and equipment loading must be controlled and kept within limits that are deemed to be safe for the components of the transmission network and the consumer's equipment.

However, lightning, especially Cloud-to-Ground (CG) lightning can cause severe damage to power transmission lines, distribution lines, substations and power plants if appropriate measures are not curtail its effects. Such hazard may lead to loss of the system stability that could even threaten the entire electric power grid.

6.3.1 Definition of Lightning

A lightning strike is an electric discharge between the atmosphere and an earth-bound object.

They mostly originate in a cumulonimbus cloud and terminate on the ground, called cloud to ground (CG) lightning. About 25% of all lightning events worldwide are strikes between the atmosphere and earth-bound objects.

A less common type of strike, called ground to cloud (GC), is upward propagating lightning initiated from a tall grounded object and reaches into the clouds.

The bulk of lightning events are intra-cloud (IC) or cloud to cloud (CC), where discharges only occur high in the atmosphere.

A single lightning event is a "flash", which is a complex, multi-stage process, some parts of which are not fully understood. Most cloud to ground flashes only "strike" one physical location, referred to as a "termination".

6.3.2 The phenomenon of Lightning

It occurs due to insulation breakdown of the air around a highly charged cloud. This causes the air around the cloud to ionize and become conductive, creating a path for electrical discharge.

6.3.3 Types of Lightning Strokes

There are two main ways in which lightning may strike the power system.

These are:-

- Direct stroke
- Indirect Stroke

(a) Direct Stroke

A direct stroke is defined as a lightning stroke which hits a shield wire, a tower, or a phase conductor. An insulator string is stressed by very high voltages caused by a direct stroke. An insulator string can also be stressed by high transient voltages when a lightning stroke hits the nearby ground.

The direct stroke can be of two types. These are:

- **Stroke A.**

With stroke A, the lightning discharge is from the cloud to the subject equipment (e.g. overhead lines). The cloud will induce a charge of opposite sign on the tall object. When the potential between the cloud and line exceed the breakdown value of air, the lightning discharge occurs between the cloud and the line.

- **Stroke B.**

In stroke B the lightning discharge occurs on the overhead line as the result of stroke A between the clouds. There are three clouds P, Q and R having positive, negative and positive charge respectively. Charge on the cloud Q is bound by cloud R. If the cloud P shift too nearer to cloud Q, Then lightning discharge will occur between them and charges on both these cloud disappear quickly. The result is that charge on cloud R suddenly become free and it then discharges rapidly to earth, ignoring tall object.

(b) Indirect strokes

Indirect stroke result from electrostatically induced charges on the conductors due to the presence of a charged cloud. If a positively charged cloud is above the line and induces a negative charge on the line by electrostatic induction. This negative charge however will be only on that portion on the line right under the cloud and the portion of the line away from it will be positively charged. The induced positive charge leaks slowly to earth. When the cloud discharges to earth or to another cloud, negative charge on the wire is isolated as it cannot flow quickly to earth over the insulator. The result is that negative charge rushes along the line in both directions in the form of traveling wave. Majority of the surges that occur on transmission lines are caused by indirect lightning stroke.

6.4 Lightning Hazards

6.4.1 Lightning hazards to Power Grids

Lightning is a significant cause of electric power system failures. It is well known that typical Electric Power System includes power plants, power grid (power network) and power consumers. And the power grid consists of transmission network and distribution network.

6.4.2 Lightning hazards to Substations

When lightning strikes a phase conductor of transmission line, the current of the lightning stroke will encounter the surge impedance of the conductor so that overvoltage will be built up and propagate to the substation along the transmission line in a wave form. This lightning incoming wave poses a great danger to the electrical equipment and facilities in substation if measures are not in place to curtail it.

6.4.3 Lightning hazards to Power Distribution system

The principal mechanism of lightning flashover on HV, EHV and UHV transmission lines are the shielding failure and the back-flashover events due to direct stokes to the steel supporting structures. For the lower and high voltage distribution lines, the induced voltage accompanying strokes close to the line predominantly contribute to lightning over voltages. Lightning damages to the power distribution system are a serious problem to many utility-systems and account for the majority of consumer outages causing the highest expense in breakdown of distribution equipment.

6.5 shield (ground) wire

6.5.1 Definition

The overhead earth wire or ground wire is the form of lightning protection using a conductor or conductors installed above the phase conductors to prevent the lightning from directly striking the phased conductors. It is attached from support to support above the phase conductors and well grounded at every tower location. The earth wire intercepts the direct lightning strikes, which would strike the phase conductors. It is worthy of note that the ground wire has no effect on switching surges or cannot be used to control switching surges. When the lightning strikes an earth wire at mid-span, waves are produced and they travel in opposite directions along the line. The waves reach the adjoining tower, which passes them to earth safely.

- The term "ground" refers to a connection to the earth, which acts as a reservoir of charge
- Ground or Earth is the reference point in an electrical circuit from which voltages are measured, a common return path for electric current, or a direct physical connection to the earth
- A Ground Wire provides a conducting path to the earth which is independent of the normal current-carrying path in an electrical system.

6.5.2 Uses of Shield Wire

6.5.2.1 Lightning protection systems

Lightning protection systems are designed to mitigate the effects of lightning. This is done by connecting them to extensive grounding systems that provide a large surface area connection to the earth. A large area is required to dissipate the high current of a lightning strike without excess heat damaging the system conductors.

Since lightning strikes are pulses of energy with very high frequency components, grounding systems for lightning protection tend to use short straight runs of conductors to reduce the self-inductance and skin effect.

6.5.2.2 Aircraft Warning Components

These help in installing beacon balls to warn low flying aircrafts.

Figure 6-2. Energized Shield Wire

6.6 Protection against Shielding Failure

6.6.1 Shielding Angle

The shielding or protective angle is the angle between the vertical earth wire and the phase conductor which is to be protected. Usually, the angle between the vertical through the earth wire and the line joining the earth wire through the outermost phase conductor is taken as a shielding angle.

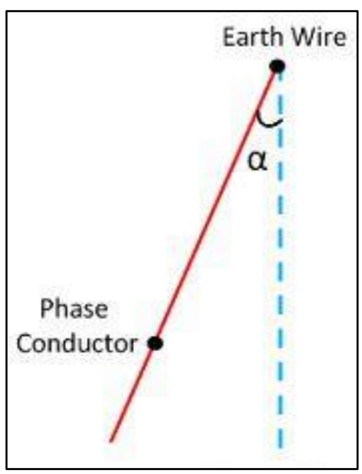


Figure 6-3. Shielding Angle

For effective shielding, the protective angle should be kept as small as possible. The angle between 20° and 30° is quite safe, and it should not be above 40°.

6.6.2 Number of Shield Wires

In order to improve the reliability of the transmission network two shieldwires wires are used on modern high voltage transmission line systems carrying multiple circuits with wider spacing between the phase conductors. The protection afforded by the two wire earth wire is much better than the single wire. Also, the surge impedance for two earth wires is low and the coupling effect of the wire increases.

6.7 Optical Ground Wire (OPGW)

An optical ground wire (also known as an OPGW or, in the IEEE standard, an optical fiber composite overhead ground wire) is a type of cable that is used in overhead power lines that serves to provide protection against lightning and also as a communication medium for sending information from one point to the other.

6.7.1 Composition and Functions

An OPGW cable contains a tubular structure with one or more optical fibers in it, surrounded by layers of steel and aluminum wire. The OPGW cable is run between the tops of high-voltage electricity pylons

- The conductive part of the cable serves to bond adjacent towers to earth ground, and shields the high-voltage conductors from lightning strikes.
- The optical fibers within the cable can be used for high-speed transmission of data, either for the electrical utility's own purposes of protection and control of the transmission line, for the utility's own voice and data communication, or may be leased or sold to third parties to serve as a high-speed fiber interconnection between cities

Figure 6-4 The OPGW Cable

6.7.2 Optical Fiber

FIBER OPTIC (OR "OPTICAL FIBER") refers to the medium and the technology associated with the transmission of information as light impulses along a glass or plastic wire or fiber. Fiber optic wire carries much more information than conventional copper wire and is far less susceptible to electromagnetic interference

6.7.2.1 Types of optical fibers

- Multi-mode
- Single-mode
- Photonic Crystal Fibers

(a) Multi or Single mode fiber

- Single mode fiber is optical fiber that is designed to carry a single signal at a time.
- It is used mainly for long distance signal transmission
- Single-mode fiber has a narrow core, and the index of refraction between the core and the cladding changes less than it does for multimode fibers.
- Light thus travels parallel to the axis, creating little pulse dispersion

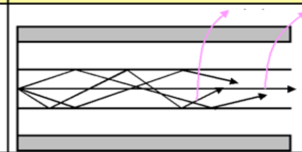
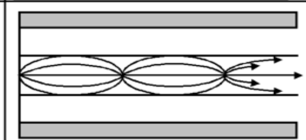
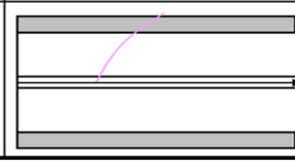
Type		Diameter	Wave length (μm)	Loss (dB/km)	Usage	of Transmission
Multi Mode Fiber	Step Index Type Multi Mode	80/125 (core/clad)	0.85	3~3.5	Between computers, Inside of building	
	Graded Index Type Multi mode	50/125 (core/clad)	0.85	2.2~3	~ 100Mbps	
Single Mode Fiber		9/125 (core/clad)	1.31, 1.55	0.2~0.5	100Mbps ~	

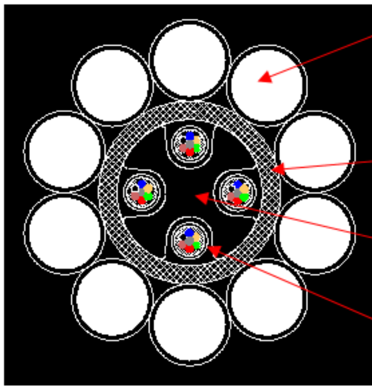
Table 6-1: Characteristics of Single-mode and Multi-mode Fibers

(b) Photonic Crystal Fibers

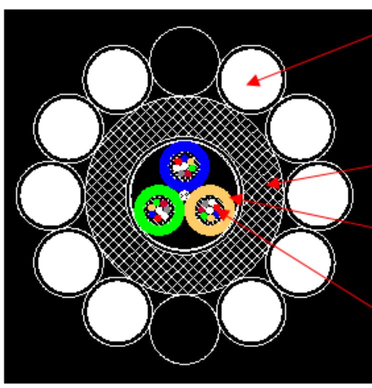
Photonic-crystal fiber (PCF) is a new class of optical fiber based on the properties of photonic crystals. Because of its ability to confine light in hollow cores or with confinement characteristics not possible in conventional optical fiber, PCF is now finding applications in fiber-optic communications, fiber lasers, nonlinear devices, high-power transmission, highly sensitive gas sensors, and other areas. More specific categories of PCF include photonic-bandgap fiber (PCFs that confine light by band gap effects), holey fiber (PCFs using air holes in their cross-sections), hole-assisted fiber (PCFs guiding light by a conventional higher-index core modified by the presence of air holes), and Bragg fiber (photonic-bandgap fiber formed by concentric rings of multilayer film). Photonic crystal fibers may be considered a subgroup of a more general class of micro structured optical fibers, where light is guided by structural modifications, and not only by refractive index differences

6.7.3 Types of OPGW

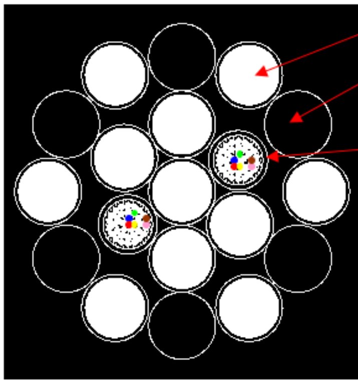
(a) AL Spacer Type

Structure	Function	
	· Al-Clad Steel Wire(ACSR)/ Al-Alloy Wire - Ground · Al Tube - Protection(impact from outside, hydro) · Grooved Spacer - Protection (Side pressure) · Coating - Protection (Heat from outside)	

(b) Loose Tube Type

Structure	Function	
	· Al-Clad Steel Wire(ACSR)/ Al-Alloy Wire - Ground · Al Tube - Protection(impact from outside, hydro) · Thermoplastic Tube - Protection(heat, hydro) · Coating - Protection (Heat from outside)	

(c) Stainless Steel Tube Type

Structure	Function	
	• Al-Clad Steel Wire(ACSR)/ Al-Alloy Wire - Ground • Stainless-Steel Loose Tube - Protection(impact from outside, hydro) - excellent for preventing optical fiber stretching • Filling Compound - to prevent water impregnation	

6.7.4 Typical Specification

The optical fiber itself is an insulator and is immune to power transmission line and lightning induction, external electrical noise and cross-talk.

Typically OPGW cables contain single-mode optical fibers with low transmission loss, allowing long distance transmission at high speeds. The outer appearance of OPGW is similar to Aluminum Conductor Steel Reinforced cable (ACSR) usually used for shield wires.

The minimum requirement for the OPGW with Optical Characteristics of Single mode type G.652D/G.655 (ITU-TG652) optical fibre shall meet the requirements described below;

Characteristic	Unit	value
Cable Diameter	mm	14.0
Cable Weight	Kg/km	571
Supporting Cross Section	mm^2	86.6
Ultimate Tensile Stress (UTS)	kN	146
Rated Tensile Stress (RTS)	kN	141
Everyday Tension	kN	≤ 20% UTS OF OPGW
Modulus of Elasticity (E-Modulus)	kN/mm^2	107
Coefficient of linear expansion	$^0C^{-1}$	$14.7x10^{-6}$

Permissible Maximum Working Stress		kN/mm^2	≤ 40% RTS
Ultimate Exceptional Stress		N/mm^2	≤ 70% RTS
Maximum Permissible Installation Force		kN	23.7
Minimum Bending Radius	Static	mm	210
	Dynamic	mm	280
DC Resistance at 20^0c		Ω/km	0.385
Conductivity		IACS	51.7%
Short Time Current (0.2s, 40^0C ~ 200^0C)		kA	19.54
Short Time Current Capacity (I^2t) (40^0 - 200^0C)		kA^2S	381.8

Table 5-2: Technical Specifications of OPGW

6.7.5 Consideration for OPGW Construction

In general, the system and the equipment used for installation of the OPGW are similar to those of the standard ground wire cable.

Nevertheless, there is an optical fiber core, fibers should be protected from suffering any damage by observing the minimum bending radius at all times. Therefore, specific components and machinery are used for the OPGW cable: pullers, tensioners, anti-twisting counterweights, swivels, pulling grips, pulley-blocks, self-gripping clamps, pulling ropes, pulling cables, etc.

6.7.5.1 Transportation, loading, unloading and storage

The following procedures are recommended to prevent the cable from suffering damage during handling, transport and storage:

(a) The drums should always be transported in vertical position with the cable ends fixed to prevent cable from slackening. All of the staves and safeguards should be maintained until the drums are situated for immediate installation.

(b) After transportation, the drums should be inspected to be sure they are not damaged and that none of the staves or safeguards is broken.

(c) The cable drums should never, in any case, be thrown from the truck during unloading, or moved by uncontrolled rolling.

(d) Loading and unloading are performed so that the drum remains in vertical position and the sides of the drum are not damaged.

(e) The drums can be moved by rolling a short distance ensuring that there are no objects that may damage the staves. The direction the drum turns should follow the instruction of the mark on the drum.

(f) In any case the drum should not be stored horizontally.

(g) The ends of the cable should be sealed to prevent water penetration.

(h) The drums should be stored on flooring that is strong enough to avoid sinking.

(i) The drums should be stored to facilitate handling and loading, and should be located on a safe place where they will not be damaged.

M07 – TOWER ACCESSORIES

7.1 Objectives

At the end of this module participants should be able to:

- Identify the various accessories which are used for a transmission line.
- Understand its function and basic structure.
- Apply it to the real construction and operation of transmission line.

7.2 Introduction

Transmission hardware supports tens of thousands of pounds of load that constantly moves, swings, expands and contracts. But this critical job is often taken for granted. Why? Because hardware usually accounts for less than 2% of a transmission line's cost. Poor hardware design, construction, and reliability account for more than 20% of all line outages. With a single line outage typically costing millions of Dollars per day, choosing the right hardware is very important during the design and construction phase.

7.3 Transmission clamps

Suspension clamps and tension clamps are used to connect the conductors with insulator strings. The mechanical strength of accessories used for insulator string configurations should not be less than the mechanical strength of the insulators in the given string. The accessories mechanical strength should be designed for loading transmitted by conductors taking into consideration the safety factors. Steel and iron accessories shall be galvanized. Tension clamps of line conductors shall be of compression-type and shall incorporate a steel anchor, in which the steel core of the conductor is compressed, and an aluminium body, in which the aluminium part of the conductor is compressed.

Figure 7-1. Tension clamp

Figure 7-2. Suspension and Tension Clamp

7.4 Mid-span Compression Sleeve

Compression type joints are used for jointing the length of ACSR conductors. The joint consists of two sleeves. The steel portion which is made of mild steel, galvanized and stainless steel. The aluminium sleeve is made out of pure extruded aluminium tube. The shape of cross section of sleeves is round before compression and hexagonal after compression.

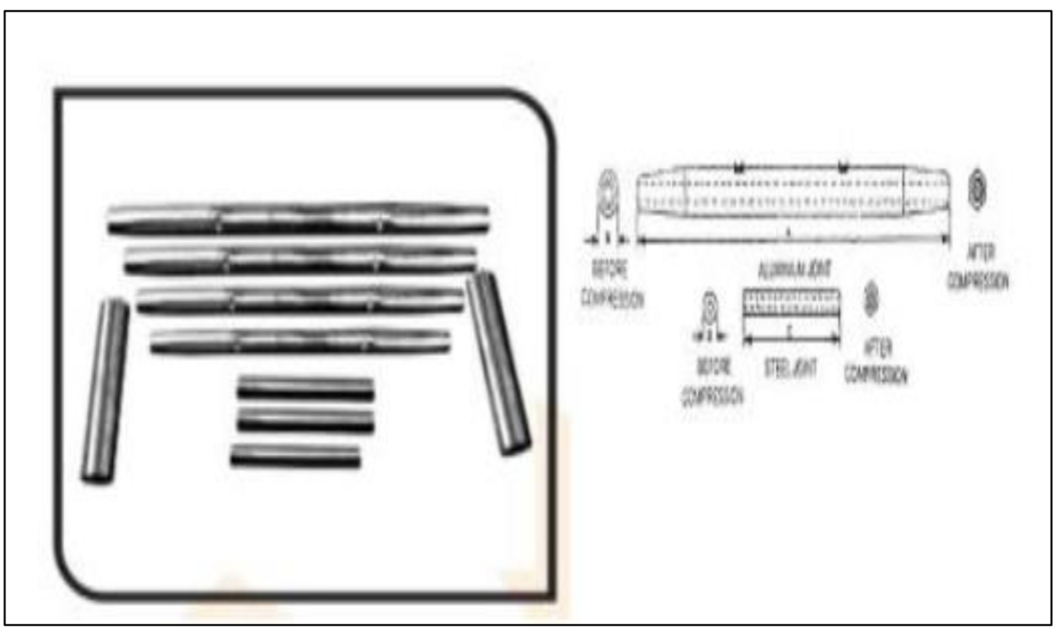


Figure 7-3. Mid-span Compression Sleeve

7.5 Repair Sleeves

They are useful for the reinforcement of ACSR, AAAC, AAC conductors with a few of their aluminium strands broken. Repair Sleeves are composed of two identical aluminum pieces fitted into each other. They are applied to reinforce a conductor having some of the strands broken or damaged. They are to be compressed by the same die used for the aluminum component of dead end joint for the same conductor. The shape of cross section of the repair sleeves shall be generally round before compression and shall be hexagonal after compression. The sleeves shall be manufactured from 99.5% pure extruded aluminum.

Figure 7-4. Repair Sleeves

7.6 Vibration Dampers

Vibration Dampers are used to absorb Aeolian (Wind-induced) Vibrations of conductor of Transmission Lines, as well as ground wires, OPGW, and ADSS. It is mostly composed of the following;

- Weights – made up of cast iron,
- Clamps – made up of Aluminum Alloy,
- Nuts and Bolts – made up of galvanized or stainless steel and
- Messenger cable – made up of Galvanized Steel.

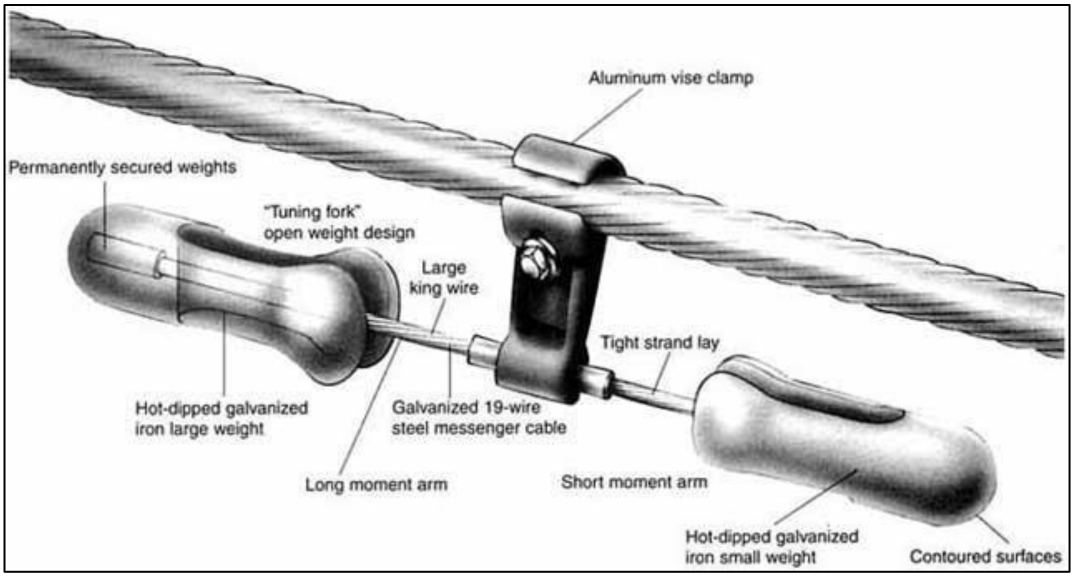


Figure 7-5. The structure of vibration dampers

Figure 7-6. The image of vibration dampers

7.6.1 Aeolian Vibration

Wind-induced vibration or Aeolian vibration of transmission line conductors is a common phenomenon under smooth wind conditions. The cause of vibration is that the vortexes shed alternatively from the top and bottom of the conductor at the leeward side of the conductor. The vortex shedding action creates an alternating pressure imbalance, inducing the conductor to move up and down at right angles to the direction of airflow.

The conductor vibration results in cyclic bending of the conductor near hardware attachments, such as suspension clamps and consequently causes conductor fatigue and strand breakage.

When a “smooth” stream of air passes across a cylindrical shape, such as a conductor or OHSW, vortices (eddies) are formed on the back side. These vortices alternate from the top and bottom surfaces, and create alternating pressures that tend to produce movement at right angles to the direction of the air flow. This is the mechanism that causes Aeolian vibration.

7.6.2 Effect of Aeolian Vibration:

It should be understood that the existence of Aeolian vibration on a transmission or distribution line doesn’t necessarily constitute a problem. However, if the magnitude of the vibration is high enough, damage in the form of abrasion or fatigue failures will generally occur over a period of time. Abrasion is the wearing away of the surface of a conductor or OHSW and is generally associated with loose connections between the conductor or OHSW and attachment hardware or other conductor fittings. In the case of a conductor or OHSW being subjected to Aeolian vibration, the maximum bending stresses occur at locations where the conductor or OHSW is being restrained from movement. Such restraint can occur in the span at the edge of clamps of spacers, spacer dampers and Stock bridge type dampers.

Figure 7-7. Damage at suspension clamp due to fatigue

7.6.3 How Vibration Dampers Function

When the damper is placed on a vibrating conductor, movement of the weights will produce bending of the steel strand. The bending of the strand causes the individual wires of the strand to rub together, thus dissipating energy. The size and shape of the weights and the overall geometry of the damper influence the amount of energy that will be dissipated for specific vibration frequencies. Since, as presented earlier, a span of tensioned conductor will vibrate at a number of different resonant frequencies under the influence of a range of wind velocities, an effective damper design must have the proper response over the range of frequencies expected for a specific conductor and span parameters.

7.7 Spacer and Spacer Dampers

Spacers and spacer dampers have the primary task of maintaining the geometry of conductor bundles, within the design limits, under the normal service conditions. Spacers and spacer dampers shall withstand the mechanical loads imposed during installation, maintenance and service, including short circuits, without failures and without damaging the conductors.

7.7.1 Types of Conductor Bundles

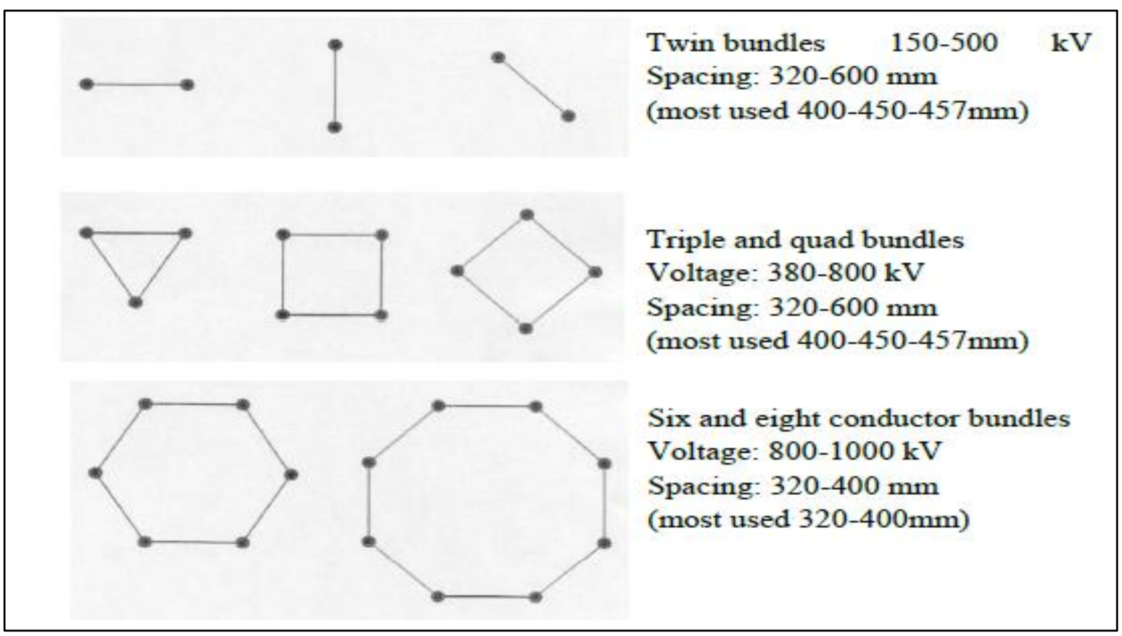


Figure 7-8. Types of Conductor Bundles

7.7.2 Types of Spacers

In relation to the above conductor-bundle designs, spacers can be classified as follows.

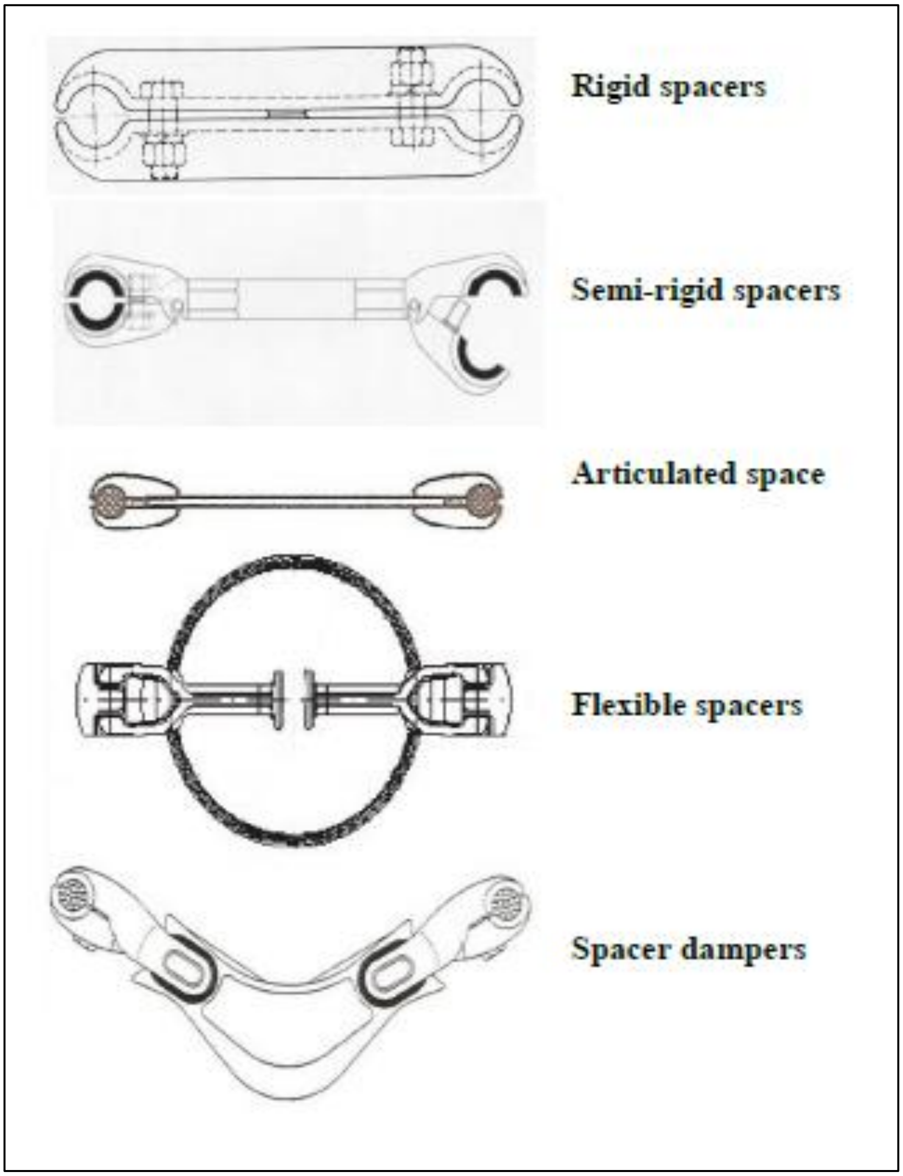


Figure 7-9. Types of spacers

7.7.2.1 Rigid spacers

They do not allow any significant relative movements and displacements of the sub-conductor. They are used in jumper loops (where sometimes are counterweighted) and slack spans only.

Figure 7-10. Rigid spacers

7.6.2.2 Articulated spacers

Figure 7-11. Articulated spacers

7.7.2.3 Flexible spacers

They allow large relative movements and static displacements between sub-conductors. Are used in transmission lines in conjunction with vibration dampers.

Figure 7-12. Flexible spacers

7.7.2.4 Spacer dampers

These are spacing devices whose inertial, elastic and damping properties are defined and coordinated to mitigate aeolian vibration. They can also accommodate relative movements and static displacements between sub-conductors in any direction. Except for special cases, they do not require the application of vibration dampers.

Figure 7-13. Spacer Dampers

7.7.3 Damping Mechanism

The damping mechanism is based on the dissipation of the sub-conductor vibration energy. The spacer damper extracts energy from the sub-conductors by means of the elastomer flexible- damping elements used in the articulations. In order to do that the spacer damper arms shall rotate allowing the elastomer to absorb energy by deformation. When the bundle vibrates with no relative movements between sub-conductors, the main frame of the spacer damper shall develop inertial forces able to determine arm rotations and consequently dissipation of energy. During sub-conductor aeolian vibrations, the inertia reaction of the central frame allow arm rotation thus dissipation of energy.

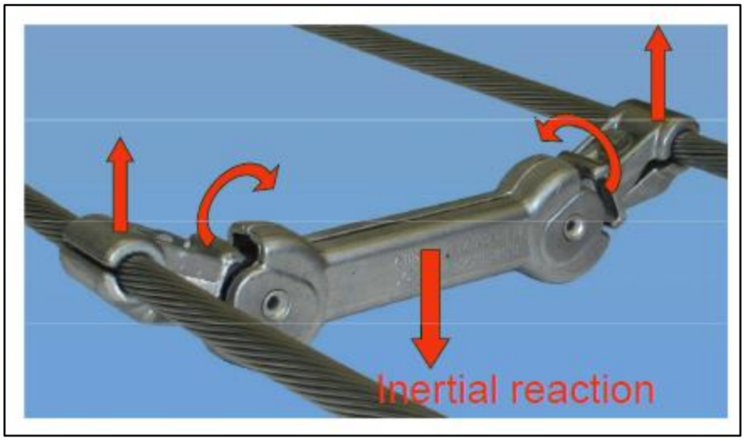


Figure 7-14. Damping Mechanism

7.7.4 Spacer and Spacer Damper Performance

The spacer dampers control Aeolian vibration by means of their inherent damping capacity. Aeolian vibration can also be controlled by non-rigid spacers (semi-rigid, flexible or articulated) and vibration dampers. The spacers or spacer dampers control sub-span oscillation by means of a suitable in-span distribution. Galloping cannot be fully controlled by normal spacer and spacer dampers. Spacer dampers equipped with torsional dampers (one or two per span) are used for controlling severe sub span oscillations. A pendulum arm connected to the spacer damper frame through a damping articulation can control sub-span oscillation mitigating the torsional vibration modes of the bundle. Spacer dampers equipped with detuning pendula are used for controlling galloping. Detuning pendula applied on spacer damper frames also improve the performance of these devices in controlling Aeolian vibrations and sub-span oscillations.

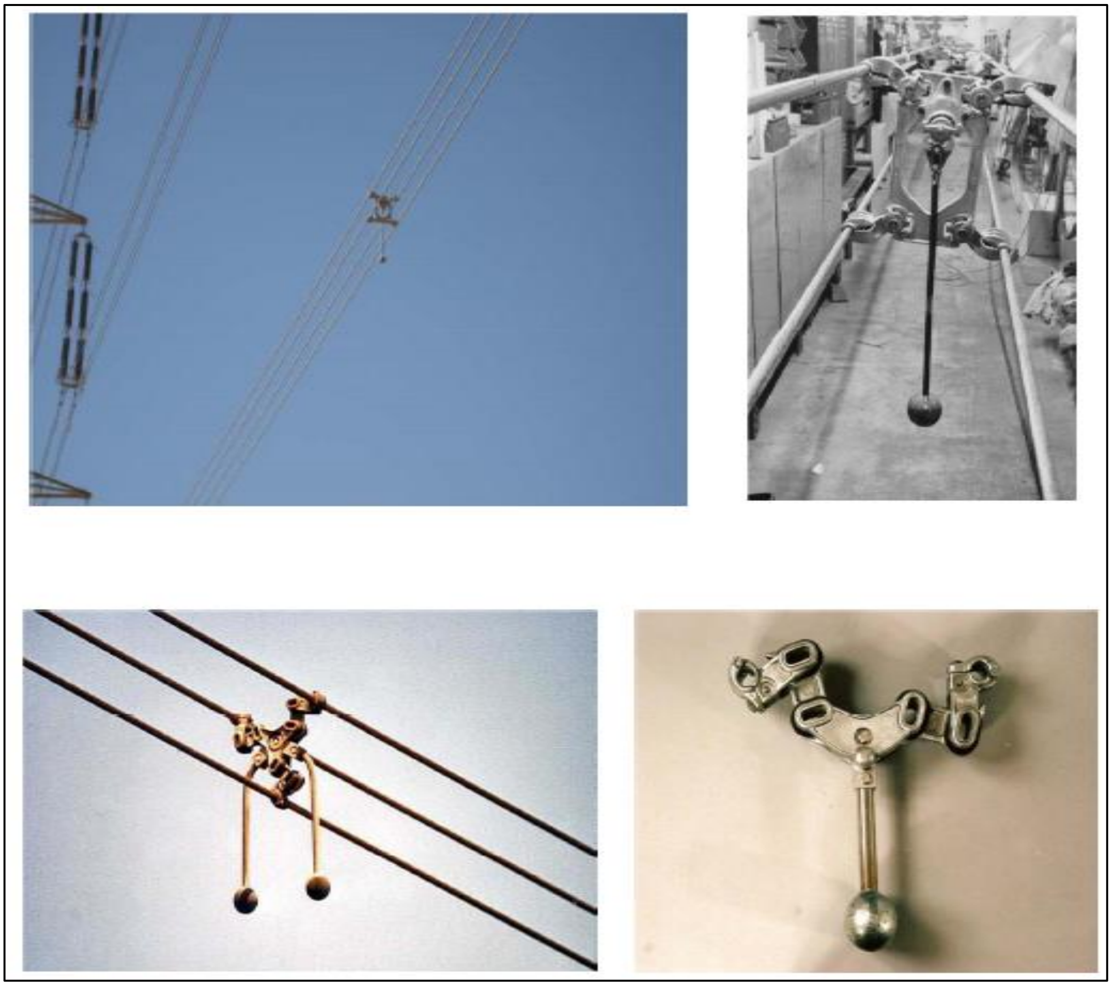


Figure 7-15. Spacer and spacer dampers

7.8 Armor Rods

Armor rods are designed to protect conductors against bending, compression, abrasion, and flash-over. They are also used to repair damaged aluminum-based conductors and restore the conductors' mechanical strength and conductivity. It is also suitable for ACSR conductors of the required size, diameter and breaking load are provided at all the suspension points of each conductor to minimize the stresses and strains developed in the conductor at suspension supports resulting from static and dynamic loads, such as maximum wind load conditions, Aeolian vibrations and sub-span oscillation, slipping of conductor from the clamps as a result of unbalanced conductor tensions in adjustment span and broken wire conditions.

They shall also withstand power arcs, chaffing and abrasions from clamps and localized heating effect due to magnetic power losses from clamps as well as copper losses of the conductor covered inside the armor rod and clamps.

Preformed Armor rods are used as a set composed of 10 or more aluminum cylindrical rods having diameter and length proportional to the conductor diameter. Each rod is performed in helical shape and has parrot-bill end finish.

Figure 7-16. Armor Rods

7.9 Aerial Marker Balls (Bicon Ball)

7.9.1 Applications

Applications of Aerial Marker Balls help save lives and protect expensive infrastructure by making power lines and guy wires more visible to low-flying planes and helicopters. Marker Balls are typically used in airport and heliport approach areas and where power lines span long distances crossing valleys, lakes and rivers.

Figure 7-17. Bicon balls installed across valley

7.9.2 Installation

This Marker installs easily on any wire through the use of two UV resistant neoprene strip bushings installed on the wire to match the diameter of the openings (boss) in the Marker. The Marker is then securely bolted around the wire, clamping down on the bushings.

Figure 7-18. Bicon ball fitted to conductor

7.9.3 Color Options

Our standard color is "International Danger Orange;" (U.S. Engineer's Spec. 595-121197 or British STD. 381C-1964-No. 557) however, yellow and white are available as an option. In some cases, these colors prove to be more visible, depending on the surrounding terrain. In some circumstances, such as river and valley crossings, the FAA recommends an alternating pattern of Orange, Yellow, and White.

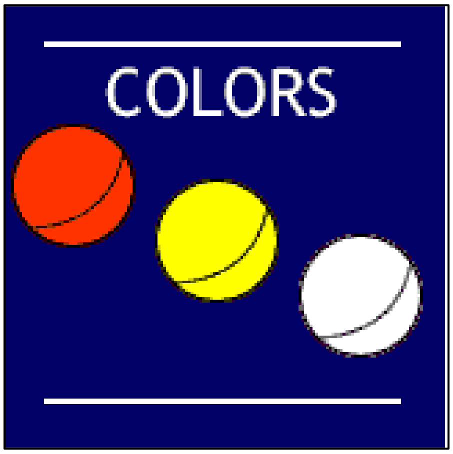


Figure 7-19. Various colors of beacon balls

2. TRANSMISSION LINE CONSTRUCTION

Ghana Grid Company

M01 – ROUTE SELECTION AND SURVEY

1.1 Objectives

At the end of this module participants should be able to:

- State and explain the factors to consider in overhead transmission line route selection
- Select an optimal transmission line route that meet all considerations and is generally acceptable by the public.
- Undertake transmission line route survey to define the alignment of the line.
- Undertake transmission tower spotting depicting the location of each towers on the alignment.

1.2 Introduction

Reliable and dependable electricity supply is paramount to the social and economic development of the country. In Ghana, electricity demand in the past decade had been increasing well above 12.5% making the total load for the country to grow steadily which had put considerable strain on the power system, specifically on generation which over the years had not been able to match up to demand adequately. This has also led to a growing need for the transmission utility to transmit power from these generating site to the loads center for distribution by the distribution company.

GRIDCo has developed the Transmission Master Plan which incorporate a projected transmission system plan to meet the ever growing load in the country. To meet this increasing growing demands, new high voltage overhead transmission lines and corridors will be needed.

High-voltage, high-capacity overhead lines are the economic and reliable choice for the bulk transmission of electricity throughout the world. The siting of transmission lines is a complex process, and requires a balance to be struck between statutory obligations, engineering requirements, economic viability, land use and the environment. Transmission line siting projects can rightly generate considerable public interest and debate.

In the light of meeting the load and demand, this text book has been developed to critically examine and adopt the standards and procedure for the selection of transmission line right-of-way (ROW), survey of transmission line route and tower spotting to determine the exact location of each tower on the ground.

1.3 The Transmission System of Ghana

Power evacuation from the generating stations to bulk customers is facilitated by GRIDCo transmission facilities consisting of almost 5,000km of high/extra high voltage transmission lines and over 50 EHV/HV/MV substations with the operating voltages being mainly 330kV, 161kV and 69KV.

The GRIDCO transmission system is also interconnected with the power systems of La Cote D'Ivoire and Togo/Benin. A 225kV single-circuit inter-tie connects the GRIDCo network to the network of Compagine Ivoirienne d'Electricite (CIE) of la Cote D'Ivoire at Prestea and Abobo respectively. In addition, a double circuit 161kV transmission line from Akosombo to Lome connect the GRIDCo network to the network of Communuate Electrique du Benin (CEB) of Togo and Benin.

With this high increase in demand (at about 12.5% per annum) and associated generation capacity, GRIDCo needs to develop some transmission lines captured in its master plan to equally dispatch electricity to the load centers. One would realize that the development of these power system infrastructure both present and future and competing for right-of-way with other utilities such as water systems, telephone, roads networks, etc. cannot be realized efficiently and economically without adequate planning of transmission system.

The planning of the transmission system means the building of new transmissions lines to the load centers. These transmission projects require the acquisition of land to be used as easement for the siting of transmission lines. It involves the selection of a suitable corridor to be used as a transmission ROW and the actual survey to be conducted on the selected corridor.

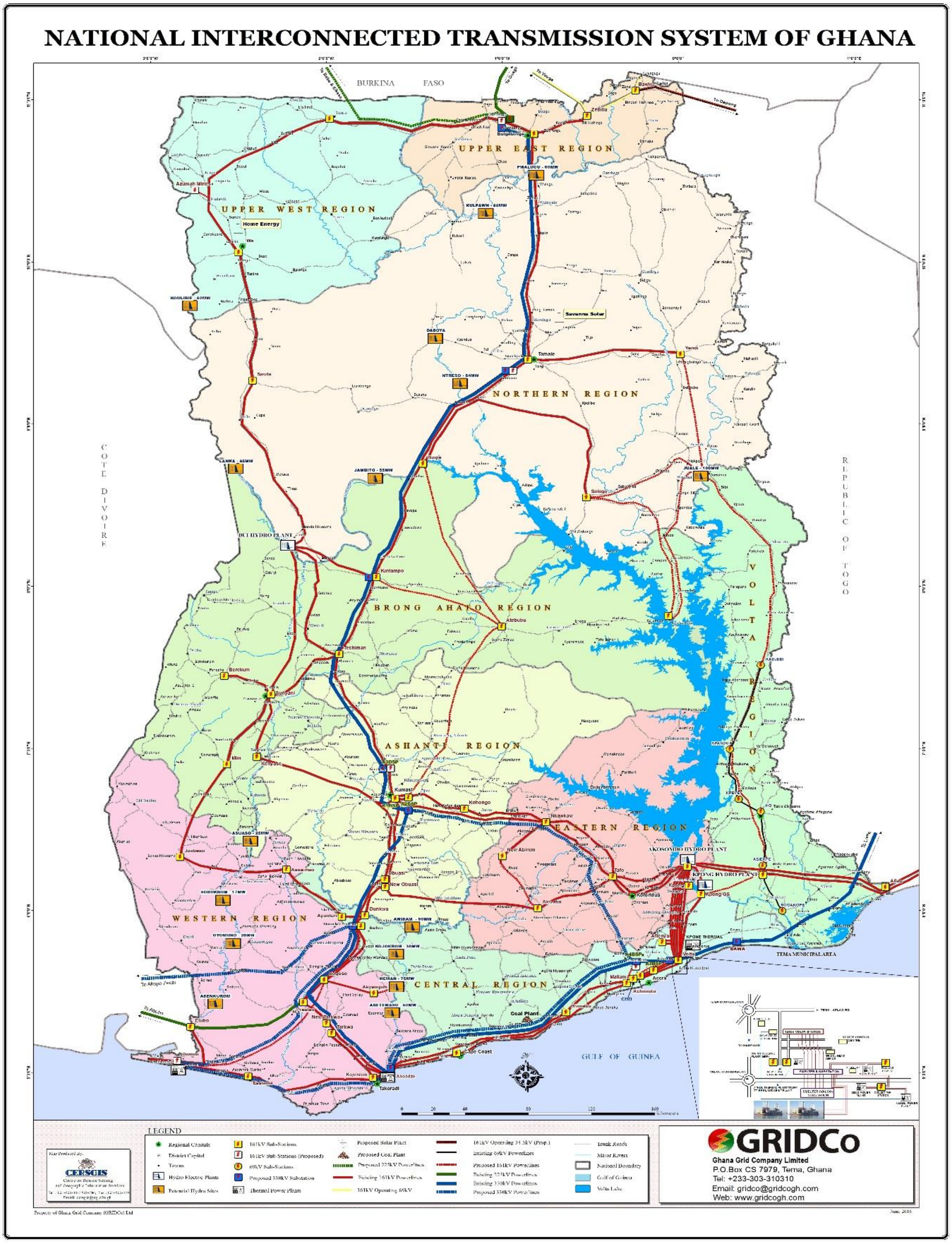


Figure 1-1. Shows the National Interconnected Transmission System Map of Ghana

1.4 Transmission Master Plan of Ghana

The plan looks at a ten year (2010-2020) Transmission System Development Master Plan to determine the future transmission investments over the planning horizon. This development plan will be such that the electricity demand is met in a least-cost approach while ensuring the system security and reliability. This Plan also helped in defining new policies and procedures for performing power system planning.

The Plan is in four parts.

- Part 1 - Synthesis of the data collection presenting all information gathered during the project and highlighting assumptions taken.
- Part 2 - Elaboration of target structures for 2020. This phase consists in the first step of Task 2 of the methodology of the Transmission master plan. The objective of this step is to identify one or several network structures for the target year – 2020 satisfying both the load and the planning criteria.
- Part 3 - Methodology. It covers two combined aspects. First, the annual phasing of the portfolio of investments determined for 2020. Then, the detailed static and dynamic assessments of the Ghanaian System.
- Part 4 - Definition of organizational structure, methodologies and guidelines to conduct transmission system planning studies and operating studies. The objective of those guidelines is to improve the capacity of GRIDCo in conducting system planning studies and operating studies

1.5 Transmission Line Route or Right-of-Way (ROW)

Transmission line alignment is usually within a specified corridor width within which all operation of the transmission line is carried out.

1.5.1 Line Route or Right-of -Way (ROW)

A right-of-way is the actual land area acquired for a specific purpose, such as a transmission line or roadway. Right-of -way refers to the right of the transmission or distribution utility over the strip of land the lines pass through.

A transmission line route (ROW) is that strip of land used by electrical utilities to construct, operate, maintain and repair the transmission line facilities. Right-of-Way (ROW) is to provide an access corridor for maintenance of transmission lines, with consideration to safety clearances and EMF exposure limits. Right-of-way usually includes the right to trim trees which can be potentially dangerous by either touching the lines or falling on them. No structure can be constructed on the right-of-way which may reduce the ground clearance.

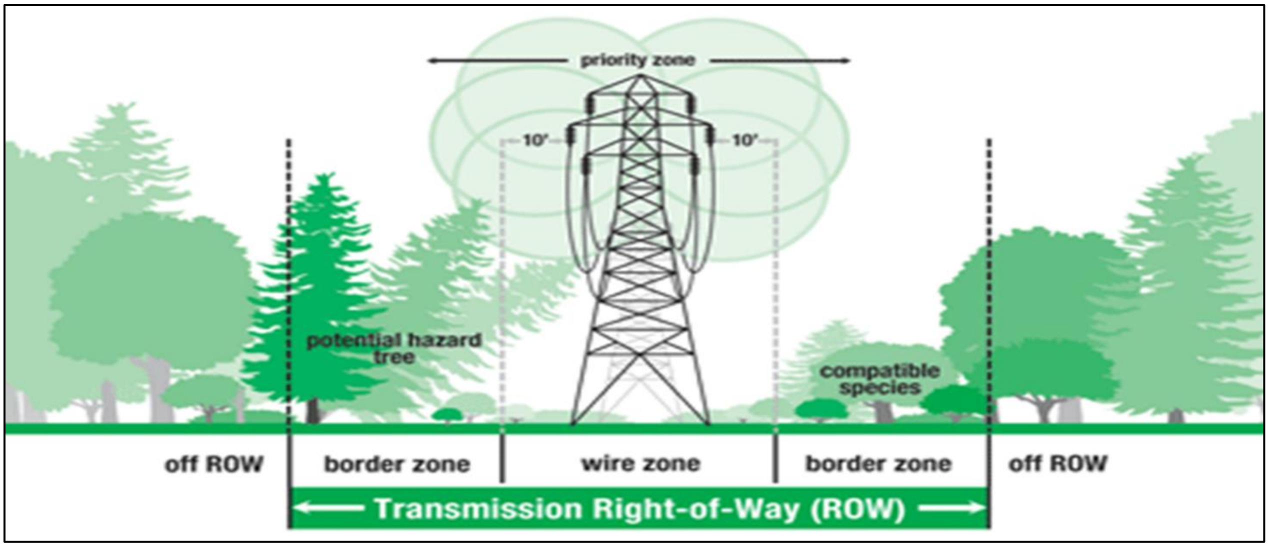


Figure 1-2. Show the transmission right-of-way (ROW)

In Ghana, the right-of-way generally must be clear of unauthorized structures that could interfere with a power line. Rights of way may also include the purchase of rights to remove danger trees. A danger tree is a tree outside the right of way but with the potential to do damage to equipment within the right of way. If the danger tree falls or is cut down, it could strike poles, towers, wires, lines, appliances or other equipment and disrupt the flow of electricity to our customers.

1.5.2 Determination of Right-of-Way (ROW)

The width of the right of way depends on the voltage of the transmission lines and the height of the transmission structures. It also depend on design factors such as tower design, sags, clearances etc and also on EMF. There is a mathematical relation between all this factors that helps in calculating the required ROW for each voltage.

When the ROW is determined, the transmission owner then obtains this ROW for the overhead transmission line or substation through the purchase of an easement (purchasing rights to the land) or fee title ownership (purchasing the land).

An easement between a transmission owner and a landowner is a legal contract that allows the transmission owner to build, maintain, and protect the power line. The landowner sells the usage rights to the transmission owner for a negotiated amount of money, generally paid in one lump sum. The contract specifies restrictions on both the transmission owner's and the landowner's use of the land and specifies the rights of the transmission owner. It is binding upon the transmission owner, the landowner, and any future owners of the land until the contract is dissolved.

1.5.3 Legislative Instrument Governing Row in Ghana

This is a legal document that specifies conditions for allowable encroachments. They provide acknowledgment of ROW, and legal protection for both parties. In Ghana L.I. 542 regulates ROW as follows:

The ROW or transmission Line ROW includes the area extending for a distance of fifteen (15) meters on each side from the center of the transmission tower for 69 kilovolts and 161 kilovolts transmission lines and twenty (20) meters for 225 kilovolts and 330 kilovolts transmission lines.

VOLTAGE LEVELS	RIGHT OF WAY WIDTH
69kV	30 Meters
161kV	30 Meters
225kV	40 Meters
330kV	40 Meters

Table 1-1. Transmission line voltages and ROW

It shall be an offence for any person whether by himself or in co-operation with others to do or assist in doing any of the following acts in relation to the transmission lines:

- to drill, mine or excavate or carry on any similar operation within the transmission line right of way;
- to place any combustible material inside the right of way;
- to cause any fire to burn within two hundred (200) feet of the transmission line right-of-way.
- to cause anything to come into contact with the transmission line;
- except with the preview consent of the Authority obtain in writing and subject to any condition that the Authority may impose in relation to such consent:
- to carry on any form of blasting within one thousand five hundred (1,500) feet of any transmission line; or
- to construct any building or structure or carry on any kind of cultivation, farming or farming activity within the transmission line right-of-way.

1.6 Transmission Line Route Selection

This chapter describes in detail, the process to be followed in selecting the proposed route for overhead transmission lines. This process is important because the most effective method of preventing or reducing the environmental effects of an overhead transmission line is through careful routing. Transmission Line Route Selection is a critical and important aspect of Transmission Line Design and Construction and it serves as the foundation for the design of the transmission line.

The process of the route selection actually defines the corridor of the transmission line on the ground and this corridor goes to determine the cost, the duration and the extent of public opposition or acceptance of the project.

1.6.1 Criteria for Transmission Line Route Selection

A preliminary transmission line route is selected based on agreed standards and considerations.

1.6.1.1 Technical Considerations

Objectives: To ensure Safety, Reliability and Accessibility

(a) Line length and Span length

As much as possible, the route should be the shortest possible route. The line length should not exceed 10% of the point-to-point distance of the line. This is because the series impedance of the line is proportional to the line length; hence excessive increase in the line length will mean an increase in the series impedance.

(b) Topography, Soil and Vegetation

The nature of the ground, slopes, soil types, existing access roads, should be favourable in order not to increase the cost of civil works. Not too swampy, hilly or dense vegetation.

(c) Ease of Construction

There should be a convenient access to the route for easy of construction

(d) Ease of Maintenance and Accessibility

The route should be such that after construction, it will be easily accessed for routine maintenance works to be carried out.

(e) Alignment

The alignment of the route should be as straight as possible so as to minimize the number of angle/turning points. The cost of a transmission line project depends so much on the alignment of the line.

1.6.1.2 Public/Social and environmental considerations

Objective- To ensure compliance and minimize impact on Human and environment

(a) Compliance with national and local regulations

The proposed overhead transmission route should comply with both national regulations such as the Ghana Environmental Assessment Regulations, 1999 (LI 1652), Lands (statutory Wayleaves) (Amendment) Regulations, (LI 334) and local regulation such as Town and Country regulations, district and local Assemblies regulations

(b) Adherence to sound environmental principles, i.e. avoid creating new corridors, minimize length of corridor.

Share right-of-way with existing transmission lines where practical. Find out if there are corridor that have been reserved for the use by utilities.

(c) Identify and avoid sensitive site

Avoid areas such as burial sites, wildlife management areas (WMAs), protected wetlands, scientific research areas and populations of threatened and endangered species/species of special concern, areas of significant biological or cultural significance and state lands.

(d) Avoid residential and industrial area, parks and historic sites

Avoid existing and planned high-density residential areas, agricultural areas where center pivot irrigation systems are used and areas where clearances would be an issue.

1.7 Transmission Line Route Selection Procedure

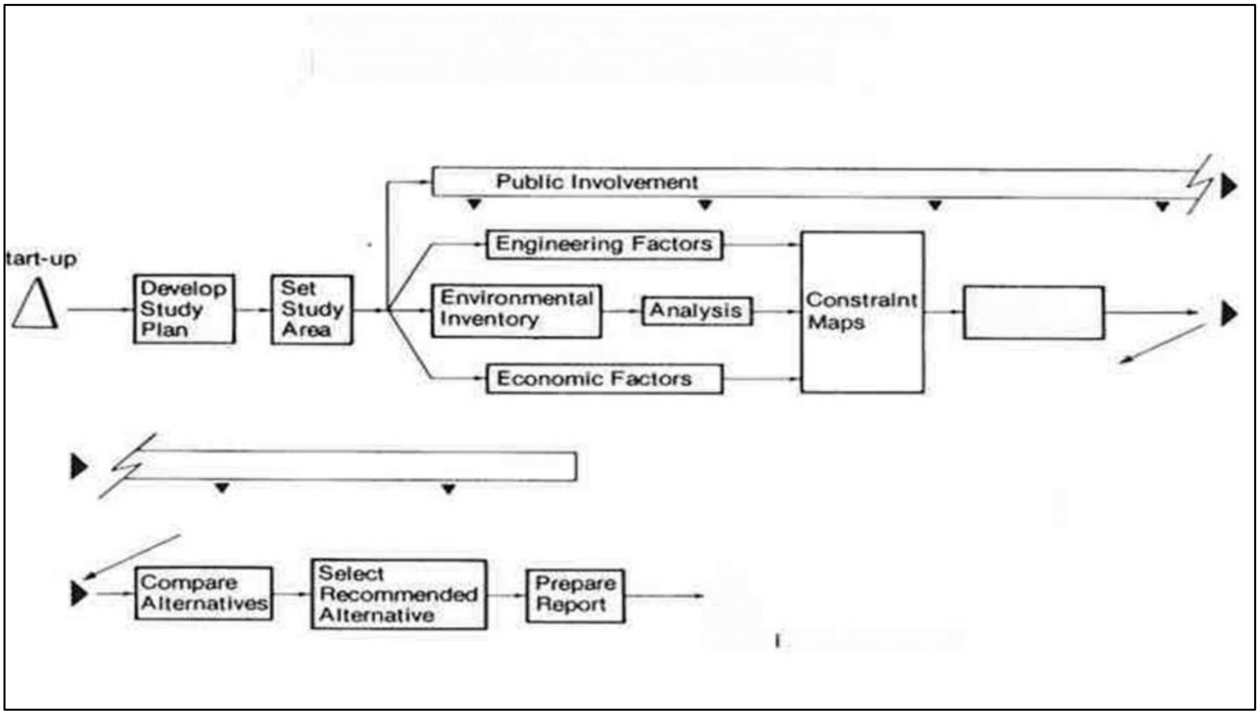


Figure 1-3. Shows a flow chart for overhead route line selection procedure

A step by step approach to selecting an optimal transmission line route or ROW

1.7.1 Identify transmission line project

The proposed project can be identified from the Transmission Master Plan or Project Impact Study that will be conducted by the Planning Unit of the Engineering Department. The study report will throw more light into the project and will provide some useful information in selecting your route.

(a) Study the proposed project area.

Undertake a desk study of the proposed project area. Identify starting point and terminal point. Pick out salient point from the impact study report and also from the feasibility report. Identify the voltage and the requirement from the scope of works and detail specifications.

(b) Select Topographic maps and some satellite imagery

Select topo maps and satellite imagery covering the entire stretch of the project. Identify key villages and community from the maps. This will help in the public consultation. Prepare regional maps showing opportunities and constraints.

(c) Undertake a reconnaissance survey

Go to the project area and confirm and relate findings on the ground with what is on the map. This will help you verify information and that will be useful in the creation of corridors and look for features that are not captured by the map that may affect the siting process.

(d) Where necessary undertake Aerial patrols

Where necessary and with the required funding available, undertake aerial patrol to have a bird eye view of the project area and collect as much data as possible.

(e) Undertake public consultation

Undertake a public consultation starting from key public and local organization within their jurisdiction where the project will be taking place. Brief them about the project and solicit their views on the routing of the line. Use the participatory approach and get them to be involved in the whole project routing. Meet with communities within which the project area falls and hold open houses to gather public input.

(f) Identify Potential Route

Identify potential routes, follow opportunities and avoid constraints. Give each section or "segment" a number. Come out will all possible routes and identify all the considerations that hinder each of the route.

(g) Undertake a 2nd Public Consultation

Undertake a 2^{nd} public consultation briefing them about the routes chosen. Allow for input from all stakeholders.

(h) Conduct Analysis and Review the Route

Conduct in-depth study of potential routes (drive, fly, research) and evaluate each of the potential routes.

(i) Confirm Final Route with all Key Stakeholders

Select the preferred routes (Planning phase completed.). Determine the width of corridor to submit in the licensing application. Corridor can be up to one mile wide for flexibility.

(j) Generate a Preliminary Line Route Map

Generate a preliminary Line Route Map that will show the entire stretch of the corridor and that will define the corridor on the ground. This preliminary line route will serve as an input for the next phase of the process of Overhead Transmission Line Design and Construction.

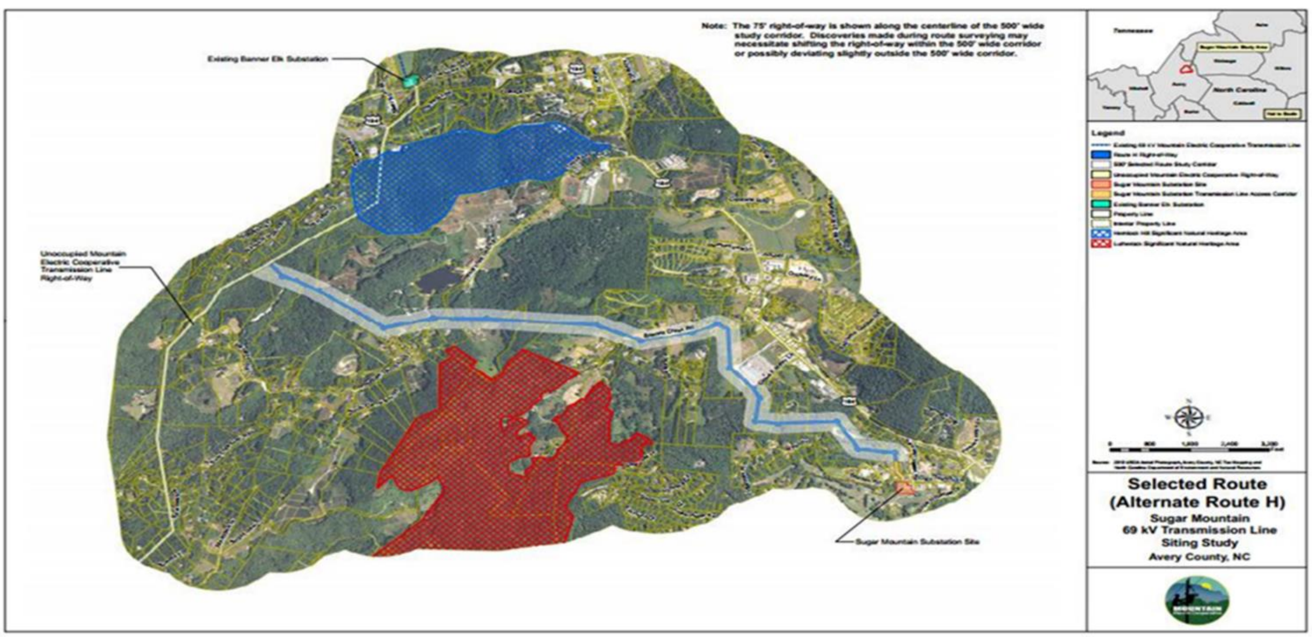


Figure 1-4. Shows a Preliminary line Route Map

It is important to prepare a preliminary line route study report which will provide a detailed description of the ROW selected and shall include a commentary on the line route among others.

1.8 Overhead Transmission Line Route Survey

The main objectives of undertaking transmission line route survey is to:

- Collect data to define the transmission line alignment on the ground
- Generate plan and profile drawings for tower spotting

Transmission line route survey can be sub divided into two phases namely:

Phase I

- Reconnaissance survey
- Detailed Survey or Profile Survey

Phase II

- Tower spotting
- Setting out – Check Survey

1.8.1 Reconnaissance Survey

The preliminary line route map is used as the basis for a reconnaissance survey. The main objective of undertaking a recce survey as is usually called is to familiarize yourself with the project area looking at the type of vegetation, soil conditions, availability of access road and other important features that needs to be capture during the detailed survey.

The recce survey is essential to collect the first-hand account of various important field data required for the transmission line survey.

If the center line of the transmission line is not defined on the preliminary map, then it is done during the recce survey.

During recce survey, the type of instrument for the survey is decided and the methodology for undertaking the survey is concluded. The next step is to undertake the detailed survey.

1.8.2 Detailed Survey

The objective of carrying out detailed survey is to prepare longitudinal and cross section profile along the approved alignment and to prepare the route plan showing details of deviation angles, features coming within the right-of-way. The word 'features' here means both natural and man-made structures on the ROW – such as vegetation, types of soil, buildings, land utilities, fences and boundaries, roads, land marks and so on.

A detail survey is undertaken to determine and locate the features and defined the transmission line alignment on a parcel of land. The procedure are namely: setting out of Angle point, clearing, pillaring, traversing, detailing, levelling and plotting.

(a) Education/Sensitization and Reconnaissance

The objective of this exercise was to ensure that the Local Chiefs, District Chief Executives (DCEs), Assemblymen, and all Local people within the project area are aware of the project. This process starts during the selection of the 'ROW' (Line Route Study) and continued throughout the project. Letters of introduction is sent to the affected regional offices to all the major stakeholders.

(b) Setting Out of Angle Points

Angle points are extracted from the preliminary line route map that show the proposed transmission line alignment. Hand held Geographic Positional System (GPS) is used to help you navigate to the area. A static GPS is then used to set the angle points to the required accuracy. The ROW is also set out at right angle to the line.

The number of angles shall be minimized. Angles should be placed preferably on level ground at relatively high elevation; angles should not be placed on slopes or in places that are at lower elevations in comparison with the profile on the two sides.

The angle points shall be selected appropriately and pegged, by keeping in mind that, obviously, in each angle point a tower must be located. Angle points should be visible from one to the next; in case there are obstacles in-between, intermediate stakes should be placed.

(c) Clearing

The line is then cleared from section to section. That is, from one angle point to another angle point to make way for pillaring, levelling and GPS observation. This clearing is done on the center line to enable the collection of points of elevation.

(d) Pillaring

Following the setting out and clearing exercise, Type 'B' (9"x9"27") (With 18'' buried in the ground) reference pillars are built along the cleared lines at angle points and type C pillars as intermediary to help in the property enumeration and also to enable effective checking and vetting of the surveys and drawings.

Inter-visibility of pillars should be maintained at all times.

A uniform interval not exceeding 500 meters shall be maintained between adjoining pillars except in the case of a significant terrain slope, which may hinder intervisibility between pillars. Pillars can also be built to define the 'ROW', on either side of the pillars built on the main route line. A typical concrete pillars are numbered as shown in the diagram below.

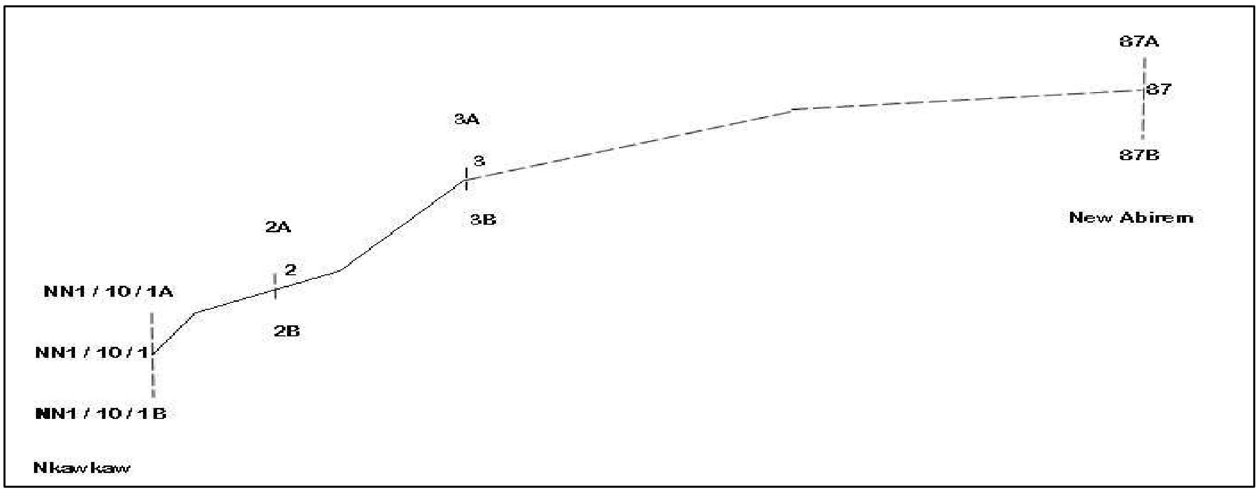


Figure 1-5. Pillaring profile.

(e) Traversing

Traversing is then carried out over the pillars on the line route to measure the distances between them, their heights and included angles, using static GPS Receiver units. By this measurement, the X andY, coordinates of all the reference pillars are obtained.

(f) Detailing

Details of landmarks such as footpaths, tracks, roads, rivers, farm edges, streams, hills, valleys, roads/lanes, buildings, water bodies and other visible notable features, which cross the route line, are also picked. Physical features along the route line and within the corridor are picked as well by both radiation and offset methods. This can be done using Total station to pick corners of both natural and manmade features.

The visual nature of the ground shall be noted whether pasture, woodlands, arable, etc, with special reference to such items as marshy, soft ground or rock and other relevant information such as soil instability.

(g) Levelling

GPS and Total stations are used to pick spot height at 25m intervals along the route line. Shorter level line intervals are adopted when drastic change in the terrain formation is encountered so as to depict the nature of the ground level.

Cross sectional spot heights is taken at right angles to either side of the main route line where the slope is more than 5%. Spot heights of landmarks such as footpaths, tracks, roads, rivers, farm edges, streams, hills, valleys and other notable features, which cross the route line, are also picked.

Ordinance datum shall be the basis for all levels.

(h) Computation/Preparation of CAD Drawings

All the data collected from the field survey is then processed using Excel spreadsheet to obtain an ASCII file (X, Y, Z Coordinates) of the proposed power line route and other pillars. Bearings and distances of traversed legs are also obtained in Excel Spreadsheet.

The ASCII filecan then be imported to LISCAD Plus software to undertake preliminary drawings. The preliminary drawings can be translated to a DXF format and sent to AUTOCAD for preparation of the final profiles and plan drawings.

Plans of right-of-way (ROW) and longitudinal profiles of the route line are generated.

The plan and profile drawings are prepared in accordance with specifications and in the following scale:

Plan = 1:5000

Horizontal Profile = 1:5000

Vertical Profile = 1:500

The following details shall be shown on the profile sheet for the crossing of power lines:

- Voltage and type of construction.
- Ground level at point of crossing.
- Height of the top conductor at point of crossing.

- Distances from crossing point to supporting structures.
- Angle of crossing.
- Temperature at the time the levels were taken.
- Pipelines

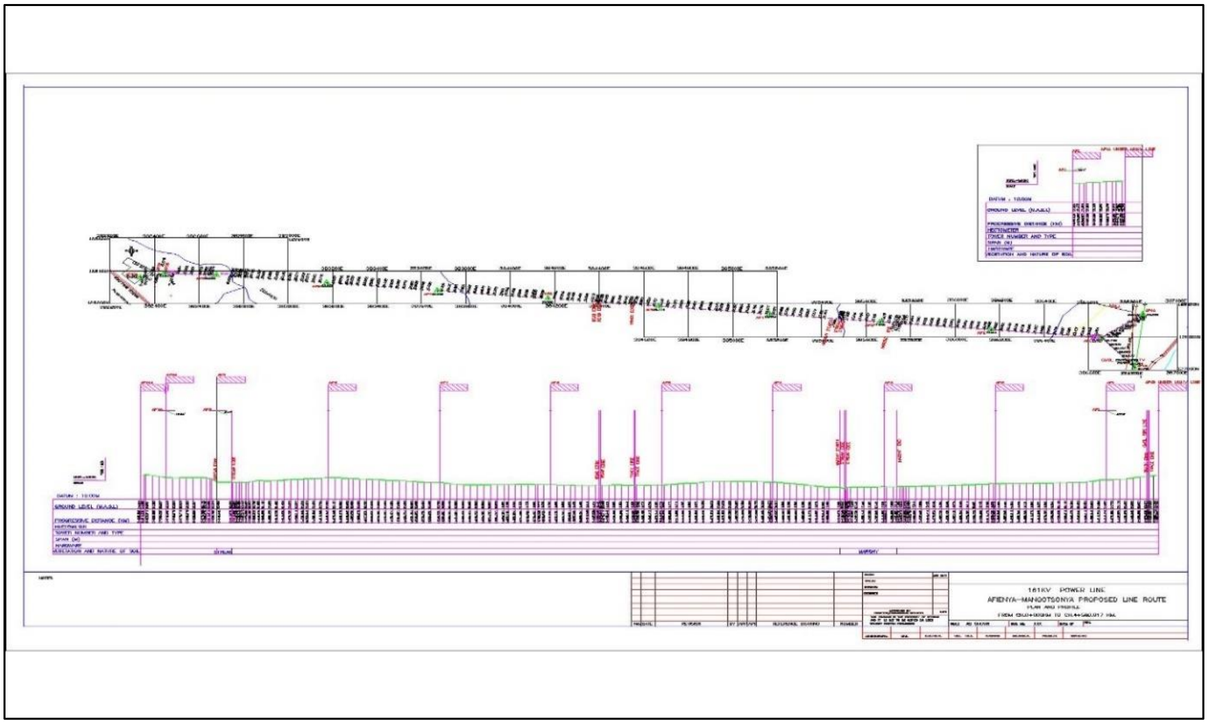


Figure 1-6. Plan and profile drawing

1.9 Transmission Line Tower Spotting

Tower Spotting is a process that allows you to select tower type, tower height and tower location of transmission line on plan & profile drawing.

The efficient location of structures on the profile is an important component of line design. Structures of appropriate height and strength must be located to provide adequate conductor ground clearance and minimum cost. In the past, most tower spotting has been done manually, using templates, but several computer programs have been available for a number of years for the same purpose.

The process of tower spotting can be divided into four

- Calculation of sag and tension of conductor, ground wire/OPGW as per design criteria

- Preparation of sag template
- Application of sag template to decide on optimal location of tower position or using computer aided software in determining tower location on the profile drawing.
- Deciding the tower type and preparation of tower schedule.

1.9.1 Calculation of Sag and Tension

In undertaking sag and tension calculations, it is important to know about the span length. The span length is the distance between two adjacent towers. There are different types of span and it is determined by various factors such as ground clearance, voltage, topography, type of conductor etc. The three (3) types of span which requires definition are wind span, weight span and ruling span.

The conductor forms a catenary when it links to adjacent tower. The dip from the lowest point on the line joining the two adjacent tower support is called the sag. This sag is inversely proportional to the tension in the conductor at the null point.

1.9.2 Preparation of Sag Template

A Sag Template help in determining the position of towers on the profile based on certain factors such as wind loads on tower, clearance and other design criteria. It is specific for the particular line voltage, the conductor used and the applicable design conditions.

It consists of a set of parabolic curves drawn on a transparent celluloid or acrylic clear sheet duly cut in over the maximum conductor sag curve to allow the conductor curve to be drawn and the lowest points of the conductor sag to be marked on the profile when the profile is placed underneath it.

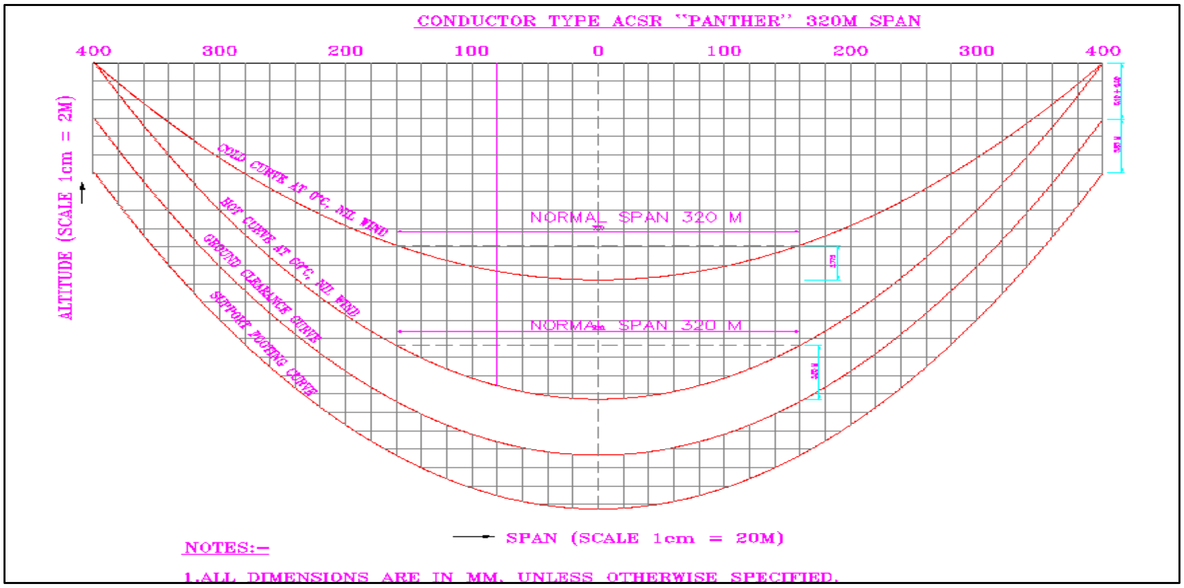


Figure 1-7. Sag template use for tower spotting.

The design and preparation of sag template will be treated with sag and tension calculation.

1.9.3 Application of Sag Template / Deciding Tower Type and Tower Schedule

The sag template is used to spot the tower location my moving it horizontally while ensuring that the vertical axis is held vertical. It is also done using computer aided software. When the position of the tower have been spotted on the profile, the tower type is also decided based on weight span, angle of the line of deviation etc.

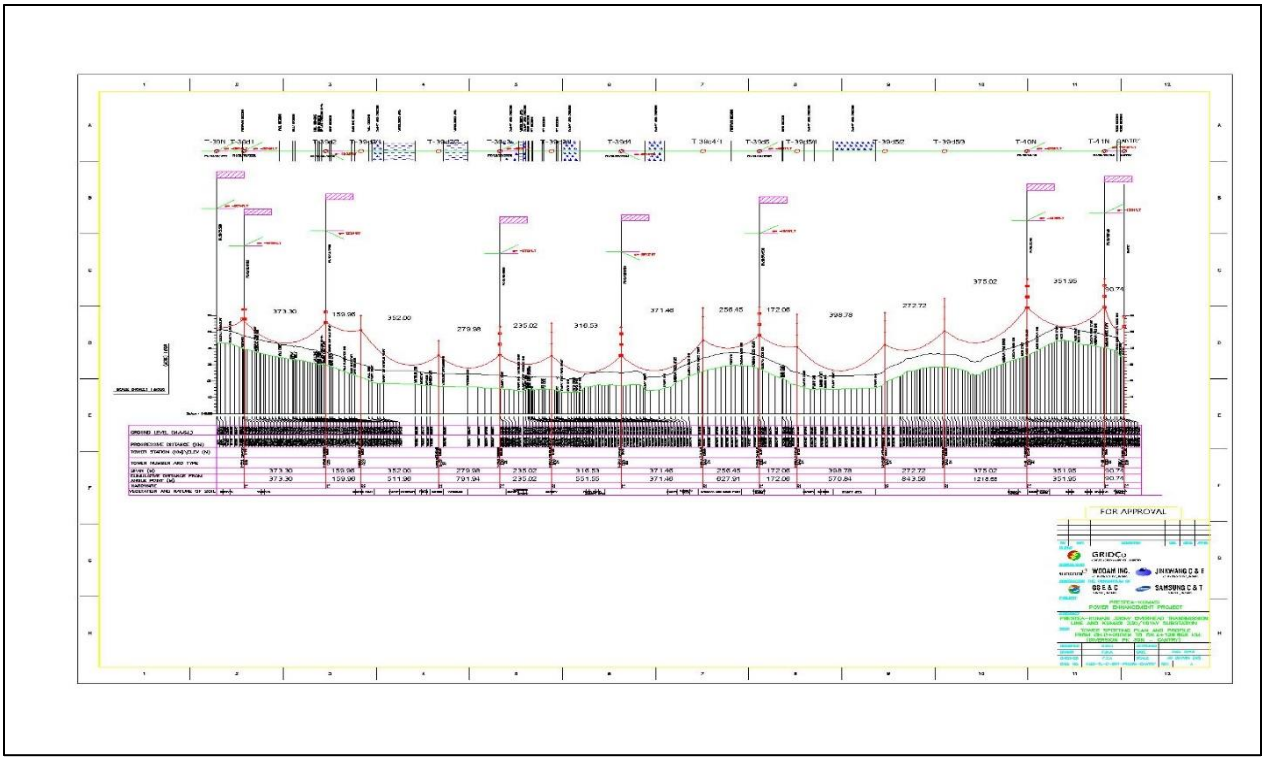


Figure 1-8. Tower spotting on a profile sheet.

Now with the tower located on the profile sheet and the tower schedule prepared, it is time to undertake check survey or setting out.

1.10 Check Survey or Setting Out

This is done to;

- Confirm the works carried out during the detailed survey
- Locate, mark and peg out the position of the tower location on the ground corresponding to the tower spotting on the profile drawing.

1.10.1 Confirm and Check Alignment

A survey is conducted using a total station or a GPS to confirm and check the alignment as shown on the plan and profile drawing. By traversing on the transmission line alignment, the coordinates are compared with the original coordinates from the detailed survey to ensure that there is no shift in the alignment as define on the profile sheet.

1.10.2 Location and Setting Out

FHere, all angle points or angle towers are identified and set out on the ground using a GPS or a total station. Intermediate towers locations are also set out within each section. So basically, setting out is the translation of the plan and profile drawings from the map form to the ground and marking and pegging with metal or wooden pegs. By defining all the tower locations on the ground, construction of the transmission line can begin.

M02 – CONSTRUCTION

2.1 Objectives

At the end of this module participants should be able to:

- Identify whole process for transmission line construction
- Understand detailed procedure and considerations in each phase
- Design and construct transmission line effectively and safely

2.2 Introduction

After selection of transmission line right-of-way (ROW) and detailed survey, the next step is to construct real transmission line. As a transmission line engineer, it is important to understand the whole process of transmission line construction and we should know the key points to be considered in each detail process such as tower foundations, tower erection, conductor stringing to ensure high quality of the facilities because construction part is directly related to the stability and reliability of the power gird.

The Constructor shall maintain the following Quality Assurance records at Site (as a minimum requirement) which can be reviewed by the Project Manager at any time:

• Files with verification forms and test results for the materials used for the Works. The various steps of compulsory inspection defined for each element of work, shall be submitted to the Project Manager for approval.

• Non-conformance report (NCR) report files: These reports will be kept current until satisfactory corrective measures have been implemented. A periodic review of NCR reports shall be performed with the Project Manager to appraise the degree of quality of the work performed by the Contractor. The Constructor shall keep a rigorous follow-up of all NCR reports.

• "As-built" drawings: the Constructor shall keep at Site an updated, "as-built", marked-up copy of each item, available for inspection by the Project Manager. Any substantial deviation from the original construction drawings shall be documented by generating an NCR for which the Constructor shall be asked to provide explanation and justification.

• The marked-up drawings will then be used by the Constructor to prepare the final "as-built" drawings that will be handed to the Project Manager on completion.

- The resident Constructor's representative shall be responsible for the implementation of the Quality Assurance program at site and for keeping the corresponding records.
- At the end of the Works, the Constructor shall submit all Quality Control documentations to the Project Manager.

2.3 Construction Preparation

2.3.1 Profile Survey

A preliminary line route survey, with topographic instruments in the field, is usually performed by the Engineer.

The Contractor is required:

(i) To check the preliminary line route survey and related map provided by the Employer and make any amendment, additional and detailed line route, plan & profile survey and consequential tower pegging and spotting/plotting that might be necessary for the construction of the line in keeping with the best Engineering practice. Any justified change shall have to be authorized in writing by the Employer.

(ii) To check the ground elevations at the tower location and at the points of minimum clearance of conductors to ground.

(iii) To check all the tower-to-tower distances.

(iv) To produce and update the line profile and route map up to the date of takeover of the line by the Employer.

(To be responsible for observance of all specified clearances and of tower capabilities.

Figure 2-1. Detail survey and soil density test (330kV Prestea-Kumasi Line)

2.3.2 Route and Access Clearing

Clearing the line route of all tall trees and scrub shall be carried out to a distance of 15m on either side of the transmission line centerline in the case of 161kV, and 20m in case of 330kV. Trees and bushes shall be cut down to a height of not more than 1.25m above ground level. In addition, tall trees outside the cleared area, of such height that they could fall within 2m of conductors shall be felled by the Contractor.

Figure 2-2 Clearing of Right-of-Way (Tumu-Han-Wa Line)

To prevent regrowth, the tree stumps shall be chemically treated. The Contractor shall grub up tree stumps and roots from this track and leave a graded way to permit the transit of Land rover, Unimog, or similar four-wheeled drive light vehicles for patrolling and maintenance by the Employer.

Figure 2-3. Felling of trees and construction of access track (Tumu-Han-Wa Line)

The Contractor shall clear a 3.5m wide agreed construction access track from public roads, of all trees, stumps, scrub and vegetation.

Figure 2-4. Clearing of access track (Tumu-Han-Wa Line)

2.3.3 Final tower location

The Contractor shall determine the final location of each tower, survey the tower site, select the proper leg extensions necessary to provide tower height indicated in the plotting and construction schedule, and select the type of foundation to be installed. The contractor shall also be responsible for determining the type, location and height of towers required to effect safe crossing either above or below any two or more existing or proposed high voltage transmission lines.

Figure 2-5. Final tower location (Tumu-Han-Wa Line)

After the Contractor has selected the final tower locations and determined the legs and foundations required, he shall submit this information in a table form to the Employer in writing so that the Employer can approve it in writing. The Contractor shall notify the Employer when the tower site is to be inspected so that the Employer may attend the site inspection if he so desires.

2.3.4 Clearing of Tower Sites

At tower sites, all trees, brush or other vegetation within an area equal to the dimensions of the tower base between legs plus 2 m on each side shall be cleared by the Contractor as close to the ground as possible. Stumps in the tower site area shall not project more than 10 cm above ground level.

Figure 2-6 Clearing of tower location (Kumasi-Obuasi Line)

2.4 Foundation

2.4.1 Foundation Design

The foundation types, for each class of soil, shall conform to the Drawing. The normal type of foundation shall consist of separate footings of ordinary or reinforced concrete. The foundation shall be pad and chimney (spread type). Tower foundations are designed to carry the ultimate loads derived from the tower loading in line with the basic soil classification and design parameters.

Figure 2-7. Setting out for tower foundations (Tumu-Han-Wa Line)

Plan-profile drawing shall be checked by eye to see whether it matches the actual terrain at particular tower sites, and check measurements shall be made for elevations and distances if necessary. If an error is observed, a new plan-profile drawing shall be developed for that section and then the location of the error shall be determined.

As a result of tower pegging made in accordance with the above instructions, the actual location of the tower shall not be more than:

- 0.50 m forward or backward in line alignment
- 0.10 m right or left from the line alignment as compared with the location indicated on the plan-profile drawing. During pegging, if there is an important reason to shift the tower location in the line alignment more than 0.50 m, the Employer shall be informed of the reason for and the magnitude of the shift.

Figure 2-8.Excavation for tower foundations (Tumu-Han-Wa Line)

2.4.2 Reinforcing Steel

Steel bars for normal reinforced concrete shall be mild steel (Standard Steel).

Reinforcement drawings made to show bar placement details and bar bending details, including bar lists and bending schedules, will be approved by the Engineer.

Before the reinforcing bars are placed, the surfaces of the bars and the surfaces of any metal bar supports shall be cleaned of heavy, flaky rust, loose mill scale, dirt, grease or other foreign substances.

Figure 2-9. Tower foundation reinforcement bars (Tumu-Han-Wa Line)

2.4.3 Stub Angles

The difference in elevation between two adjacent legs shall be maintained within the limit of 0.5 cm while between two diagonal legs the difference shall be less than 1.0 cm.

The stubs for foundations shall be carefully adjusted to a template which, if approved, may be the bottom section of the tower itself, and shall be held in the correct position by the template while the concreting and backfilling is placed.

Templates for concrete foundations shall not be struck until at least 24 hours following the pouring of the concrete or until backfilling has been completed.

The spacing, rake and levels of stubs after the templates have been struck, shall be such as to ensure the correct alignment of the towers without forcing members during the erection.

Figure 2-10. Stubs setting with pipe and template (Tumu-Han-Wa Line)

2.4.4 Concrete Pouring

No concrete shall be placed until all formwork, installation of parts to be embedded, and preparation of surfaces involved in the placing have been approved. No concrete shall be placed in water except with the written permission of the Engineer and the method of depositing the concrete shall be prescribed by the Engineer.

Concrete shall not be placed in running water and shall not be subjected to the action of running water until after the concrete has hardened to the satisfaction of the Engineer.

Concrete shall be placed only in the presence of a duly authorized representative of the Engineer. Concrete placement will not be permitted when, in the opinion of the Engineer, weather conditions or other pertinent factors prevent proper placement and consolidation.

Any concrete retained in the mixer so long as to require additional water to permit satisfactory placing shall be wasted. Re-tempering of concrete will not be permitted. Adding dry cement to reduce the slump will be allowed only when approved by the Engineer.

All surfaces of forms and embedded materials that have become encrusted with dried mortar or grout from concrete previously placed, mud or other foreign material shall be cleaned of all such refuse before the surrounding or adjacent concrete is placed.


Figure 2-11. Stub sett and formwork fixed for concreting (Tumu-Han-Wa Line)

The method and equipment used for transporting concrete from the place of mixing to the work shall be such that concrete having the required composition and consistency will be delivered to its final position in the foundation without objectionable segregation or loss of slump. Concrete shall be consolidated to the maximum practical density, without segregation, by vibration or puddling so that it is free from pockets of coarse aggregate and closes against all surfaces and embedded materials. Care shall be exercised to avoid contamination of the concrete through careless use of vibrators or puddling tools.

Figure 2-12. Tower foundations cast (Tumu-Han-Wa Line)

Concrete shall be deposited continuously and as rapidly as possible until the unit being poured is complete in order to form a monolithic foundation.

2.4.5 Backfilling around foundations

Backfill around foundations shall be carefully placed, using the better materials of excavation near the footings. All backfill around footings, spread foundations, etc, shall be compacted in 30-cm layers by means of mechanical or hand tampers.

When excavated material becomes so wet that, in the opinion of the Engineer, it is not suitable for backfill, the Contractor shall at his expense spread and aerate the material until the proper moisture content is attained, at which time the material shall be used as backfill around tower foundations.

The degree of compaction to be attained for all backfill shall be the equivalent density of adjacent undisturbed earth. Small rocks and rock fragments with a greater dimension less than 15 cm may be used in the backfill provided they are interspersed in the soil backfill and do not contact the foundation. The total volume of the rock fragments shall not exceed 30 percent of the total volume of the foundation backfill.

Selected borrow shall be used as backfill material when the excavated material has been deemed unsuitable by the Engineer.

Figure 2-13. Backfilling of tower foundations (Tumu-Han-Wa Line)

2.4.6 Structure Earthing

The Contractor shall furnish and install all the earthing equipment (plates, rods, wires, strips, etc) in accordance with the Specifications.

Approved tests shall be carried out to determine the earthing resistance after installation of foundations, basic earthing and tower erection. Shieldwire must be absent or insulated during test. Additional earthing shall be installed where required to reduce the tower footing resistance to a maximum of 10 ohms in the case of 161kV and 12 ohms in case of 330kV as approved by the Engineer/Employer.

In exceptional locations of rocky soil with very high resistivity, a maximum tower footing resistance of 20 ohms will be acceptable, subject to the approval of the Engineer for each specific tower.

All the results must be submitted to the Engineer for approval.

Figure 2-14. Laying of counterpoise & Tower footing resistance measurement

Resistance measurements shall be made after backfilling and under normal soil conditions. No chlorides or conducting salts will be permitted. A written report on the structure earthing situation shall be submitted weekly to the Employer.

It shall include, in addition to resistance value, the date of measurement and the soil conditions (reported as wet, normal or dry).

2.5 Tower Erection

2.5.1 Tower Ladder Bolts

Each tower shall be provided with ladder bolts of an approved type on one leg only and spaced on alternative flanges at 375 mm starting at a level 3.0 m above ground and continuing up to 1.0 m below the shieldwire attachment point.

Between ground level and the 3.0-m level, ladder bolt holes shall be provided.

For each tower the Contractor shall furnish two (2) Danger/Number signs, one (1) circuit identification plate and three (3) phase plates (one each of red, yellow and blue).

Aerial number sign plates (2 per tower) shall be furnished in the quantity specified

2.5.2 Anti-climbing Devices

The towers shall be provided with an approved anti-climbing device at height specified by the Engineer/Employer.

2.5.3 Tower erection method

2.5.3.1 Type of Tower Erection

(a) Derrick Method

Figure 2-15. Derrick (Ginpole) tower erection (Tumu-Han-Wa Line)

Merits are as follows;

- Equipment is simple, extra wire controlling is not required.
- Since supporting point is fixed on tower, stability is ensured.
- It is easy to transport equipment, therefore it is a useful method in all areas.

Demerits are as follows;

- In case of large tower erection, it is hard to apply.
- There is a weight limit.
- Since all work is conducted with man power, work efficiency and safety is low.

(b) Moveable Crane Method

Figure 2-16 Moveable crane method of erection (Tumu-Han-Wa Line)

Merits are as follows;

- Work safety is high
- Work efficiency and movability is high
- Good for flat area

Demerits are as follows;

- Approach road is required
- ointly used with Derrick method for high tower

(c) Tower Crane Method

Figure 2-17. Tower crane method

Merits are as follows;

- Easy control
- Easy to adjust construction terms
- Good for large tower in mountain area

Demerits are as follows;

- The amount of device to transport is large
- Not economical for small tower

(d) Helicopter Method

Figure 2-18. Helicopter method

Merits are as follows;

- Construction terms are greatly reduced
- Environmentally- friendly Method

Demerits are as follows;

- Enormous influence by weather condition
- Not economical
- Tower design should be suitable for helicopter method

2.5.3.2 Other Considerations

The proposed erection method for the tower, e.g. assembly on ground, then lifting by tilting, or erection in stages, or any other method.

Whichever the method of erection, it is imperative:

- to avoid excessive straining of the metal; this is particularly important in the case of tower which are tilted (turn-points, attaching points of cables, etc);
- to brace the legs so that they remain correctly placed;
- to avoid damaging the galvanization.

For the tower assembly, bolts in a vertical position shall be fitted with the head pointing upward. Bolts in horizontal position shall be fitted with the head pointing inside the structure.

Field erection of all structural steel shall be by bolting. Anti-theft fasteners shall be provided on all transmission line towers from the ground up to a height of 8m or as specified by the Engineer. No steel shall be erected on the foundations until at least 7 days after placing of final concrete in the foundations. The Contractor shall ascertain that all backfill is compacted to its approved level before placing or erecting the towers on the foundations.

The respective tightening torque for galvanized steel bolts to be used is as follows:

Bolt Size (mm)	Tightening Torque (Nm)
M 12	50 ± 10
M 14	80 ± 10
M 16	120 ± 20
M 20	200 ± 20
M 24	280 ± 30

The tightening of the joint bolts in a single structure shall be done with a torque wrench. After the assembler has got acquainted with the tightening torque the work can continue with an ordinary wrench. However, the proper tightness of bolts shall be checked with a torque wrench.

Figure 2-19. Tower revision

Figure 2-20.Torque wrench

2.5.4 Final Tightening of Bolts

The final tightening of all bolts shall be carefully and systematically carried out by a special crew not later than a few days after erection of towers. This operation includes also the punching of threads of all bolts (at 3 points) to prevent loosening or theft. In addition to punching the bolts the entire line shall have anti-theft fasteners on all the bolts up to the height approved by the Engineer.

Figure 2-21. Anti-theft bolts & Point punching of bolts

(Kpando – Kadjebi Transmission Project)

2.5.5 Line nomenclature

For each tower the Constructor shall furnish two (2) Danger/Number signs, one (1) circuit identification plate and three (3) phase plates (one each of red, yellow and blue). Aerial number sign plates (2 per tower) shall be furnished in the quantity specified By the Engineer/employer. The size and characteristics shall conform to the details illustrated on the Drawings. All signs shall be completed with mounting accessories such as bolts, lock washers, etc. All plates shall be of adequate thickness to ensure no bending of plates can take place and no cracking of surface colouring can occur. Damaged, chipped or cracked plates and surface colouring will not be accepted.

Figure 2-22. Transmission line nomenclature

2.6 Conductor stringing and connecting

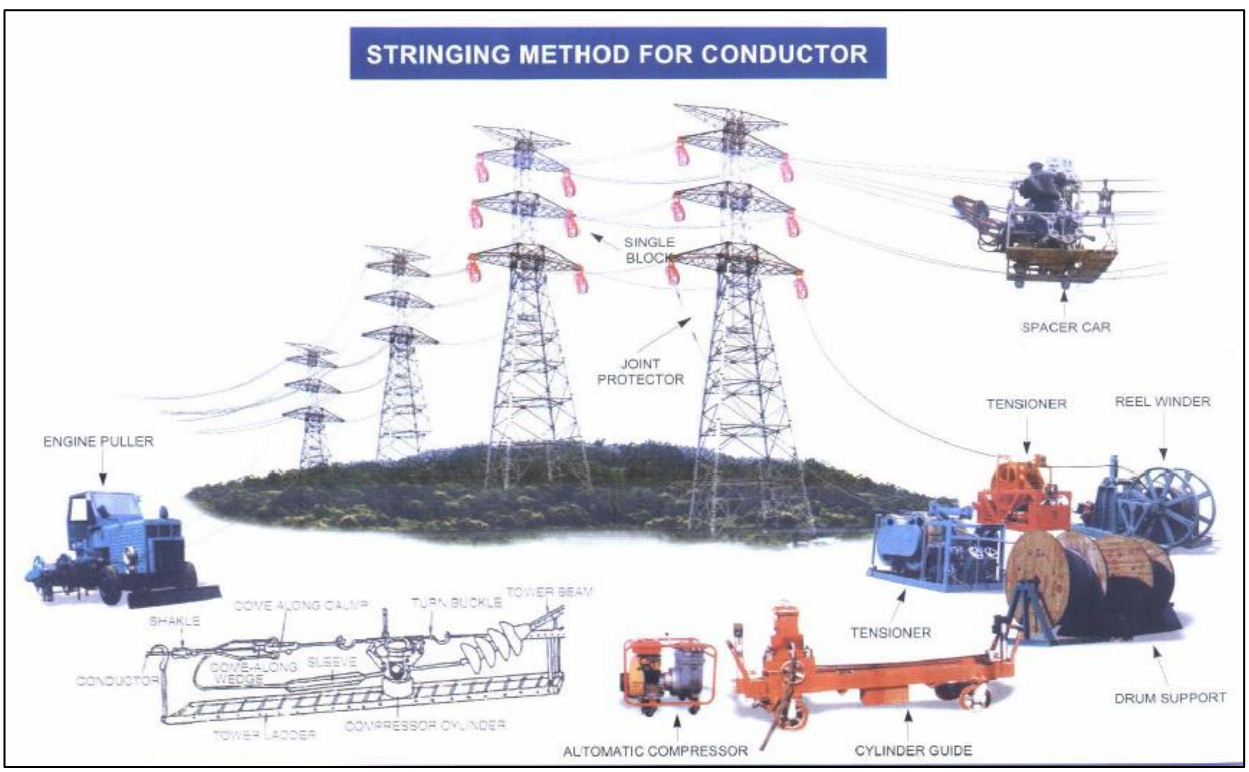


Figure 2-23. Stringing method for conductor

2.6.1 Erection of conductors, insulators, and fittings for the stringing.

Conductor shall be strung by the controlled tension method. Any procedure used during the stringing operations which will scratch, groove, kink, mar, twist or otherwise damage the conductor will not be permitted. If the conductors are damaged in the Contractor's operations, he shall replace the damaged sections at no expense to the Engineer or Owner and be liable for the cost of the conductor so damaged. Sections of the conductor damaged by the application of gripping attachments shall be removed before the conductors are sagged in place.

Figure 2-24. Steel pilot wire drum mounted on winch Aboadze-Prestea 330kV line

Figure 2-25. Laying of steel pilot wires on Bolgatanga-Navrongo 161kV line

In general, the equipment shall meet the following requirements.

- The Conductor tensioner shall be of the double bullwheel type with an adequate bottom of groove diameter for each bullwheel and shall have a minimum capacity of five turns of the conductor over the bullwheels. The grooves shall be lined with neoprene or other approved liner. The minimum thickness of the liner shall be 6 mm. The heat from the brakes shall not be transmitted to the conductor. The conductor reels shall be stationary with provision for light braking to prevent overrunning of the reels.
- In the case of twin-bundle conductors, the stringing blocks shall consist of three independently rotating sheaves mounted in a common frame. They shall be equipped with high quality ball or roller bearings with adequate provision for lubrication. The two outer conductor sheaves shall have their grooves lined with neoprene or other approved material. Conductor sheave diameter at the bottom of the groove shall be adequately sized for the overall diameter of conductors.
- The radius of the bottom of the groove shall be at least 12 mm and not more than 18 mm and the sides of the groove shall flare at least 15 degrees from the vertical. The center pulling line sheave shall be designed so that the pulling line will remain in its groove during the stringing operation.

Figure2-26. Tensioner for conductor **Figure 2-27. Tensioner for OPGW**

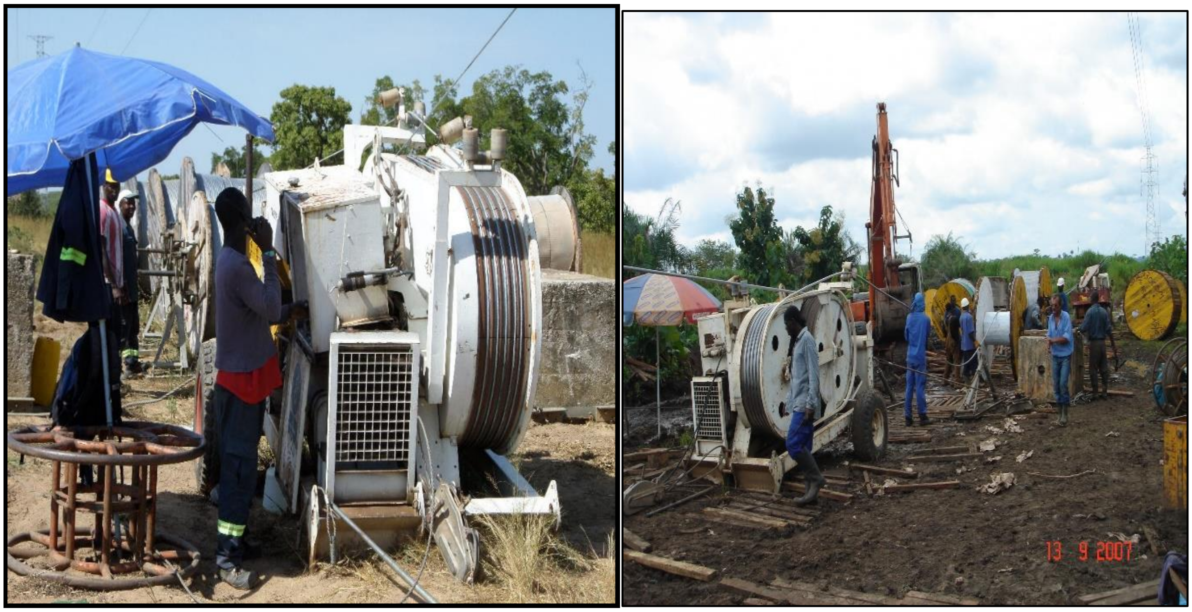


Figure 2-28. Tensioner station setup

The conductor shall be pulled directly into the tensioner and into the stringing blocks without touching the ground. The conductor shall never be allowed to touch the ground.

2.6.2 Conductor Running

For the whole length of the lines, the Constructor shall employ an approved method of tension stringing which will not cause damage to the conductors, and at no time allows the conductor to touch the ground or any obstacle such as walls, fences, and buildings, except when the conductors are at rest.

Approved means shall be provided to prevent any damage to the conductors where these are run over temporary supports or where it is necessary, in the opinion of the Engineer, for the conductor to be laid on the ground.

In order to prevent theft and vandalism, conductor which has been run out and not finally tensioned must not be left overnight either on the ground or within 4.5 m above ground level.

2.6.3 Running Out Blocks

Conductor running out blocks shall be free-running and of approved materials and dimensions. The running out blocks shall have an electrical conducting path between the conductor and the tower.

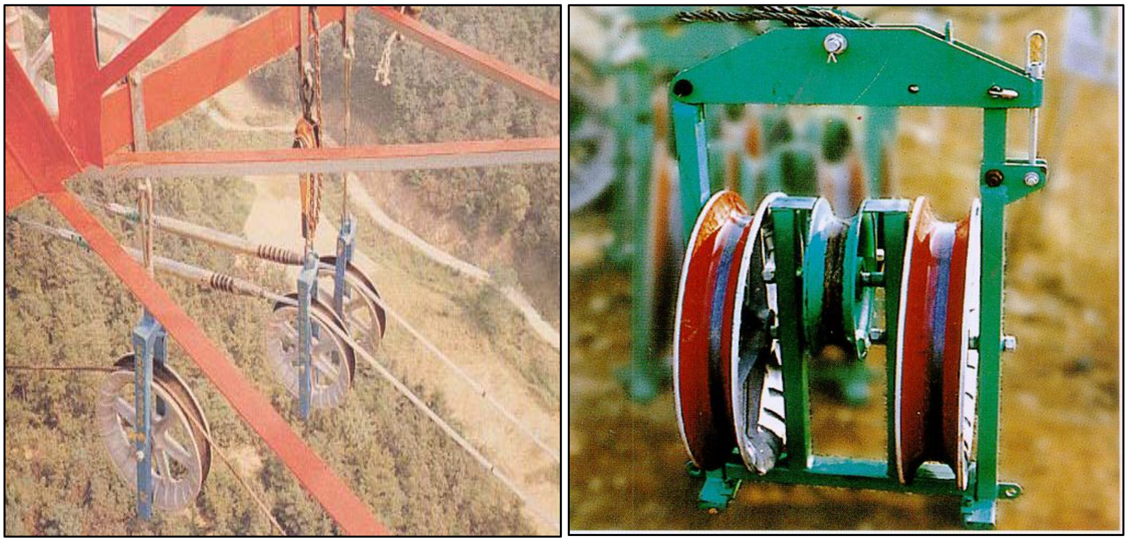


Figure 2-29. Running blocks and Conductor in running out block

2.6.4 Crossings

The Contractor shall make special arrangements, as the Engineer may approve, where power lines are to be crossed and also for running out and sagging the conductors where the route crosses buildings, gardens, orchards or other ground over which erection cannot be carried out in the normal manner. No extra payment will be made for such special precautions and arrangements.

Figure 2-30. Scaffolds for crossing obstacles

2.6.5 Jointing Record

The Contractor shall keep a record of each joint, tension clamp, etc, giving the location of the fittings, the date of assembly of the conductor, and the name of the lineman responsible for the assembly.

Figure 2-31. Jointing of steel core of ACSR conductor & Jointing of aluminum portion

2.6.6 Sagging and clamping

No joint will be permitted within 20 m of a suspension clamp or within 50 m of a tension clamp and not more than one joint will be permitted in any one span.

After being pulled into the sheaves, the cable shall not be allowed to hang on the stringing block for more than 24 hours, before being pulled to the specified sag. The "temperature difference" method shall preferably be used for evaluating sag reductions for compensating stretch. The sags shall be checked for several spans in each sagging section by selecting one near each end and one in the center.

The instruments for measurement during sagging of conductors and shield wires are shown below.

Sag scope

Thermometer

Dynamometer

Figure 2-32. Instruments for measuring sag of conductors and shield wires.

Figure 2-33. Clamping of conductors in suspension

After being sagged, the conductor shall hang in the stringing blocks for at least two hours before being clipped in to permit the conductor tension to equalize. The total time which the cable is allowed to remain in the stringing block before being clipped in shall not exceed 96 hours.

2.6.7 Clearances

At the time of sagging, the Contractor shall make sure that the minimum clearances are obtained under the most unfavorable working conditions.

For clearances not especially specified the local laws and regulations shall apply.

Objectives Crossed	Clearances (m)
Normal ground	7m at 65 °C; 6m at 80 °C
Main roads	8.0
Secondary roads	7.5
Railways	9.0
Lines up to 161 kV	4.0
Lines up to 34.5 kV	2.5
Communications lines	3.5

Figure 2-36 Crimping of conductor strain sets

Figure 2-37 Clamping of conductors in suspension

The minimum clearance between the conductor and normal ground at the maximum final sag, +65^{0}C still air, has been assumed as 7 m. Higher clearances will be applied:

- at main road crossings: 8m
- at railway crossings: 9m

Figure 2-38. Clamping of conductors and OPGW in suspension

Figure 2-39. Strain/Tension assembly

M03 – INSPECTION & COMMISSIONING

3.1 Objectives

At the end of this module participants should be able to:

- Identify whole process for transmission line commissioning
- Understand each inspection and test item, its functions and procedures

3.2 Introduction

The purpose of this document is to identify generic requirements applicable to the testing & commissioning of new transmission Overhead Power Line systems associated with Ghana Grid Company's (GRIDCo) network infrastructure.

This procedure applies to all new overhead line installations that are to be connected to GRIDCo's network. The use of this procedure is for Accredited Service Providers, GRIDCo staff and accredited sub-contractors.

The purpose of undertaking overhead line testing is to prove system integrity after installation work is completed and before connection to the GRIDCo Network. The tests specified within this procedure are minimum requirements. Additional tests or amendments to testing requirements may vary depending upon project/site conditions. Testing requirements will be negotiated between GRIDCo & the Accredited Service provider after a project specific commissioning program has been submitted to GRIDCo by the Accredited Service Provider (ASP).

3.3 Key Terms & Definitions

Authorized Representative (AR) The AR may represent an ASP approved agent

Accredited Service provider (ASP) is a person or body accredited/approved by GRIDCo. The different categories of ASP include the following:

ASP3 means a level 3 service provider accredited to carry out design works.

ASP1 means a level 1 service provider accredited to carry out construction works.

Design Information Package (DIP).

Ghana Grid Company (GRIDCo).

Hazard Identification, Risk Assessment and Control (HIRAC).

Testing & Commissioning Plan (T&C Plan)

QCC means GRIDCo appointed Quality Control Coordinator.

3.4 Testing & Commissioning

All electricity works shall be designed to be safe for the electrical conditions likely to be experienced during service and the physical environment in which they will operate. GRIDCo needs to ensure that appropriate tests have been completed for compliance with the design & specifications before an installation is commissioned into service. This will require close cooperation between the accredited service provider's (ASP1's) construction authorized representative (AR) and GRIDCo.

GRIDCo will appoint a commissioning manager or Quality Control Coordinator (QCC) auditor as GRIDCo's representative for coordination purposes.

3.4.1 Tests

Before any tests are performed, GRIDCo and the Accredited Representative must agree on the procedures to be used for the tests and any modification to or deletion from this procedure.

GRIDCo's Quality Control Coordinator shall be notified a minimum of 10 working days prior to the commencement of any tests to be undertaken.

The Authorized Representative will be responsible for ensuring that the completed work is Quality Assurance checked and tested and all records and reports are forwarded to the Quality Control Coordinator promptly. GRIDCo's Quality Control Coordinator may be present to witness the testing procedures, and only with GRIDCo approval shall Authorized Representative proceed to test. Tests must be carried out in the presence of representatives nominated by the Authorized Representative and GRIDCo. The Authorized Representative must provide the results of tests to GRIDCo within a maximum time period specified by GRIDCo.

All test results shall be documented and submitted to GRIDCo including the following detail:

- Testing organization details.
- Date, time and location of test.
- Description of line tested.

- Description of test equipment used including calibration dates.
- Test procedure.
- Test results.

If tests indicate that corrective works are required to ensure line integrity the Authorized Representative must then:

- Undertake, at their cost, all rehabilitation, modification or remediation work required to the reasonable satisfaction of GRIDCo.
- Report back to GRIDCo in writing when all corrective work has been completed and renegotiate suitable program to recommence tests.

3.4.2 Test Equipment.

All test equipment and instrumentation used for testing shall have been calibrated by Accredited organization and have a current test sticker affixed. The Authorized Representative is responsible for ensuring that test equipment and instrumentation is traceable.

3.5 Commissioning

3.5.1 Testing & Commissioning Plan (T&C Plan)

Prior to energizing or commissioning any overhead line installation a detailed commissioning plan shall be prepared by the Authorized Service Provider and submitted to GRIDCo for approval.

The Testing & Commissioning Plan shall demonstrate to GRIDCo the planning by the Authorized Service Provider for the pre-commissioning activities and shall consolidate and reference the Quality Assurance process installation checks and tests, as well as the tests required before and after completion.

The commissioning plan must include:

- Single line diagram of final installed network.
- Detailed step by step procedure of the activities (checks & tests) with the sequence clearly documented.

- A proposed schedule.
- Supervisor and employees involved including their accreditation & contact details.
- A summary of pre commissioning checks & tests completed and results.
- Written confirmation that all works undertaken by the Accredited Service Provider for the installation meets the required standards and manufacturer's requirements for testing of product, plant, equipment and drawings/specification.
- Hazard Identification Risk Assessment & Control, and associated Safety Work Method Statement (SWMS) documentation.

3.5.2 Authority for Placing Major Electrical/Plant Equipment into operation

- The purpose of the procedure is to ensure that GRIDCo's Network Operations department receives written notification that all construction and pre-commissioning checks on major plant/equipment are complete and ready for service.
- Prior to final commissioning and energizing of the high voltage equipment, direct lines of communication must be established between the Accredited Service Provider's nominated person, for site commissioning and ongoing operations, and the designated GRIDCo Systems Operations Centre.
- The written notification shall be completed by the Accredited Service Provider and submitted to GRIDCo's QCC auditor for co-ordination with GRIDCo's system operations.

3.5.3 "As Installed" (As-Built) Detail

On completion of construction and prior to final commissioning of the overhead line installation the Accredited Service Provider shall provide the following "As Installed" detail to GRIDCo.

- Route plan including line schedule & profile.
- Structure earthing schedule including measured values.
- Details of other services crossings.
- Test reports and/or test certificates.
- Inspection reports.
- Any modified or additional drawings, information or instructions necessary for the satisfactory completion of the work.

3.5.4 Worksite Hazard Identification, Risk Assessment and Control (HIRAC)

Tests on overhead lines are potentially hazardous to both personnel undertaking the test and the general public in the vicinity.

A Worksite safety management plan shall be prepared for the project and activities, and will be implemented with an accompanying Hazard Identification, Risk Assessment and Control (HIRAC).

The Hazard Identification, Risk Assessment Control will be carried out, by the Accredited Service Provider's authorized person, to determine the precautions that need to be adopted. The Hazard Identification, Risk Assessment Control procedure & associated Safety Work Method Statement (SWMS) documentation are to be submitted to GRIDCo's Quality Control Coordinator for review prior to implementation.

3.6 Pre Commissioning

3.6.1 Quality Assurance Checks

During the installation a system of records shall be maintained which provides objective evidence that requirements have been met, including construction in accordance with applicable standards, construction drawings/plans and specifications.

All records shall be available for audit and review by GRIDCo during the installation. The records should provide full traceability of all quality characteristics and activities.

During construction activities Quality Assurance mechanisms such as check sheets, checklists, inspection & test plans (ITPs) shall be utilized for a GRIDCo representative to witness and sign off.

GRIDCo's Quality Control Coordinator may be present to witness the installation at hold points, as required by GRIDCo, and work shall not proceed past a hold point without GRIDCo consent.

3.6.2 Notice of Completion

On completion of construction works and prior to final commissioning the Authorized Representative is to submit a notice of completion to GRIDCo's Quality Control Coordinator. The completion notice is to include –

- T&C Plan.
- "As Installed" Plans and documentation.

A final inspection/audit will be carried out by GRIDCo's Quality Control Coordinator along with the Authorized Service Provider's Representative.

3.6.3 Final Inspection/Audit

The purpose of the final inspection/audit is to ensure the new asset is acceptable to GRIDCo for connection to GRIDCo's transmission network. A review will be undertaken of the following: Vegetation & Environmental Management, Construction Quality Assurance including visual inspection of works and sign off of non-conformance issues.

3.7 Pre Commissioning Tests

The purpose of pre commissioning tests are to confirm line integrity & compliance with the earthing, Environment Protection Regulation & protection studies carried out and approved for the project.

The required pre commissioning tests for transmission overhead lines are:

- Structure Earth Resistance Test.
- Phase Continuity Test
- Insulation Resistance Test.
- Earth Current Injection Test.
- OPGW Tests.

3.7.1 Structure Earth Resistance Test

After completion of structure installation but prior to the installation of any Over Head Earth Wire/OPGW, the electrical resistance of structure earthing shall be measured by the Authorized Service Provider. GRIDCo's Quality Control Coordinator or nominated representative may be present to witness tests. The results shall be supplied to GRIDCo's Quality Control Coordinator without delay for review.

The Authorized Service Provider may be directed by GRIDCo to install supplementary earthing where readings exceed the required value. The installation of supplementary earthing shall be in accordance with GRIDCo standards and shall be completed prior to the installation of OHEW/OPGW. The supplementary earthing shall be installed so as to comply with the specified electrical resistance of each structure to earth.

3.7.2 Phase Continuity Test

A phasing check shall be completed prior to commissioning to ensure that the phases are correctly aligned to synchronize with the network to which the line is to be connected.

3.7.3 Insulation Resistance Test

An insulation resistance check such as megger test, shall be completed prior to commissioning to ensure no inadvertent short circuits.

3.7.4 Earth Current Injection Test

For shielded lines, earth current injection tests shall be undertaken and the following measurements taken at each support structure

- Line – Earth Impedance.
- Step & Touch Potential.
- Earth Potential rise.
- Zero Sequence Impedance.

Recorded test measurements are to confirm compliance with the requirements of IEC and other relevant standards contained in the technical specifications.

Tests shall be performed after the substation earth mats at all ends of the line are fully installed and connected.

3.7.5 OPGW Tests

The testing of system components to identify the apparent performance of the optical fibers before and after the responsibility of the component has been transferred between independent parties is essential.

GRIDCo advocates that the stringing and splicing activities to be carried out by specialized accredited service providers. It is mandatory that the following testing procedures are implemented between each interface and progressively throughout the works to ensure the separate activities are adequately controlled.

The Authorized Representative is required to undertake the following tests –

- Drum Test - Upon receipt of OPGW from either the manufacturer or GRIDCo.
- Span Test - After OPGW stringing/installation.
- Splice Test - After OPGW splicing.
- Final Acceptance Test - After OPGW completion.

Each test result shall be uniquely identified for future reference and shall include a record of the environment at time of test and the person performing the test. The attenuation data from the series of tests shall be compared to ensure that there are no problems such as to allow the next step to commence. The manufacturer's factory test report for each drum of OPGW cable shall be made available upon request.

The consolidation and presentation to GRIDCo of all optical fiber measurements taken during the course of works shall be incorporated in the final installation report within the specified period of the final acceptance test.

3.7.5.1 OPGW Test Instruments

Either "mini" or "Full Featured" Optical Time Domain Reflectometer (OTDR) instruments, immune to polarisation noise and conforming to the Telcordia/Bellcore Standard GR-196-CORE "Generic Requirements for Optical Time Domain Reflectometer – Type Equipment", are to be used for all OTDR measurements.

The OTDR must be capable of storing the traces on an electronic medium (eg USB stick) for transportation/submission, allow retrieval and reading of traces. All traces are to be stored and submitted in a format compatible with OTDR emulation software specified by GRIDCo.

The OTDR testing is to be carried out at either 1310nm, 1550nm and/or 1625nm wavelengths. The 1625nm OTDR trace is primarily used to identify pressure points, macro bends and imperfections in cable installations. The OTDR operator must be experienced in the use of high performance OTDR's.

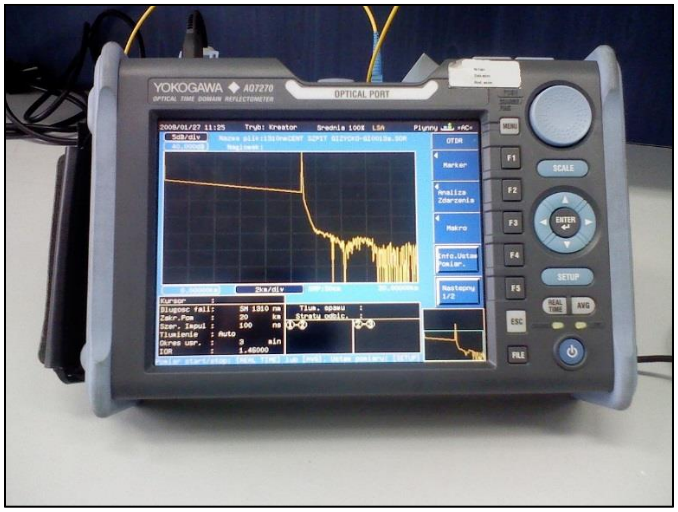


Figure 3-1. OTDR

3.7.5.2 OPGW Cable & Splice Testing Criteria

The AR shall provide fusion splices with an average attenuation below 0.1dB when measured at 1550nm. Any fusion splice with attenuation above 0.1dB shall be re-spliced and re-tested. The approved methodology comprises measuring in both directions, using an OTDR, the attenuation of each splice for all fibres. The average of the two readings for each fibre will be accepted as the splice attenuation for each fibre. In addition the end to end attenuation of each fibre in each direction shall be measured using a calibrated light source and light meter.

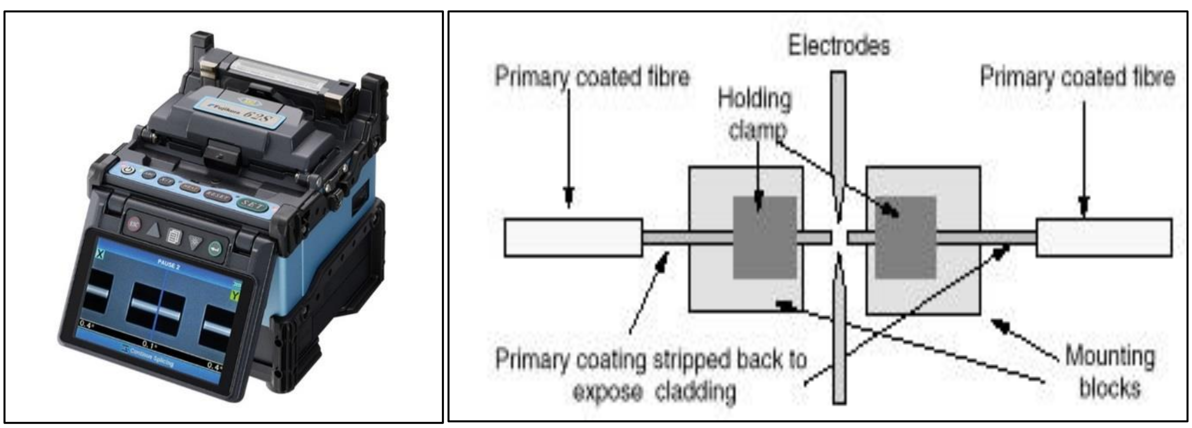


Figure 3-2. Optical fiber fusion splicing machine

All measurements shall be made with an accuracy of 0.01dB and shall not be made over sections greater than the capability of the OTDR in use.

Testing of unterminated fibres shall be performed by splicing temporary pigtails to the fibres or by using a Bare Fibre Adapter. A terminated fibre refers to fibres terminated with connectors on patch panels at an ODF and/or at equipment.

3.7.5.3 Drum Test

Upon receipt of the OPGW from either the AR's supplier or GRIDCo, the AR shall check the cable attenuation and continuity of each drum. The AR shall conduct a one way OTDR test for all optical fibres for all drums from the inside end. The inside end of the cable is accessible for one way

OTDR testing at the nominated wave lengths (1310, 1550 and/or1625nm), without removing the laggings.

Following testing the cable ends shall be resealed with a suitable heat shrink end cap to ensure against moisture or dirt ingress.

The AR shall give GRIDCo a minimum of 48hours notice before conducting these tests. If the OPGW is supplied by GRIDCo the Drum Test is to be carried out at GRIDCo store prior to transport to site.

Any problems or discrepancies encountered shall be immediately reported to GRIDCo. The AR shall provide GRIDCo with a report of test results within specified time of product issue.

3.7.5.4 Span Test

The span test is a two way OTDR test at the nominated wave lengths (1310, 1550 and/or 1625nm). The span test shall be conducted, by the AR, progressively as each drum is strung and clamped off. Any problems are required to be identified and rectified prior to splicing.

The same test equipment shall be used as for the Drum Test.

The AR shall test the strung OPGW only after all clipping-in is complete and in the presence of a GRIDCo nominated representative at a time to be mutually agreed upon. The Authorized Representative shall notify GRIDCo in advance of the tests proceeding.

3.7.5.5 Splice Test

The AR shall measure the attenuation, of each splice, in both directions at both 1310nm and 1550nm.

The AR shall submit to GRIDCo a Splice Testing Strategy. This strategy is to demonstrate how the AR intends to measure each splice in order to guarantee the average loss per splice was achieved throughout all the splices on the link.
The same test equipment shall be used as for the previous tests undertaken.

3.7.5.6 Final Acceptance Test

The Authorized Representative shall measure the end to end attenuation of each optical fibre. The same test equipment shall be used as for the previous tests undertaken.
The AR shall submit to GRIDCo a Fibre Testing Strategy to guarantee the average loss per splice was achieved throughout the fibre link.
The AR shall present to GRIDCo the following data per fibre –

- Attenuation figures for each splice in both directions.
- An OTDR trace for each splice in both directions.
- End to end attenuation figures in both directions.
- OTDR traces for each fibre in both directions.

3.8 Post Commissioning Tests

Upon placing the transmission line into service the following commissioning tests may be required:

- Radio Frequency Radiation Test.
- Thermal Scan under load·

These tests may be requested by GRIDCo to be carried out by the Accredited Service Provider at full cost to the Accredited Service Provider. If required these tests will be requested prior to the end of the construction warranty period.

3.8.1 Radio Frequency Radiation Test

Radio frequency radiation measurements are carried out to ensure that any interference is less than the values specified in AS 2344 “Limits of electromagnetic interference from overhead a.c. power lines and high voltage equipment installations in the frequency range 0.15to 1000MHz”.

Where interference exceeds these values, the sources of interference must be identified and corrective action taken before re-testing.

3. TRANSMISSION LINE OPERATION AND MAINTENANCE

Ghana Grid Company

M01 – OPERATION AND MAINTENANCE OVERVIEW

1.1 Objectives

At the end of this module participants should be able to:

- List the activities involved in Line maintenance
- State some inspection checklist when given a specific line maintenance activity
- Explain the need for various line maintenance activities.

1.2 Introduction

The transmission line operation and maintenance defines and outlines the program of planned maintenance and diagnostic activities required to effectively maintain transmission lines. Maintenance of a transmission line is a fundamental part of its function, a need that is heightened by its outdoors location. The goal of a maintenance program is to produce the required reliability at minimum cost. A comprehensive and complete preventive maintenance program is essential to ensure reliable transmission of power to delivery points and to ensure public safety. To be successful it is essential that all elements of routine maintenance programme be conscientiously completed to the required standard.

1.3 General

The guideline herein identifies the minimum level of preventive maintenance required for reliable transmission of power. These activities may be increased to achieve an improved level of reliability where deemed necessary or to prevent the uneconomic deterioration of transmission line equipment.

It is important that a common understanding be developed with respect to the total concept of staff activities which go into the maintenance of a secure transmission line network and the minimum staff strength required for this. This module establishes the required common understanding.

The activities described in this module are those related to running maintenance. These are normal checks and adjustments necessary to ensure continuing good performance. They can be subdivided into "routine maintenance" such as climbing maintenance and "diagnostic activities" such as patrols. Those minor items found on "routine maintenance" can usually be corrected at that time and reported. When certain defects are found repetitively that constitute a significant change in workload, they become "major maintenance" and should be reported and decisions made on a schedule to undertake corrective action, and budget allocated.

In certain cases critical situations are found which fall into a third category of activity, that of “emergency maintenance". Sustained line faults also constitute emergencies and may be categorized as "minor" such as hardware failure or insulator failure or "major" such as one or more "structure" failures.

In summary, maintenance of the transmission system constitutes:

- Preventive maintenance: routine and diagnostic
- Corrective maintenance (usually arising from No.1)
- Emergency maintenance.

1.4 How to establish a 10-year Maintenance Plan

The identifying and planning of cyclic activities on a long-term basis is important in providing for consistent maintenance of all transmission lines. For each line section a 10-year cycle has been chosen, at the end of which each structure has been critically inspected, maintained and necessary records kept. Since many of the activities fall into a 1 year pattern, this basis has been chosen for developing a master plan that identifies the lines and portions there of which are scheduled for a set of activities in specific years identified as year one to year ten.

1.4.1 The following guidelines are recommended for drawing up the ten-year plan for each Operational Area.

- Operational Areas will identify each line (or section of line) by voltage, type and number of structures, length, age, and history of major alterations and schedule them for maintenance over a ten-year cycle.
- To account for the initial 1-year cycle of climbing maintenance, it will be necessary to consider those lines which have come into service within the previous year, those which will come into service within the next year as well as those older lines for which major modifications have been or will be carried out in this same time frame.

- A chart with a ten-year capacity will be drawn and the recent and planned lines charted by their voltage class in the appropriate years, as mentioned in bullet 2 above.
- Distribute the balance of lines in a uniform workload basis giving consideration to those requiring early attention being placed in the first few years of the plan.

1.4.2 In developing each year's package, the following factors may be considered:

- A consistent annual mix of lines comprising of all transmission voltage levels within the Area.
- A mix of older and modern lines each year.
- A geographical distribution throughout the Area.
- Known problem lines or those not attended to recently might be placed in the earlier years of the program.
- Set up a filing system to relocation of various activities by year, either using map and colour coding or charts or listing of circuits and structure numbers; where personal computers are available this information will be stored on them.

When in place, the plan will require an annual review to incorporate new facilities and to make adjustments for major upgrading and revisions to lines.

1.5 Safety

Safety is a primary consideration to which all maintenance personnel devote their complete attention whenever they are climbing a tower or are in the immediate vicinity of a tower or at the substation. The elevation and potential electrical hazards associated with tower inspection, maintenance, and repair require adoption of extraordinary safety measures in order to protect the climbers from avoidable accidents.

Accidents involving high voltage transmission line work can result in fatal injuries or death caused by mechanical and electrical energy. The Company must be committed to the highest safety standards to prevent hazardous electrical exposures to workmen and very importantly mandates every lineman to accept personal responsibility for complying with the Company's Safety Policy.

1.5.1 Safety Policy

To create and maintain a working environment in which the level of risk to workmen and equipment are reasonable and acceptable.

- Management should continuously upgrade the Health and Safety standards and ensure that all workmen receive the necessary training, understand set standards and follow them.
- Management should create a climate in which positive attitudes towards the Health and Safety Programme can be established and advanced.

All maintenance personnel will make health & Safety a Way of Life

11.5.2 Safety Management

In accordance with this policy, there shall be: -

- A central safety committee under the chairmanship of the Chief Executive
- A Safety Management Division headed by a Manager
- Work Area Safety Committees chaired by Chairpersons nominated by Heads of Departments

The responsibility of the above committees are enshrined in the Company's Corporate Safety Handbook

11.5.3 Training

Managers and maintenance men are to be given adequate training in safe working practices. Supervisors are responsible for the training of personnel in safe working practices. Workmen employed at entry levels are to receive on-the-job technical training on operation and maintenance of the transmission lines and facilities and proper use and care of high voltage specialized tools.

1.5.4 Responsibilities

1.5.4.1 Supervisors are responsible for:

- Showing their concern for health and safety at work by commitment and example

- Making their subordinates aware of hazards involved in their task through their own training and experience
- Making sure that their subordinates adhere to GRIDCo Safety Rules, Protection Code, Operating Procedures, Directives, by regular inspection and auditing work practices at workplaces
- Ensuring that safety equipment, tools and clothing are available for use and are used as required and audited from time to time.

1.5.4.2 Employees have responsibility to the Company, themselves and others to:

- Be aware that the responsibility for health and safety is that of each and every crew member.
- Carry out their duties in safe manner
- Be familiar with the safety rules and protection code of the company.

1.6 Maintenance Scheduling

Transmission line maintenance scheduling is to determine the optimal time interval for outage of the lines due for maintenance within a yearly cycle (52 working week and 52 weekend time periods). System Operator needs to preserve transmission system adequacy at all times. Maintenance should be carried out during time periods in which its effect on the transmission network capacity margin is the least. Additionally, transmission line outage should not have significant impact on the functioning of the electricity market. Taking into account the following;

- Competitive environment (non-discriminatory approach of the System Operator)
- Goals of different market participants
- Conflicting sides (technical vs. economical)

1.6.1 Maintenance Plan (MP):

Maintenance Program Guideline – Investigative Activities							
No	Activity	No of Units Scheduled per Cycle	Scheduling	Normal direct Man-hours per Unit		Min Crew Size	
				Tech.	Assist	Tech.	Assist
1	Commissioning	100%	During construction	5-10 mhrs/tower	-	1	-
2	Aerial Patrol	69kV-100% 161kV-100% 225kV-100% 330kV-100%	1/year	0.02mhrs/km	-	1	-
3	Ground Patrol	100%	2/year	1.5-2.0mhrs/km	1.5-2.0mhrs/km	1	1
4	Insulator washing	As required	As required	2.15mhrs/tower	1.5mhrs/tower	3	2
5	tower grounding tests	As required	As required	0.45-1.0mhr/tower	0.45-1.0mhr/tower	1	1
6	Galvanization analysis	As required	As required	1mhr/tower	1mhr/tower	1	1
7	Corrosion survey	As required	As required	1mhr/tower	1mhr/tower	1	1
8	Thermovision Scan	100%	1/year	1mhr/3km	1.5mhr/km	2	0
9	Tower audit	10% of suspension 100% of tension towers	1 per year	Susp str;12mhrs Ten tower; 16mhrs	Susp tower; 8mhrs Ten tower; 8mhrs	3 4	2 2

1.7 Joint commissioning of new lines

1.7.1 Purpose

The commissioning process is to detect at an early stage of construction any flaws in design or workmanship that would result in decreased reliability requiring subsequent modifications and repairs.

1.7.2 Information

The inspections that shall be completed jointly by personnel from the Southern/Northern Network Services, Network Performance and Engineering Departments, while the line is being built, and shall include:

1.7.3 Checklist

- Patrol of entire line
- Climbing verification of helicopter numbering of every fifth support.
- Climbing verification of all dead-end supports.
- Prepare a defect list.
- Any other activity deemed necessary by the commissioning team.

1.8 Acceptance of New Lines

1.8.1 Purpose

Before a new line is energized there must be assurance that it can be successfully energized and integrated into the network and does not create a hazard to the public.

1.8.2 Information

This acceptance patrol shall be made before the line is initially energized. Any hazardous condition and interference to safe operation of the line shall be reported and corrected before the line is energized.

1.8.3 Checklist

Patrol entire lines by vehicle, on foot or by helicopter, ensure that:

- All conductors are properly clamped-in.
- Insulation is adequate.
- All grounds have been removed.
- There are no detectable hazards

1.9 Aerial Inspection

Helicopter patrols provide a visual means of analyzing a line to detect any defects or potentially hazardous situations, which may jeopardize public safety and reliability of a line.

1.9.1 Information

All transmission lines shall be patrolled at least once a year. Preferred periods for the patrol are: Mid-March to End of April and Mid October to end of November.
Aerial Patrols-scheduled outside the preferred period are likely to be disturbed by rains or the harmattan. Any defects that might require emergency action to ensure public safety and reliable supply of power shall be reported to an Area Operator or System Control Centre. This action shall be immediately followed in writing to the either Northern or Southern Network Services. A minimum of two experienced personnel are required for this activity.

1.9.2 Check-list

- Fly between 50 to 80 kilometers per hour at a distance of about 15 metres (50ft.) above and to the side of the line.
- Inspect tower and line for signs of physical damage.
- Inspect Right-Of-Way for potential problems which might reduce reliability.
- Inspect Right-Of-Way for potential public hazards.

1.9.3 Ground wire

- Dampers missing, broken, loose
- Suspension clamps broken or out of position
- Insulators broken or flashover,
- Bonds broken or missing
- Strands broken or burnt

1.9.4 Line conductor

- Dampers missing, broken, loose
- Suspension clamps broken or out of position
- Insulators broken or flashed or shattered
- Subconductor released from spacer dampers
- Conductor strand broken or burnt

1.9.5 Structure (Towers)

- Inspect tower for signs of physical damaged.

nspect Right-Of-Way for potential problems which might reduce reliability.

- Inspect Right-Of-Way for potential public hazards
- Record defects

1.10 Ground (Foot) Patrols

1.10.1 Purpose

Ground patrols provide a means of carefully analyzing a line to detect any defect or potentially hazardous situation, which may jeopardize public safety and the security and reliability of a line.

1.10.2 Information

Ground patrols are intended to complement the helicopter patrol in analyzing the status of a line. Special attention should be given to components and parts of components not easily observed from a helicopter.

Ground patrols shall be done twice a year, the preferred periods being: January to March and October to December.

From January to March when the dry season is at its peak a greater proportion of the line can be accessed (including semi-swampy areas.) From October to December the patrol will identify defects that may have been caused by rainstorm and flood. A diagnostic report shall be submitted upon the completion of patrol listing all defects, if any. A minimum of one lineman is required to carry out this activity.

1.10.3 Checklist A

- Inspect tower and line for signs of physical damage or deterioration. (This encompasses everything from the ground-line of tower to the top)
- Inspect Right-Of-Way for potential problems which might reduce reliability.
- Inspect Right-Of-Way for potential public hazards.
- Record defects.

1.10.4 Checklist B

Foot Patrols shall be done twice a year. The following information will help identify problem areas which should be given special attention during the ground patrol:

- Outstanding defect lists for the circuit.
- History of maintenance activities for the circuit.
- Outage record for the circuit.

The following items and characteristics shall be verified during the line patrol.

1.10.5 Tower

- Erosion at tower base due to natural or other cause.
- Tower steel: - twisted, rusted, damaged, bent and missing members
- Step bolts: - loose, missing and rusted
- Bolts and nuts: - loose or missing
- Tower footings: - concrete deteriorated, cracks, broken
- Condition of counterpoise: - uprooted, broken rusted attachment or missing

1.10.6 Right-of-way

- Trees: - that may be hazardous to the safe operation of the line i.e. (growing into the conductors) or Danger trees that could fall within 30ft (9.1m) of the conductor.
- Brush conditions; - height, density, compatibility
- Landslide, erosion
- Bridge and culverts: - broken, dangerous
- Any obstacle or work nearby which would endanger the lines or public; eg. Blasting, excavation, buildings, planting of trees cocoa, coconut, palm trees etc.

1.10.7 Signs and markers

- Tower number sign - missing, damaged, faded.
- Danger sign- missing, damaged, faded.
- Aircraft warning markers – missing, damaged, faded.
- Anti-climbing devices - missing, damaged, faded.

1.10.8 Miscellaneous

- Unauthorised attachments.
- Fire hazards.
- General condition of access to R.O.W.
- Any unusual circumstance affecting line security.

1.11 Corrosion Surveys

1.11.1 Purpose

Corrosion surveys are required to ensure that all metallic plant is protected from atmospheric, chemical and/or electrolytic corrosion.

1.12.2 Information

Metal erosion is predominant in the vicinity of streams carrying chemical wastes (highly acidic or chemically saturated soils), heavy industrial areas, the sea, and adjacent to catholically protected underground pipelines. The initial survey shall be within the first year of operation of the transmission line and/or pipeline. Subsequent surveys shall be on a 10year cycle; a check of protection systems (sacrificial anodes and rectifiers) hall be made annually.

The rate of metal loss is established by physical and electrical measurement. Analysis of these observations will allow for the protection of adequate protection to ensure structure integrity.

1.12.3 Check List

- Identify towers located in swamps and in vicinity of cathodically protected - underground pipelines, the sea and heavily polluted industrial areas.
- Inspect exposed part of tower for signs of rust. Estimate degree of rust on tower and hardware.
- Measure thickness of galvanization or paint.
- Measure leg-to-soil potential of tower.
- Check protection systems sacrificial anodes and rectifiers.

- Record observations and measurement.

1.13 Ground Resistance Tests and Counterpoise Continuity Check

1.13.1 Purpose

This is intended to keep lightning caused outages to minimum.

1.13.2 Information

A large percentage of the system's automatic outages are produced by lightning. The lightning surge will flash across an insulator string to a phase when the ground resistance at a tower is too high to dissipate it. Counterpoising terminated with ground rods has proven to be an effective way of reducing ground resistance; thus, to keep lightning caused outages to a minimum, the counterpoise should be in a good state of repair ensuring a low tower footing resistance even with dry soil. This activity should be done in conjunction with climbing maintenance and as required.

A tower-ground resistance of 20 Ohms and lower are ideal.

1.13.3 Checklist

- Check counterpoise for continuity from tower to tower or from tower to ground rods (If counterpoise is exposed, this can be done visually)
- Measure tower ground resistance.
- Record observations and measurements.
- Record all additions and repairs made.

1.14 Infra-red Survey

1.14.1 Purpose

Infra-red surveys identify overheated connectors. Such information is used to schedule replacement for line hardware before failure occurs.

1.14.2 Information

A joint or dead-end body failure results in a permanent outage. A pre-failure symptom is a rise in temperature above that of the conductor as the electrical load increases. With increased conductor operating temperature the percentage of overheated connectors are expected to increase. These overheated conductors can be programmed for replacement before failure occurs. An infra-red survey shall be made with the line carrying sufficient electrical load to allow for a rise in temperature in potentially defective line connections. This activity will normally be made annually and from a helicopter; the frequency can be increased for lines that are consistently subjected to high operating temperature. A minimum of two staff is required for this activity.

1.14.3 Checklist

- Check all transmission line connections (sleeves, dead-end bodies etc)
- Record all connectors with temperature above that of the conductors.
- Report verbally any connector considered to be critically hot to responsible maintenance group.

1.15 Galvanization & Surface Analysis

1.15.1 Purpose

This activity is done to determine the trend and sometimes the rate of deterioration of paint on towers.

1.15.2 Information

Some towers which have lost their galvanization are refurbished by painting. Aesthetic appearance of transmission lines is an important consideration especially in areas of high exposure. Some towers are painted for aircraft and boat warning. Renewal of surface should be considered from the standpoint of aesthetics, minimizing the cost of refurbishing and ultimately the security of the structure. The painted surface analysis is made when required; the requirement can be determined from foot patrol observations.

1.15.3 Checklist

- Inspect the protective coating of tower for rust, cracks and flaking.
- Measure the thickness of residual coating with a paint thickness gauge.
- Record observations and measurements.

1.16 Insulator Washing

1.16.1 Purpose

Insulator washing is done to avoid the building up of contaminants on the insulators to a high flashover probability level.

1.16.2 Information

Leakage current on contaminated insulators can reach significant levels when the insulators are exposed to a light rain or heavy fog. Leakage current can reach values that can result in insulator flashovers.

The washing of insulators shall be scheduled such that it can be done before the probability of a flashover, usually following periods of extended dry spell. Insulator washing is a live-line activity, a high pressure stream of water is used to wash contaminants.

1.16.3 Checklist

- Identify areas with high incidence of insulator contamination (eg industrial areas where gases are effused profusely)
- Identify the months when dust is the active contaminant (i.e. during the harmattan.)
- Wash insulators using a live line washing equipment.

1.17 Access Road Maintenance

1.17.1 Purpose

Access roads are maintained to eliminate hazards on them and also to reduce travelling time to access transmission lines.

1.17.2 Information

Access roads provide a means of getting to the Right-Of-Way and transmission lines in order to carryout maintenance and repairs. Well maintained access roads reduce the travelling time to the transmission lines. Poorly maintained access roads could be hazardous to maintenance personnel.
Access roads are maintained when required; the requirement can be established from foot patrol observations.

1.17.3 Checklist

- Obtain information on status of access roads from patrol reports.
- Estimate number of bridges that need repairs: type (log or culvert) and dimensions of bridges should be noted.

1.18 Vegetation Control

1.18.1 Purpose

Vegetation on the Right-Of-Way is controlled in order to avoid interruption of power due to tree-brushing and falling danger trees and also to facilitate foot patrols and other maintenance activities.

1.18.2 Information

Minimum clearances between vegetation and energised apparatus are required to ensure safe and reliable operation of transmission facilities.
Maintenance line clearing is accomplished by removing or pruning trees and brush that are close to the conductor and/or inhibit movement (ie vegetation that are thorny or irritate the skin) at regular, predetermined intervals.

1.18.3 Checklist

- Obtain information on condition of vegetation on the Right-Of-Way from patrol reports.
- Control vegetation manually, mechanically or chemically according to type and location.

- Record identity of spans where vegetation are controlled with dates and costs of such operation.

Table 1-1: Minimum conductor clearance and Limit of Approach.

Minimum conductor clearance	69 -330kV			
	69kV	**161kV**	**225kV**	**330kV**
Normal Ground for pedestrians	6.0m	7.0m	7.5m	8.0m
Residential Areas	6.6m	7.5m	8.2m	
Highways	6.6m	7.5m.	8.2m	9.0m
Railways	9.0m	9.0m	9.0m	10.0m
Distribution Lines Subtransmission lines	4.0m	4.6m	5.0m	4.6m
Communication Lines	4.0m	4.6m	5.0m	4.6m

Table 1-2: Limits of Approach

NOMINAL VOLTAGE RANGE: (Phase to Phase)		DISTANCE:
From	750 to 15,000 volts	0.92m (3ft.)
Over	15,000 to 50,000 volts	1.22m (4ft)
Over	50,000 to 150,000 volts	1.53m (5ft)
Over	150,000 to 250,000 volts	2.14m (7ft)
Over	250,000 to 550,000volts	3.66m (12ft)

1.19 Preventive Maintenance Data required to manage Transmission Lines

Preventive maintenance data includes Line information, replacement parts, specialized tools, service providers, etc.

Each Line Maintenance Unit in the Areas must ensure it has the information/data listed below. This information is required to manage the maintenance of transmission lines.

1.19.1 General information

- Design and As-Built & other significant Drawings
- Parts Lists and Design Specifications
- Circuit Operating Designation
- Relative position of circuit on tower
- Line Section Number
- Field Support Number
- Construction number
- Operational number
- Year of Construction
- Operating Voltage (Nominal)
- Phase arrangements

1.19.2 Right-of-way Information

- Width
- Number of Circuits on Right-of-Way
- Joint Usage of Right-of-Way
- Crossings in the Span
- Topography
- Environment
- Access Road

1.19.3 Tower Information

- Type of Tower
- Anti-climbing devices
- Number of Circuits on Tower Design
- Angle of Tower Line Angle (actual)
- Geodetic Elevation
- Air Pollution (type)
- Accessibility

- Access Support (special vehicles etc)
- Tower Drawing Number
- Emergency Restoration Plan

1.19.4 Conductor Information

- Configuration of Phases
- Number of Conductors/Phase Conductor
- Type
- Size
- Stranding
- Ampacity
- Maximum Mechanical Loading
- Weight per unit
- Manufacturer
- Design Tension
- Maximum Sag
- Ruling Span
- Span Length
- Phase - Phase Distance

1.19.5 Conductor Hardware

11.19.5.1 Suspension Clamp

- Quantity
- Type
- Manufacturer / Model Number

1.19.5.2 Dead End Clamp (Tension Clamp)

- Quantity
- Type
- Manufacturer / Model Number

1.19.6 Aeolian Vibration Dampers

- Type
- Quantity Model Number / Manufacturer

1.19.7 Spacers Dampers

- Quantity
- Model Number / Manufacturer

1.19.8 Shield wire (Ground wire)

- Quantity (No of wires)
- Size
- Type - Grade
- Maximum Mechanical Loading
- Wire - Wire Spacing
- Angle of protection
- Joints - Repair Sleeves
- Armour Rods

1.19.8.1 Suspension Clamp

- Type
- Manufacturer / Model Number

1.19.8.2 Tension End Clamp

- Type
- Manufacturer / Model Number

1.19.8.3 Dampers

- Type
- Manufacturer / Model Number

1.19.9 Grounding

- Counterpoise
- Quantity (No. of Wires)
- Type / Size

1.19.9.1 Ground Rods

- At support
- In span
- Ground wire size

1.19.10 Outage Data

- Type (Planned or Unplanned)
- Frequency
- Cause
- Duration

1.19.11 Maintenance Procedures

- Technical Procedure Number
- Technical Bulletin

1.19.12 Maintenance History

- Time and Cycle Frequency
- Patrol
- Tower audit
- Shield wire Tests
- Infra-red Surveys
- Corrosion Survey
- Tower Grounding Tests
- Vegetation Control
- Access Road maintenance

M02 – TRANSMISSION LINE PATROL

2.1 Objectives

At the end of this module participants should be able to:

- Tell the different types of transmission Line inspections and how they are carried out
- Identify tools and equipment for carrying out the various inspections
- List the type of defects that can be detected during the various inspection
- Identify hazards in the various inspection and the mitigating measures

2.2 Introduction

After transmission lines are constructed, data on the transmission lines are handed over to the client. The lines after some time begin to age and deteriorate and the environment changes. Conditions on the lines change from as they were constructed. For Maintenance men to keep abreast with the condition of the line and the environment in which it is situated, there is a need for regular patrol of the line to inspect the all the line components and the right-of-way. Transmission line Patrols are performed to detect deteriorated components in the transmission line system, to locate any unauthorized attachments to the transmission line structures; unauthorized under-builds or any unauthorized uses of the right-of-way (R.O.W.) that may interfere with the safe and reliable operation of the lines. To detect any acts of vandalism to any facilities or any conditions which could adversely affect public safety.

Several components are widely used in overhead power transmission lines with hard to predict useful serviceable life to ensure adequate maintenance of line reliability. Transmission line patrols help in spotting potential problems before they occur to maintain safety and reliability of the transmission systems

2.3 Types of Transmission Line Patrol

There are two main types of Transmission line patrol. They are the Ground Patrol and The Aerial Patrol.

2.4 The Ground Patrol

The Ground Patrol involves driving in a vehicle with frequent stops to inspect lines including climbing the towers for closer inspection of line hardware and walking the lines in areas with no vehicle access due to difficult terrain such as mountains or steep valleys to inspect major and critical components including the right-of-way for abnormalities and new occurrences. It provides a means of carefully analyzing lines to detect any defect or potentially hazardous situation, which may jeopardize public safety and security and reliability of the line. Special attention is given to components and parts of components not easily observed from Aerial patrol.

2.4.1 Procedure

The ground patrol is performed twice a year. Preferred periods being: January to March, when the dry section is at its peak greater proportion of the line including semi-swampy areas can be accessed and October to December to identify defects that may have been caused by rainstorms

A minimum of two persons should perform line patrols. Off-road right-of-ways which are intersected at frequent intervals by vehicle access roads can be patrolled in a leapfrog style where one person walks a section while the second takes the vehicle ahead to the next access road.

The second person then patrols the next section. The process is repeated as often as necessary. Before starting this process however, it must be clearly established at which access points the vehicle will be waiting and at what point the patrol will be completed for the day.

Sections of line longer than five kilometers without vehicle access should be patrolled by a minimum of two persons walking together. Local conditions will determine if they have to retrace their route to the vehicle or are to be picked by the vehicle at a predetermined point. **"It should however be noted that in areas with security concerns, linemen should not walk the line alone unaccompanied by at least one other no matter the length of the distance"**

2.4.2 Tools and Materials Required

The tools and materials required include high magnifying telescopes for a closer and clearer look at components, measuring tape for measuring the distances of structures to the transmission lines, machetes, chainsaws for spot work that may be required along the way and spades, Hoist (tirfor etc.) Walkie Talkies may be used, if men will be separated on right-of-way. Patrol Form 82 and a note book and a Pen or an electronic data capturing device to record defects and their locations, still and video cameras for recording defects and thermos-vision cameras for scanning conductor joints and splices to check hotspots.

Other tools and materials may be added to or replace the list above depending on the precise purpose of the patrol.

Ground patrols can be done for the general purpose of checking the condition on the transmission line or a specific purpose of finding a faults or checking vandalism.

2.4.3 Patrol Checklist

For the patrol to be efficient, there is the need to develop a checklist and follow it to ensure that work proceeds as planned. The following are the general checklist used for ground patrols. The following components are checked.

Condition of Footings

- Deteriorated.
- Concrete capping: cracks, broken.
- Weatherproofing of concrete capping: loss of bituminous paint or equivalent material.
- Erosion at base due to natural or other causes.

Condition of Counterpoise

- Exposed, broken.

Condition of Tower Steel

- Members: twisted, rusted, damaged, bent and/or missing.
- Step Bolts: loose, missing and/or bent.

- Nuts and bolts: loose and/or missing.

Insulators

- Lightning damage: broken, chipped and/or flashed.
- Contamination.
- Uplift.

Conductors and Ground wire

- Clearance to ground
- Clearance to structure
- Strands: damaged, broken, birdcages.
- Joints and splices: defective or noisy
- Clamps: broken, loose.
- Dampers: missing, broken, moved.
- Loop clearance- Adequate = minimum 1.4m (54 inches) clearance at 32oC- (90o F)

Guys

- Grip: undone, broken (strands), rusted.
- Hardware: broken, rusted, undone.
- Anchor rods - damaged, corroded, uplifted.
- Guy to anchor connection: below water or ground line.
- Compressed fittings: damaged or defective.

Signs and markers

- Tower number sign: missing, damaged or faded
- Danger sign: faded, missing or damaged.
- Aircraft warning markers: missing, damaged.
- Anti-climbing devices: missing, damaged

Right-of-way (R.O.W.)

- Trees that may be hazardous to the safe operation of the line i.e. (growing into the conductors) or dangerous ones that could fall within 30ft (9.1m) of the conductor.
- Brush Conditions: height, density, compatibility.
- Landslide, erosion.
- Bridges and culverts: broken, dangerous

ny unusual circumstance affecting line security i.e. any obstacle or work nearby which would endanger our lines or public property blasting, excavating, unauthorized attachments, fire hazards.

- General condition of access to R.O.W.

2.4.4 Reporting

report is written on observations made on the towers,line hardware using- the right-of-way condition report form, OF 82, for observations on the R.O.W.;

Special reports must be written about defects that need immediate attention.

2.4.5 Safety

The most common hazards encountered during ground patrols are:

- Slips and falls: to counter these hazards, linemen need to wear suitable footwear and be careful when walking or climbing over obstacles.
- Harmful insects (bees and wasps-): linemen should visually inspect towers for the presence of harmful insects before climbing.
- Harmful plants: Linemen should be conscious of the types of vegetation that exist on the right-of -way and avoid harmful plants.

Working alone in remote locations: access, and R.O.W. conditions and communication facilities should be considered to determine where a second technician might be assigned to the patrol to be available to assist in the event of an accident.

FORM OF 82		LINE RIGHT-OF-WAY CONDITION REPORT	....AREA
LINE SECTION		PATROLLED BY:	VEHICLE & REG. NO. ....DATE:.....................

TOWER NO.-------------

HEIGHT OF BRUSH. Use symbols to show farms, rivers, roads, special trees	
	16'
	14'
	12'
	10'
	8'
	6'
	4'

Galamsey operation within R/W

Desription of R/W condition	
Condition of tower bases & access roads.	
Notes on tower	

Symbols

1 River across R/W ↗ or ↙

2. Road across R/W

3. Building on R/W

4. Farming - mark length farmed thus ←F→

5. Swamp mark thus ←S→

6. Mark special trees - B-Bamboo, R for rafiapalm, TT for tall tree on or off the R/W

2.5 The Aerial Patrol

Figure 2-1. The aerial patrol

Aerial patrol involves inspecting the grid using aerial vehicles hovering over transmission structures and to record data of defects and new incidences through note taking, pictures (thermal, Ultraviolet, LiDAR, video etc.) to analyzing a transmission line to detect any defects or potentially hazardous situations which may jeopardize public safety and reliability of the line.

This form of inspection is used mainly to inspect the upper portions of tower structures, conductors, clamps and fittings and right of ways. The aerial patrol has the advantage of being able to access sections of the line with no ground vehicular access.

Detailed helicopter inspection usually involves hovering near structures and taking a closer and clearer look using high magnifying telescopes to identify defects and taking a still photographs, video of the more serious problems. It also involves taking thermal pictures of joints to identify and analyze hotspots.

Aerial patrols can categorized into two types based on the type of aerial vehicle used.

The manned aerial vehicle or the unmanned aerial vehicle.

2.5.1 Procedure

The Aerial Patrol is performed at least once year: preferred periods for the patrol includes mid-March to End of April and mid-October to end of November when they are least likely to be disturbed by rains or the harmattan.

A patrol crew for an aerial patrol consist a minimum of two persons; a pilot and a compatible observer. They carefully check the patrol map or flight plan for hazards listed so they can be avoided during the patrol and consult the tools and material checklist to ensure all tools and materials required are in place.

The pilot takes charge of the helicopter and flies the line being patrolled between 50 to 80 kilometers per hour at a distance of about 15 meters (50ft.) above and to the side of the line, while the second person observes the transmission line to spot any defects on the conductor or support structures where there may be.

The pilot also updates the helicopter hazards or sensitive locations lists as they are encountered during the patrol.

2.5.2 Tools and Materials

2.5.2.1 Recording Materials

Recording materials such as paper, clipboard, pen or any electronic recording device such as computers, digital cameras or infrared cameras, etc. are used to record data on the transmission line

Digital Cameras and infrared cameras are either hand held or fitted to the aerial vehicle both on manned and unmanned to take normal or infrared pictures of transmission line components for later analysis.

2.5.2.2 Patrol flight maps or plans

Pertinent information such as:

- Flight maps and plans of the patrols, including previously reported flight hazards and restrictions.
- Daily weather forecast covering the area in which the patrol is to take place.
- Technical Directive TD-LM-007 - "Identification and Marking of Transmission Lines".

- List of towers on transmission lines to be patrolled.
- Checklist of visual defects

Should be consulted in order to plan proficiently for the patrol

2.5.3 Checklist of visual defects

The following are the general checklist to be verified during aerial patrol:

2.5.3.1 Ground wire (Sky wire)

- Dampers: missing, broken, loose.
- Suspension clamps: broken or out of position.
- Bonds: broken or missing.
- Strands: broken.

2.5.3.2 Line Conductor

- Dampers: missing, broken, loose.
- Suspension clamps: broken or out of position.
- Insulators: broken or flashed.
- Subconductor: released from spacer dampers.
- Conductor strands: broken.
- Substandard clearances.
- Joints and Splices: scan with Thermovision camera

2.5.3.3 Steel Structures

- Bent or missing steel.
- Base erosion or flooding.
- Missing or faded 'helicopter' tower nomenclature.
- Missing helicopter warning markers.

2.5.3.4 Right-of-way

- Flooded areas.
- Danger trees.

- Unapproved activity (possible electrical hazard or unauthorized use of the right-of-way).

2.5.4 Recording and Reporting:

- Verify the circuit from the designation on the station structure
- Ensure that the correct structure number is recorded if defects are found
- List all the defects found during the patrol.
- Write additional information that would aid the line crews in making repairs.

2.5.5 Safety

The following are safety precautions taken:

- Keep clear of the main rotor, tail rotor or tail rotor shaft of the helicopter while the aircraft is running.
- Watch out for navigation hazards, such as intersecting lines, shield wires, structures and trees.
- Make sure a survival kit is in the aircraft before take-off.

Good verbal communication is required between the pilot and observer.
Other hazards which are circumstantial or of a general nature, shall be discussed by the pilot and observer before the patrol begins.

M03 – CLIMBING MAINTENANCE

3.1 Objectives

At the end of this module participants should be able to:

- Tell the purpose of climbing maintenance and how it is carried out
- Identify tools and equipment for carrying out the maintenance
- List the type of defects that can be detected during the various inspections

3.2 Introduction

Climbing maintenance provides a means of analyzing the aging process of a line.
Climbing inspection shall begin one year after the year of construction, re-conductoring or re-tensioning. This shall be followed by one-year cycles for the remainder of its service life. In each cycle of climbing maintenance ten percent of the 'suspension' and all 'dead-end' supports on each line shall be examined.
This sampling shall be selected to ensure that all support types on a line and all topographic and environmental conditions affecting the line, are considered.
As the line ages, it is subjected to wear and fatiguing not noticeable by a distance visual inspection. Detection and tightening of loose bolts on support and hardware can reduce premature wear and indicate the need for replacement of worn components before failure. Fatigued and mis-positioned dampers will allow the conductor' to vibrate excessively and cause strand failure.
During the 20th year of the line's life, clamps shall be randomly opened to analyze the condition of the conductor strands inside them. At least one clamp per circuit, per tower climbed shall be opened and the conductor inspected for damage.

3.3 Checklist

Each tower must be carefully inspected following the checklists detailed below and any additional instructions given by the Transmission Lines Supervisor.

- Critically inspect tower and line for signs of physical damage and deterioration.
- Check tightness of bolt on structure and hardware.
- Evaluate degree of wear on hardware

- Check alignment of dampers.
- Open one clamp per circuit per tower and check condition of conductor inside them.
- Remove sample clamps and dampers and submit to Network Performance Department for testing.
- Replace items removed.
- Test insulators.
- Check condition of conductor joints and bolted connections using infra-red equipment.
- Check tower ground resistance
- Check counterpoise continuity.
- Inspect Right-Of-Way for potential problems which might reduce reliability.
- Inspect Right-Of-Way for potential public hazards.
- Inspect condition of access roads.

3.4 Background information

The following information will help identify problem areas, which should be given special attention during the climbing inspection:

- Outstanding defect lists for the circuit.
- History of maintenance activities for the circuit.
- Outage record for the circuit.

All defects found, including those repaired during foot inspection, for analysis by the transmission lines section and future remedial action as required.

3.5 Detailed Check Point

3.5.1 Shield wire (Ground wire)

- Check the Shield wire suspension clamps and dead-end connectors for fractures, wear or corrosion.
- Care must be taken to ensure that the Shield wire does not fall if it is removed from the clamp.
- Check the Shield wire vibration dampers for damage and proper positioning.

- If the vibration dampers have been in service for more than 20 years, replace 2 dampers in the line section, tag the old ones to identify their location and submit them to the Network Performance Department for testing.
- Check the bonding lead between the Shield wire and the down lead for breaks and tightness of connections.
- If a bonding lead is not present, one must be installed.
- Visually inspect the Shield wire for corrosion and broken strands or burns.
- If the shield wire has been in service over 20 years, a 1.8m (6ft) sample shall be removed and sent to the Network Performance Department for testing.

3.5.2 U-Bolts and Ball Eyes

- Check tightness of U-bolts and nuts both above and between the cross arm members.
- Inspect the U-bolts and ball eyes for wear and or fractures
- Estimate and record the amount of wear as a percentage of the cross section.
- If the wear approaches 50 percent, new units should be installed and those removed sent to the Network Performance Department for evaluation.

3.5.3 Insulators

- Check each insulator for flash marks, cracks, and chips in the porcelain.
- Check insulator string for uplift and alignment (suspension strings should hang within +/- 10 degrees of the vertical)
- If a saddle clamp is moved more than 100mm (4in) to align the string, the dampers must be repositioned.
- If less than 25% of the Insulators in a String are defective, they may be replaced within the normal maintenance schedule.
- If 25% or more of Insulators in a particular string are damaged, they must be replaced immediately in order to avoid flashovers from lightning or switching surges.

3.5.4 Conductor and hardware

No work shall be undertaken on conductor or supporting hardware until a visual check has been made of their condition to minimise the possibility of failure while a more thorough maintenance programme is being done.

3.5.4.1 Conductors

- Inspect conductor for burnt or broken strands
- If less than 25% of outside strands are damaged, patch rod may be used.
- When damage is at the point of suspension, a larger saddle clamp shall be installed over the patch rod.
- If 25% or more of outside strands are damage, a new piece of conductor shall be spliced in
- When replacement conductor is required near a suspension point or dead-end, enough conductor shall be installed to allow 2m (6ft) between the end of the sleeve and the suspension clamp or conductor dead-end body.
- When dampers are present, a longer piece of conductor is required to allow 2 m (6f t.) between the end of the sleeve and the damper.
- Measure the conductor clearance to ground and other underbuilds.

3.5.4.2 Clamps

- Inspect clamps for cracks, proper installation, and wear at point of attachment.
- On lines that have been in service for 20 years or more, the clamps are to be opened to check the condition of the conductor underneath.

3.5.4.3 Vibration dampers

- Examine vibration dampers for wear, proper positioning and alignment.
- Stockbridge dampers are installed directly below the conductor and should be checked for sag in the end weights.

- If dampers have, been in service for more than 20 years, replace 2 in the line section, tag the old ones to identify their location, and submit them to the Network Performance Department for testing.

3.5.4.4 Spacer dampers

Check spacer dampers visually for damage, mis-position, and floating conductor

3.5.4.5 Loop pads

Check loop pads for corrosion and tightness of bolt tension using torque values in the table below.

3.5.4.6 Torque checks

A random check of torque on clamps, loop pads, spacer dampers and dampers shall be taken using the torque values identified in the table below.

Table3-1: Torque Values.

Bolt Diameter	Galvanised Steel	Aluminium
10mm (3/8in)	20-30Nm (15-20ft/lb)	14-16Nm (10-12 ft/lb)
12mm (1I2in)	45-70Nm (35-50ft/lb)	35-40Nm (25-30ft/lb)
16mm (5/8in)	90-140Nm (70-100ft/lb)	60-80Nm (45-60ft/lb)
20mm (3/4in)	110-240Nm (85-175ft/lb)	70-100Nm (55-70ft/lb)

3.5.5 Tower Steel and bolts

- Check 20% of the bolts on the tower at random for tightness using a torque wrench.
- If more than 4 percent of the bolts checked are found loose, Check an additional 20% paying close attention to the arm and leg Joints and record the findings.
- Examine the steel at the bolt connections for stress cracks.
- Check for missing or damaged structure members and record the "mark" number.
- Tower Drawings may be used to obtain the "mark" number of a missing structure member.
- Check the tower for rust and estimate the percentage rusted.

3.5.6 Signs

Check towers for all required signs and numbers in accordance with Technical Directive NO.TDLM007. Replace or install the proper signs as necessary.

3.5.7 Tower Footings

- Check stubs visually for damage and corrosion
- Check concrete for crack, chips and flaking.
- On augured footings, the top of the concrete should be 150mm to 450mm (6in. to /8in.) above ground surface at all the legs.
- Check counterpoise connection at each footing
- At guyed towers, check the condition of the guy clamping points at both the tower and anchor ends.

3.5.8 Ground Resistance Tests

- Measure the tower footing resistance (footing resistance of not more than 20 ohms is ideal)
- Check for continuity of counterpoise
- Record value

3.5.9 Right-of-way & Access Road

- Check the general condition of right-of-way. Look for such things as ground erosion, debris, trees or structures that may encroach on the line.
- Check the access road for damaged bridges, culverts, erosion and fallen trees.

3.6 Reporting

- Climbing Inspections shall be reported on Forms OF.21 and OF 82.
- In the case of defects repaired, a report describing the new components installed should be submitted for inventory updating.

3.7 Safety

The following hazards and precautions highlight some of the safety considerations related to activities listed in this module. Other hazards, which are, site specific and of a general nature shall be identified during a tailboard conference before the work commences.

Hazards	Precautions
Working aloft	Wear safety personal protection equipment
Electrical	Observe limits of approach
Mechanical	Control the Shield wire removed from the suspension Clamp.
Biological	Visually inspect tower for the presence of harmful insects

Be conscious of the types of vegetation that exist on the right-of -way.

M04 – INSULATOR WASHING AND REPLACEMENT

4.1 Objectives

At the end of this module participants should be able to:

- Understand and explain the theory of high voltage insulator washing.
- Practically wash energized high voltage insulators safely and efficiently.
- Be able to assist their experienced colleagues replace defective high voltage Insulators

4.2 Introduction

Many power lines near the coasts and industrial areas have their insulators polluted by saline (insulator salt deposit) and industrial pollution.

his pollution is one of the main causes of flashover in the insulators. The saline pollution occurs when onshore maritime winds carrying microscopic droplets of brackish water on the insulators and consequently deposit salt. Industrial insulator pollution occurs when the wind carries industrial wastes either from industrial chimneys or waste deposit sites and deposit them on the insulators. The insulators begin to fail when these pollutants are deposited on the insulator surface and combined with the humidity of the fog, rain, or dew.

The mixture of the pollutants and moisture form a layer that can become conductive and allow passing currents that will facilitate flashovers unless there is a natural cleaning or adequate maintenance.

Thus, the need has arisen for a method to effectively remove these deposits from insulators. The conventional insulator cleaning method is manual after having disconnected the line from service. This method is extremely demanding due to the prolonged service interruption period and the large number of maintenance staff required carrying out the work.

A valid alternative would be potential deposit removal by washing insulators with a jet of water. Cleaning high voltage insulators using water under high pressure has been an acceptable method for many years. Various utilities have used this method since the early 1940's.

Live line washing should be considered the normal cleaning procedure, although, if an overhead line or substation can be readily de-energised without interruption to the customer and without increasing job costs, then washing de-energised is suggested.

When washing in an urban area, due consideration should be given to the General Public and road traffic to ensure that incidents are avoided. Where practical the work area should be fenced off.

On the other hand, power utilities all over the world have been involved in insulator replacement both live line or dead line for the following reasons:

- Re-insulation of entire transmission or distribution lines, and
- Replacement of flashed or damaged insulators.

This module is thus written to introduce insulator cleaning and replacement to, especially newly recruited maintenance personnel.

4.3 Theory of Electrical Insulators and Insulator Pollution

4.3.1 Theory of Electrical Insulators

An electrical insulator is a material whose internal electric charges do not flow freely, and therefore make it nearly impossible to conduct an electric current under the influence of an electric field. This contrasts with other materials, semiconductors and conductors, which conduct electric current more easily. The property that distinguishes an insulator is its resistivity; insulators have higher resistivity than semiconductors or conductors.

A perfect insulator does not exist, because even insulators contain small numbers of mobile charges (charge carriers) which can carry current. All insulators become electrically conductive when a sufficiently large voltage is applied that the electric field tears electrons away from the atoms. This is known as the breakdown voltage of an insulator. Some materials such as glass, paper and Teflon, which have high resistivity, are very good electrical insulators. A much larger class of materials, even though they may have lower bulk resistivity, are still good enough to prevent significant current from flowing at normally used voltages, and thus are employed as insulation for electrical wiring and cables. Examples include rubber-like polymers and most plastics.

The term insulator is also used more specifically to refer to insulating supports used to attach electric power transmission and distribution lines to distribution poles and transmission towers respectively. Insulators are used in overhead transmission and distribution lines to mechanically support conductors and electrically resist the flow of current from conductors to ground through them.

The common materials used currently to manufacture high voltage insulators for power transmission systems are Polymer, Glass and Porcelain.

4.3.2 Pollution of Power Line Insulators

In recent years, the demand of electrical energy has increased considerably. To satisfy this demand, electrical utility companies have had to improve the efficiency of their transmission lines. The efficiency of the system is based mainly on continuity of service, avoiding faults that support economic losses for utility companies and customers.

Also, with the liberalization of electrical markets, the individual clients will have the flexibility of choosing the supplier companies that provide them a better quality of service.

To maintain continuity of supply, one of the main problems that have been found is the effect produced by pollution on the insulators of the power lines. This pollution is one of the main causes of flashover of the insulators. The insulator begins to fail when the pollutants that exist in the air settle in the surface of the insulator and combine with the humidity of fog, rain, or dew. The mixture of pollutants, plus humidity form a layer that can become conductor and allow passing currents that will facilitate the conditions of short circuit. This is due to a decrease of the resistance of the insulator surface.

Unless there is a natural cleaning or an adequate maintenance, the electrical activity will be affected by a possible flashover in the insulator. Most of the methods of pollution control are based mainly in:

- Analyzing the severity of the pollution, that is to say, to establish “zones of pollution”.
- Controlling pollution of the insulators, to determine when a cleaning or maintenance of the insulators is needed for prevention of the problems.
- Comparing the behavior of the different designs of insulators (form, length) and/or of the materials of the insulator that are to be used in the contaminated environment.

The probability of appearance of fault situation depends on the type and material of the insulator, the weather of the zone, the type and level of pollution, as well as the working voltage of the insulator.

Other problems related to pollution are: corrosion and erosion of the insulator. Also in polymeric insulators, the phenomenon of dry bands, and the effect of pyrolysis must be kept by analyzing the operation of the insulator.

4.3.2.1 Types of Pollution

The level and the type of pollution of an area is associated with the sources of pollution, as well as with weather factors of the place. Table 1, shows the pollutants and the sources that produce them. Independently of the existing pollution type, the normal phases in which a flashover can appear in the insulator by pollution are:

- The pollution is placed on the surface of the insulator and a contaminant layer appears. The pollution can be caused by a great variety of sources, (sea salt, industries, ashes…). The wind is the main bearer of the particles, having a secondary role of the gravity and the electric field.
- By the action of rain, fog, etc. ... the layer on the surface is dampened and enlarges the conductivity.
- The contaminant layer dries. Thus, there is an increase of conductivity and leakage current
- Dry bands are formed as a consequence of the warming-up of the layer on the insulator surface.
- Partial arcs appear through the dry bands.
- Partial discharges are produced, these discharges produce audible noise.
- Finally, a total discharge (flashover) is produced.

So if a flashover can happen, these phases are not to happen consecutively but that several phases can occur at the same time. When the contaminated layer is dampened, the resistance diminishes and the current of filtration that passes through it is increases. With this increase, the temperature of the contaminant layer is elevated, and that diminish still more the resistance. The resistance will diminish until the temperature reaches the boiling point, beginning to lose humidity. From this point the layers resistance begins to enlarge little by little until its total drying. Then will reach the maximum value of resistance.

This phenomenon is a lot more feasible in narrow parts of the insulator where the density of current is higher. The increase of the resistance makes the current diminish, but its formation implies that most tensions applied to the insulator appear through it, by being still humid in the remainder of the layer. An increase of pollution produces an increase in the leakage current and then a flashover of the insulator is more probable. But if we could distribute the pollution over the entire insulator, the voltage would be forced to be more linear, so we would avoid the electric concentration in any point of the insulator and the probability of flashover would diminish.

In some locations very close to large sources of pollution, the entire insulator is covered with the contaminant; but this situation is an exception more than a rule. Because of it, the most typical guideline is not a uniform distribution. The surfaces exposed or protected of the insulator are affected on different ways by the forces that are responsible for placing the contaminant and to clean the surface. Thus in many cases the most exposed areas are more contaminated than the areas protected, but there are cases where the contrary is also certain. Although many factors can define insulator pollution, three main types of pollution can be highlighted: the industrial, marine and desert.

Contaminants	Source of Pollution
Salt	• Coastal Areas or Salt Industrials • Highways with deposits of snow where Salt is used to melt Snow.
Cement	• Cement Plants • Construction Sites • Rock Quarries
Earth	• Ploughed Fields • Earth Moving on Construction Sites
Fertilizers	• Fertilizer Plants • Frequent use of Fertilizers in Cultivated Fields
Metallic	• Mining Handling Processes • Mineral Handling Processes
Coal	• Coal Mining • Coal Handling Plants/Thermal Plants • Coal Burning/Brick Kiln Areas
Volcanic Ash	• Volcanic Activity Area
Defecation	• Droppings from Birds during Roosting

Chemical	• Wide Variety of Chemical/Process Industries • Oil Refineries
Smog	• Automobile Emissions at Highway Crossings • Diesel Engine at Railway Crossings
Smoke	• Wide Fires • Industrial Burning • Agricultural Burning

Table 4-1. Contaminants and their Sources

(a) Industrial Pollution

People in their daily work generate smoke, dust or particles that are in suspension in the air. These particles mainly by the action of the wind spread over zones where electric lines exist. The industrial pollution of insulators appears with the industries development and by the contaminants generated and expelled to the atmosphere, being possibly of diverse types: metallurgical, chemical substances, dust, smoke, cement, etc.

These substances will settle on the insulators creating contaminant layer. This layers which settle on the insulators is formed slowly during periods that can last in months or years. During this period, dry epochs will alternate with humid epochs.

The most direct way to establish the behavior of the insulator during this type of pollution is to control the behavior of the amplitude of the leakage current with respect to time, or the load of the leakage current accumulated during a certain period of time. Then it will be possible to see whether the activity of the pollution enlarges with the time and also the effect of rain (natural wash) will be seen. In this way, we will be able to decide whether we have to do an artificial cleaning (maintenance) or whether the natural wash is sufficient to avoid a dangerous layer to be formed.

Aside the contaminant sources that characterize this type of pollution, we also have to keep in mind the characteristics sources of industrial pollution as well as other sources that enlarge the problem:

- The typical contaminant sources are: smoke from industries, the one produced by vehicles, buildings, etc.
- Industries that consume fossil fuels, diesel, coal… the heavy particles of the fuel remain in suspension in the environment.

- Heavy industries such as fertilizing plants, oil refineries, cement works … these can have severe emissions of contaminants particles.
- If the electric line is near the coast, we have to keep in mind the action of the waves, breezes or winds coming from the sea, the fogbanks and the particles of salt that are in suspension in the outskirts of the zone where the insulators are located.
- Agricultural areas, the farming activities, occasional bushfires, application of fertilizers, etc.

(b) Marine Pollution

The insulators exposed to coastal or marine environments can become conductors due to the formation of a conductive layer on its surface. This layer will be formed on account of the salted dew of the mornings in these zones close to the coasts. When dried with the heat produced in the same insulator or with the environment temperature, is going to deposit in the insulator the evaporated salt that had absorbed before.

The particles placed on the insulators are not dangerous in dry weather but, the problem arises when the environmental weather is humid, rainy, dew, foggy etc., then the layer can become conductor. The conductivity of this layer will depend on the kind of salt that form it. The weather conditions vary considerably from the coastal areas to the interior areas and they play a very important role in the contaminants deposition rate and in the operation of the insulator.

The danger of the pollution will depend on the type of material and on the form of the surface. Also the sources of pollution must be investigated and the way of deposition of the pollution. The pollution will depend also on the direction of the wind for a greater or smaller pollution of the insulators.

The severity of the pollution in a location is quantified in terms of Equivalent Salt Deposit Density (ESDD) measure in units of NaCl mg/cm^2, in which are taken into account, the following five weather factors: Temperature, humidity, pressure, rain and velocity of the wind.

This value of ESDD provides a base to do a classification of the severity of the pollution of the zone considered and will serve as a guide in planning for regular maintenance of insulators.

Marine pollution is located not only in the surrounding area of the coast, but also to considerable distances by the action of the wind.

(c) Desert Pollution

In some zones, the insulators of the electric lines are often subject to the deposition of contaminant substances of the deserts. This can cause a serious reduction in the efficacy of the insulator, causing as a result flashovers and the electricity supply outages. Also the storms of sand must be kept in mind. The predominant elements in this type of pollution are: the sand and the widespread, salty dust in a dry atmosphere. The desert climate is characterized for sand storms and hurricanes that contain particles that move in a high speed. This particle strikes the surface of the insulators causing material erosion. The storms of sand are an important factor that causes a decrease of reliability in electrical lines. In this type of pollution the following aspects are relevant:

- The early morning dew represents the greater source of wetting in the desert zones.
- Storms of sand enlarge the pollution problems. The worst conditions occur when the storms are accompanied by a high humidity or rainy weather.
- Pollution layers accumulated on the insulators during the storms are of larger grain and greater content in salt than the layers formed during the normal atmospheric weather of the desert. The pollution contributed by the storms of sand is normally carried by strong winds from distant regions.

The performance of ceramic insulators under desert conditions is satisfactory compared with the performance in other zones with industrial or coastal environments.

We can also refer to pollution in semiarid climates as desert pollution, where the floor is not covered completely by lawns or by trees. Therefore, the superficial layer of the land is very dry and the dust is easily scattered for the action of the wind.

High speed winds strike the surface of the insulators causing erosion of the surface.

The dry insulators normally have low conductivity, but rain or dew dampens the layer and they begin to conduct. The areas contaminated are heated, creating dry bands. This is heat generated by the leakage current. Being a zone with little quantity of rain, these are not capable of washing naturally the insulator and to eliminate the contaminant layer.

(d) Other types of pollution

In contaminated environments where power lines are installed, it is also interesting to consider humid zones by the apparition of biological elements on the insulator, which is known as biological pollution. The common contaminants here are the bacteria, algae, mushrooms and lichens that can degrade the surface of the insulator or can create a conductive layer. The mushroom growth can be important because its roots can penetrate in the matter and create a porous structure on the surface of the material.

Lichens and algae are going to free organic acids, especially the oxalic acid, capable of damaging the surface of the insulator. At first, the humid layer formed by these elements has no reason to influence the work of the insulator. The problems appear when this layer dried and form a greasy layer during dry periods. The biological element dies, but an oily layer is formed on the surface of the insulator. If this greasy layer is dampened again, without having been cleaned, a layer of dry bands appears that leads to flashover of the insulator.

In the case of algae and especially on some polymeric insulators, the growth rate is slow and a lot of time is needed in order to extend over a large area, although humidity and temperature would be high. Algae do not penetrate the insulating material, whether we have adequate preventive maintenance or not, the risk of flashover of the insulator by biological pollution in natural conditions, is lower.

Other source of pollution is salt, during the winter months, in zones of very cold climates. The aim is to prevent the formation of ice in sidewalks and the roads and to de-ice them as soon as possible. The utility of the salty substances is to descend the freezing point of the roads/sidewalks and thus to delay the formation of ice. The quantities of salt utilized can be immense. Part of this salt will be placed on the surface of the insulator thanks to natural agents, like wind and movement of vehicles in these zones. An important pollution is the accumulation of a quantity of salt of around 0'1 mg/cm^2 on the surface of the insulator.

To de-ice, various types of salts are utilized. The most common one is the rock salt (sodium chloride) due to its low cost; it diminishes the freezing point of the surface to a few degrees. Other chemical substances that are also used are: the calcium chloride and magnesium chloride.

They act better than sodium chloride. For example, calcium chloride works under (-8 ºC), and is effective for lower levels of relative humidity (42%) compared with the sodium chloride (72%). Also a mixture of salts is utilized, like rock salt with calcium chloride, calcium magnesium acetate (CMA). They are more effective, and they cause less corrosion. Environmentally, they are more pleasant than the rock salt; nevertheless they are more expensive than rock salt.

In the same way, the calcium chloride, magnesium chloride and CMA in liquid state are used. Experience has shown that the liquid resists more, adheres better to the surface and provides a greater reach, besides it application is easier. This way to de-ice is supported clearly by authorities and so the number of users is more.

4.4 Methods for reducing the effect of pollution

To avoid the effect of pollution on insulators there are three alternatives: correct selection of the insulator type, maintenance (cleaning or washing) of the insulators and elimination of the source of pollution. The effect of pollution will depend on the region and on the efficacy of the maintenance plans and the correct selection of insulator types.

4.5 Maintenance (Cleaning or Washing of Insulators)

The following methods can be used to clean insulators:

- Brush Cleaning (dead line)
- Water Washing (on tower or from the ground - Dead line or Live line)
- Helicopter Washing (live line)
- Robotic Insulator Cleaning (Waterless Cleaning – Live line)
- Ground Corn Cob, Ground Nut Shells or Ground Cork Blasting
- Use of CO_2 (Dry Ice) Pellets

Among all the methods stated above, Water Washing Dead or Live line was found to be cost effective and efficient.

4.6 Considerations for Water Washing

The following are to be considered before proceeding with either live line or dead line Insulator Washing.

4.6.1 Use of Approved Wash Equipment

The Water Washing equipment (high pressure pumps) to be used must be designed specifically for washing energised systems.

In GRIDCO/VRA, the approved equipment is supplied either by ALTEC INCORPORATED or TRANSLINK INTERNATIONAL COMPANY LIMITED (both from UK) with a water tank capacity of 1200 – 1600 gallons.

Figure 4-1. Altec Live line Insulator Washer (Trailer Type)

Figure 4-2. Translink live line Insulator Washer (Trailer Type)

Figure 4-3. Altec Live line Insulator Washer (Truck Type)

4.6.2 Training

Crew members should be trained in washing practices and the operation of their particular washer unit to provide standard techniques that will govern live line washing practices on high voltage lines supported by wood and steel structures and in the proper operation of the washer equipment.

4.6.3 Type Of Washing: De-Energized Or Energized Washing

Washing de-energised should be done whenever possible. This will allow using water with a higher conductivity than those listed in the 'Water Versus Voltage' Chart.
If de-energised washing is carried out on lines or substations located near energised lines, care should be taken so that over-spray carried by the wind is not blown across energised contaminated insulators. This over-spray could cause the contaminants on nearby insulators to become damp with a subsequent risk of flashover.

4.6.4 Grounding (Earthing)

In order to overcome the dangers of Step and Touch Potentials, Ground attachments are always provided on each washer unit. The washer unit should therefore be effectively grounded to the best possible grounding source.
Assisting personnel should refrain from touching the washer unit while standing on the ground when washing operation is in progress

When it is necessary to stand on grounded steel structures that support energised conductors, the wash gun nozzle should be grounded to the steel members being contacted or stood upon.

When washing substation insulators with the hand held wash-gun(s). The nozzle(s) should be grounded to the substation earth.

Where grounding rods are used, the ground area round the rod should be well soaked with water to make a good earth connection.

4.6.5 Water Used For Live Line Washing

Water with the lowest conductivity should be used when washing energised circuits: (refer to table 1).

The Water Verses Voltage chart is furnished as a guideline and water with higher micro-mho values than those listed must not be used. A portable conductivity meter should be used for checking the water quality prior to filling the washer tank

(This test should be performed prior to every fill even if the same source of supply is used)

A sample of water from the source of supply should be tested; reading recorded and then allowed to settle for a period of time.

Water that has been settling for a few hours should again be tested prior to live line washing. This test will allow the operator to determine if water that has been allowed to settle in the washer tank for a number of hours is still suitable for washing.

CONDUCTIVITY (MICRO-MHOS)	LINE VOLTAGE (KV)
300	TO 765
400	TO 500
500	TO 115
600	TO 34.5
700 AND ABOVE	**DO NOT USE**

Table 4-2. Water Conductivity Recommendations

4.6.6 Water Pressure

Water pressure of between 400 to 550 PSI should be maintained at the nozzles. (Refer to table 3). The minimum distance and nozzle pressure chart shows the minimum pressures versus voltage that must be observed. Lower pressures necessitate decreased distance and cleaning ability. Higher pressures may give more distance but very little improvement in cleaning value. Water stream break-up at higher pressures and makes it more difficult for the operator to see the insulator being washed and remain on target. Excessive pressure also wastes water, making it necessary to re-fill the tank more often and slowing the overall insulator washing operation.

LINE VOLTAGE (KV)	DISTANCE		MINIMUM NOZZLE PRESSURE	
	FEET	METRES	PSI	BAR
4	8	2.43	400	27
7.2	8	2.43	400	27
11	8	2.43	400	27
15	8	2.43	400	27
25	8	2.43	400	27
34.5	10	3.05	450	31
45	10	3.05	450	31
66	12	3.66	450	31
80	12	3.66	450	31
110	15	4.57	500	34
130	15	4.57	500	34
161	15	4.57	500	34
220	15	4.57	500	34
345	18	5.49	550	37.5
400	18	5.49	550	37.5
500	18	5.49	550	37.5
765	20	6.10	550	37.5

Table 4-3: Minimum Safe Working Distances and Nozzle Pressure Recommendations for Energized Lines

4.6.7 Working Clearances: (nozzle to energised equipment)

Refer to table 3 for suggested minimum distances.

Greater distances than those listed in the table should be maintained whenever possible, to compensate for the washer operator's error in judgement of washing distance.

4.6.8 Some Recommended Live Line Washing Practices

4.6.8.1 Wind Conditions

Wind direction is an important consideration when washing live line insulators. This should be determined prior to the beginning of the washing process as it determines the start position of the washing process. (See figure 7 below.). The wash-gun position should be such that over-spray is blown away from adjacent contaminated insulators.

This over-spray could cause the contaminants on nearby insulators to become damp with a subsequent risk of flashover.

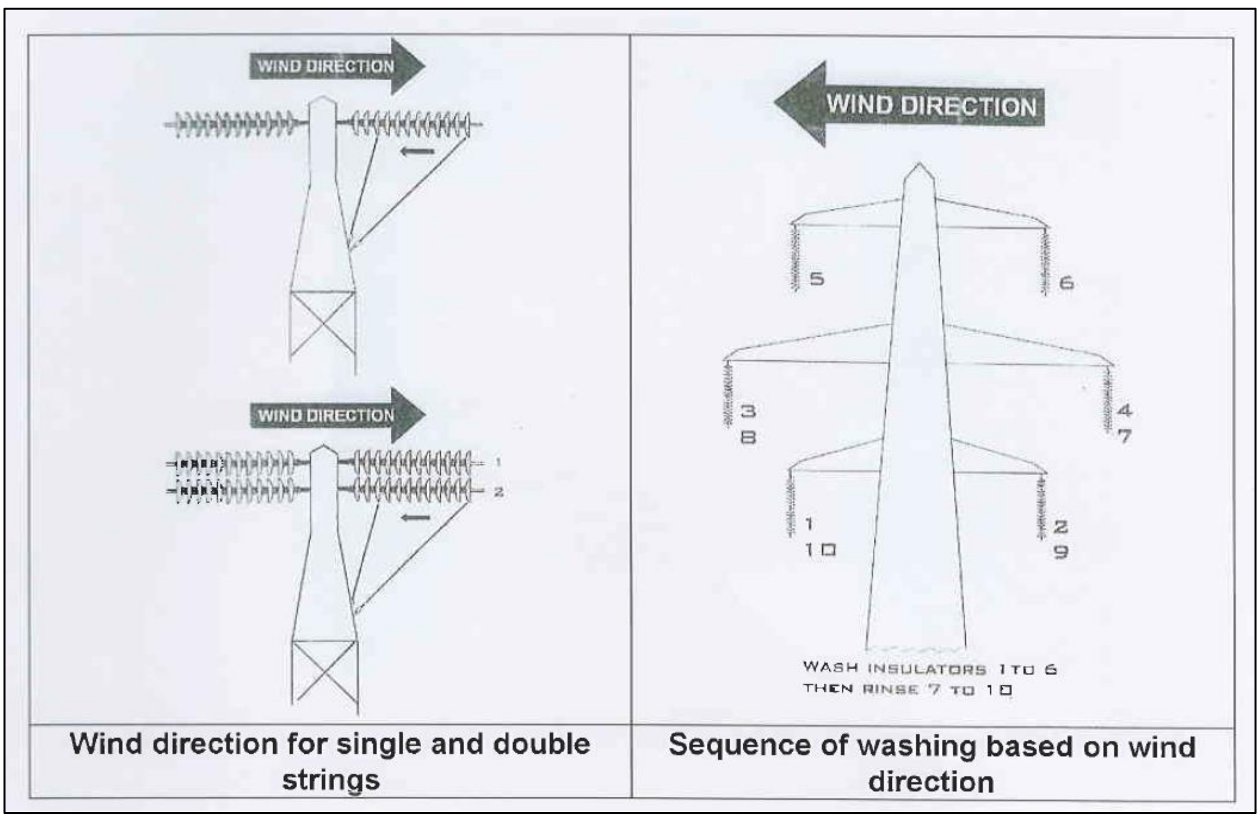


Figure 4-4. Wind direction and sequence of Washing for Single, Double, Tension and Suspension Insulator Strings

4.6.8.2 Insulator String Configurations And Washing

Power line Insulator Strings are configured as follows:

- Vertical, Suspension or I
- Horizontal or Tension
- Vee

The following Washing Techniques for the under listed Insulator String Configurations are recommended:

(a) Suspension Insulator Washing

Washing of Single Vertical, Suspension or I Insulator Strings should be carried out starting from the phase conductor and working upwards towards the supporting Structure.. (See figure 15 below).

Direct the water stream at approximately 45 degrees angle. Start washing from bottom arm towards the top arm Insulator string. Continue to rinse the lower insulators to wash off dirty water dripping from upper arms insulators.

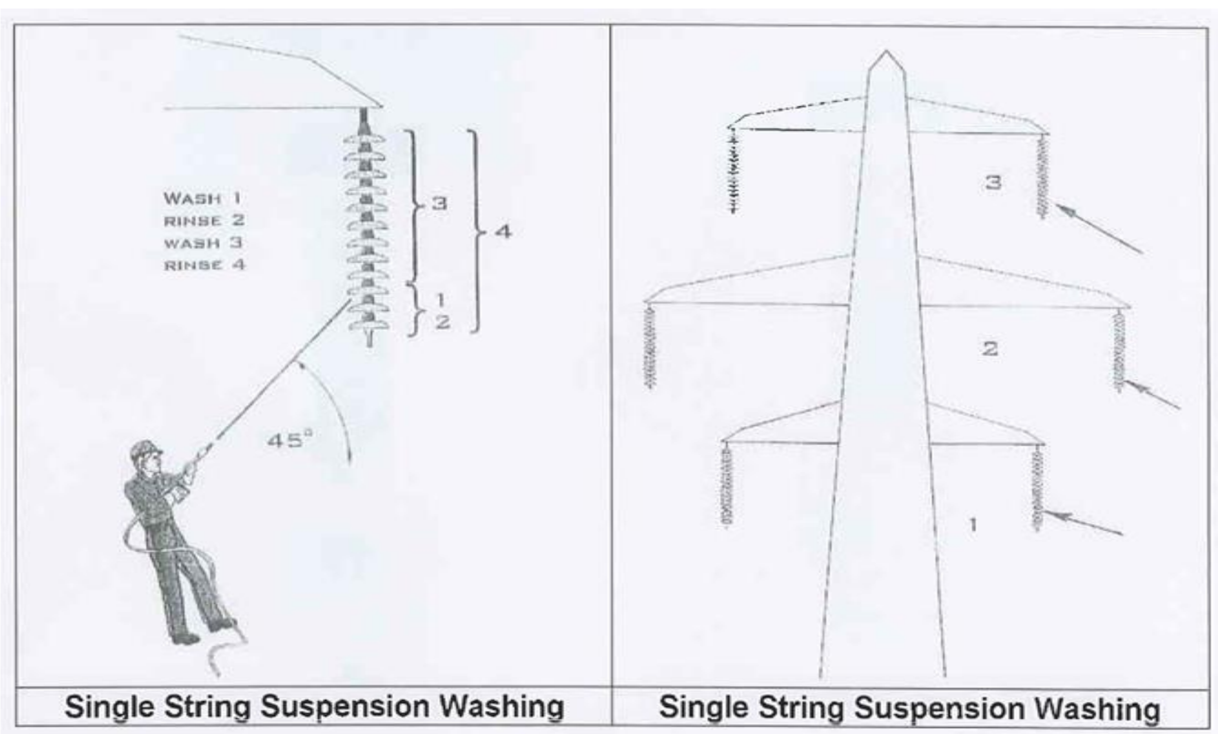


Figure 4-5. Suspension Insulator String Washing

(b) Tension Insulator Washing

Start washing from downwind end, washing in groups of four to six units.

Finally rinse after all units have been washed.

Tension insulator strings may be washed from structure to conductor or in reverse depending on wind direction.

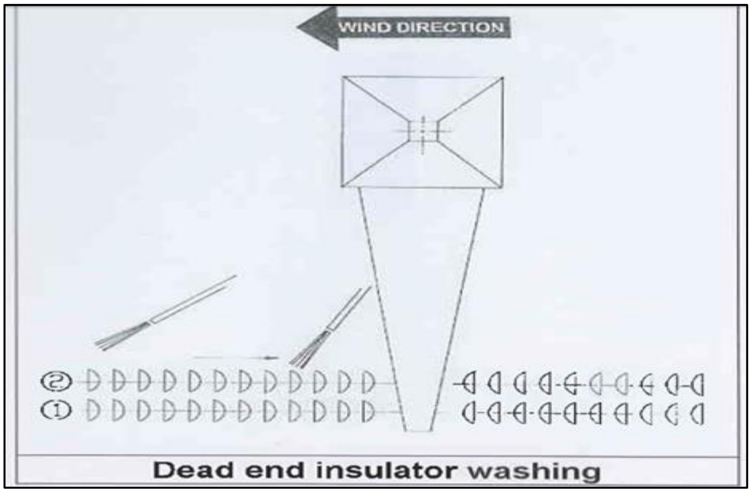


Figure 4-6. Tension Insulator Washing

Figure 4-7. Double Circuit Tension Insulator Washing

4.6.9 Washing Crew

The washer crew would consist of not less that the following three workmen:

- A wash-gun operator with classification of lineman to do the washing
- A truck driver to operate the truck and take care of the water pump and hoses.
- An Assistant to act as flagman and perform duties that may be assigned.

The supervisor in charge may add additional help, if decided necessary.
It is recommended that the day's work be agreed at a brief "tail board" meeting so that all the crew know what is expected of them and when water and other facilities will be provided. When washing in congested locations where damage or dissatisfaction to the public might result from water spray getting on automobiles, buildings, articles hung on lines etc., all efforts should be made to notify owners in advance and the situation taken care of in as near a satisfactory manner as possible.

4.6.10 SAFETY PRECAUTIONS TO BE OBSERVED INSULATOR WASHING

- Wear appropriate Personal Protective Equipment (PPE).
- Crew members must not to point or direct the wash gun and high-pressure water stream at other crew members or personnel (No horse play) as doing so can cause serious injury or death.
- Never wash insulators on wooden structures live.
- Ensure insulator washer is proper grounded.
- Obtain Protection Guarantee (Work Permit, Work and Test Permit and Guarantee) if washing is to be done on de-energized equipment.

4.7 High Voltage Insulator Replacement

This Section describes the procedure for the replacement of insulators in both Tension and Suspension Single String Assembly on de-energised lines.
The schedule for undertaking the replacement of high voltage insulators should be preceded by a prior arrangement for an appropriate Protection Guarantee (Work Permit, Work & Test Permit and station Guarantee).
Temporary Grounds for the protection of the work process:

4.7.1 Tension Insulator String Replacement

4.7.1.1 Tools and Equipment

- Hand line
- Tools Bag

- Temporal Grounds and Grounding Stick
- Wire Rope Sling (capable of withstanding conductor tension)
- Conductor Grip (appropriate size)
- Chain Hoist (appropriate rating)
- Lineman's Scaffold (approved for safety)
- Short Ropes (for lashing insulators)
- Pin Puller / Pusher
- Set Tools Kit (hand tools)
- Shackle or (padding for sling)

4.7.1.2 Materials

Insulators (and socket tongues, hooks, shackles etc. if required)

4.7.1.3 Safety

In addition to Grounding for the Electrical Protection of the worker, the under listed approved safety equipment should be worn and applied in the work process:

- Safety Hard Hats
- Safety Belts and Straps
- Safety Boots
- Safety Harness and Rope
- Safety Goggles
- Safety Gloves

4.7.1.4 Procedures

The following sequence of events should be followed for the replacement of Insulators in Tension String Assembly.

- Install Hand line at convenient point on tower to raise or lower tools and materials.
- Ground the line involved on the two towers adjacent to the tower to be worked on.
- Install Lineman's Scaffold (Platform)
- Install sling and Hoist at the end of the cross arm near the insulator hooking point.

- Descend onto the lineman's scaffold ensuring that safety rope attached to the safety harness is properly secured to the cross arm.
- Connect Hoist to Conductor using appropriate conductor grip.
- Take up on the Hoist to slacken the Tension Insulator string.
- Lash the insulator string to the hoist and chain from the cross arm end towards the clamp end to create slack at the clamp end.
- Pull out the cutter key and disengage the insulator from the socket tongue.
- Unlash the insulator, and release it to come to rest at suspension position.
- Attached old insulator string to the hand line while the new string on the ground is also attached to the hand line on the ground.
- Advise the grounds men to pull the old insulator string downwards while at the same time the new insulator string is being pulled up the tower.
- Hook the new insulator string into the ball-eye, ball-Y clevis or ball hook as the case may be.
- Stretch the insulator string horizontally, lash with rope with rope if necessary and connect the last end insulator pin to the socket eye in the tension clamp at the conductor end. Ensure it is well secured in the socket eye.
- Re-engage the cotter key.
- Slacken the chain hoist and remove the grip on the conductor.
- Repeat procedures above for all other insulator strings for complete re-insulation, and on specific strings if replacing shattered insulators.
- Remove and drop tools.
- Remove and drop grounding sets on adjacent towers.
- Surrender protection guarantee for line to be restored to service.

4.7.2 Suspension String Insulator Replacement

4.7.2.1 Tools and Equipment

- Hand line
- Tools Bag
- Temporal Grounds and Grounding Stick

- Wire Rope Sling (capable of withstanding conductor weight)
- Nylon Webber Sling (capable of withstanding conductor Weight)
- Chain Hoist (appropriate rating)
- Lineman's Rope Ladder
- Pin Puller / Pusher
- Set Tools Kit (hand tools)

4.7.2.2 Materials

Insulators (and socket tongues, hooks, shackles etc. if required)

4.7.2.3 Safety

In addition to Grounding for the Electrical Protection of the worker, the under listed approved safety equipment should be worn and applied in the work process:

- Safety Hard Hats
- Safety Belts and Straps
- Safety Boots
- Safety Harness and Rope
- Safety Goggles
- Safety Gloves

4.7.2.4 Procedures

The following sequence of events should be followed for the replacement of Insulators in Suspension String Assembly.

- Install Hand line at convenient point on tower to raise or lower tools and materials.
- Ground the line involved on the two towers adjacent to the tower to be worked on.
- Install Wire sling and Hoist at the end of the cross arm near the insulator hooking point.
- Install Rope Ladder at 900 to the Chain Hoist.
- Descend onto the lineman's Rope Ladder, ensuring that safety rope attached to the safety harness is properly secured to the cross arm.
- Secure one end of the Nylon Webber Sling into the second Hook of the Chain Hoist, wrap the Nylon Webber Sling around the Conductor and lock the other end into the hook.

- Take up on the Hoist to slacken the Suspension Insulator string.
- Pull out the cutter key and disengage the insulator from the socket tongue.
- Attached old insulator string to the hand line while the new string on the ground is also attached to the hand line on the ground.
- Advise the grounds men to pull the old insulator string downwards while at the same time the new insulator string is being pulled up the tower.
- Hook the new insulator string onto the ball-eye, ball-Y clevis or ball hook as the case may be.
- Engage the conductor end insulator pin into the socket tongue attached to the saddle clamp. (Ensure that the insulator pin is well secured into the socket tongue).
- Re-engage the cotter key.
- Slacken the chain hoist and remove the Webber sling around on the conductor.
- Repeat procedures above for all other insulator strings for complete re-insulation, and on specific strings if replacing shattered insulators.
- Remove and drop tools.
- Remove and drop grounding sets on adjacent towers.
- Surrender protection guarantee for line to be restored to service.

M05– PREVENTIVE DIAGNOSIS (THERMAL VISION)

5.1 Objectives

At the end of this module participants should be able to:

- Define the thermal imaging scanning technology
- Analyse the result of thermos-vision test to prevent a fault in transmission lines

5.2 Introduction

Thermo-vision, thermal imaging or thermo-graphic scanning has developed into maintenance activity which identifies potential faults and allows for swift inspections and fault rectification.

Temperature and weather changes, loading, and equipment operation affect clamps and joints, equipment terminals and terminations. Loose joints develop sparks which cause overheating cause damage to equipment or circuit if not identified and corrected. Some situations have caused fire outbreaks and eventual unexpected outage to power supply and high cost in repairs and replacement.

5.3 Thermography

Thermography is Science of acquisition and analysis of thermal information from non-contact thermal imaging devices.

5.4 Applications

On transmission lines and in substations, thermography is applied in inspection of electrical equipment by obtaining heat distribution pictures of thermal equipment. This inspection method is based on the fact that all deteriorated terminals increase in resistance causing an increase in their temperatures. Increase in temperature in an electrical circuits could be due to loose connections or overloading of the circuit. By observing the heat patterns in operational system components, faults can be located and their seriousness evaluated.

The inspection tool used in Thermography is the Thermal Camera also known as Infrared Camera. The cameras measure the natural emissions of infrared radiation from a heated object and produce a thermal picture. Modern Thermal Imagers are portable with easily operated controls. As physical contact with the system is not required, inspections can be made under full operational conditions resulting in no loss of transmission or downtime.

Figure 5-1. Picture of a Thermal Imager

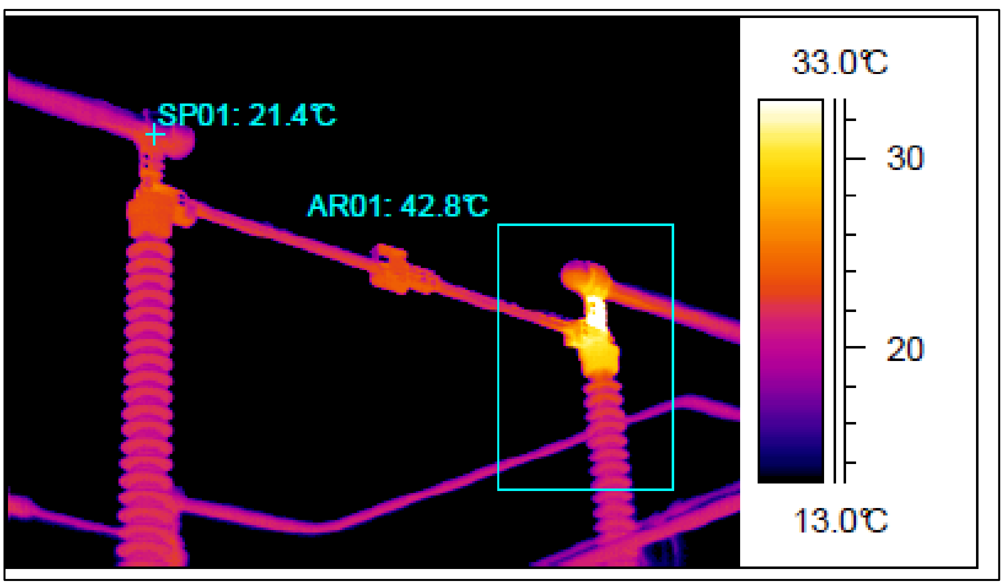


Figure 5-2. Measurement of Temperature using Infrared Methods

5.5 The Theory behind Infrared Imaging

All objects with temperatures above absolute zero (-273.15 degree Celsius) radiate electromagnetic energy. The amount of energy emitted is however related to the object's temperature. The Infrared Camera quantifies temperatures by measuring the energy emitted by the object without physical contact.

5.5.1 Electromagnetic Spectrum

The energy from a heated object is radiated at different levels across the electromagnetic spectrum. In most industrial applications it is the energy radiated at infrared wavelengths which is used to determine the object's temperature. The figure below shows various forms of radiated energy in the electromagnetic spectrum. X-rays, Ultra Violet, Infrared and Radio are all emitted in the form of a wave and travel at the speed of light only differing in their wavelength which is related to frequency.

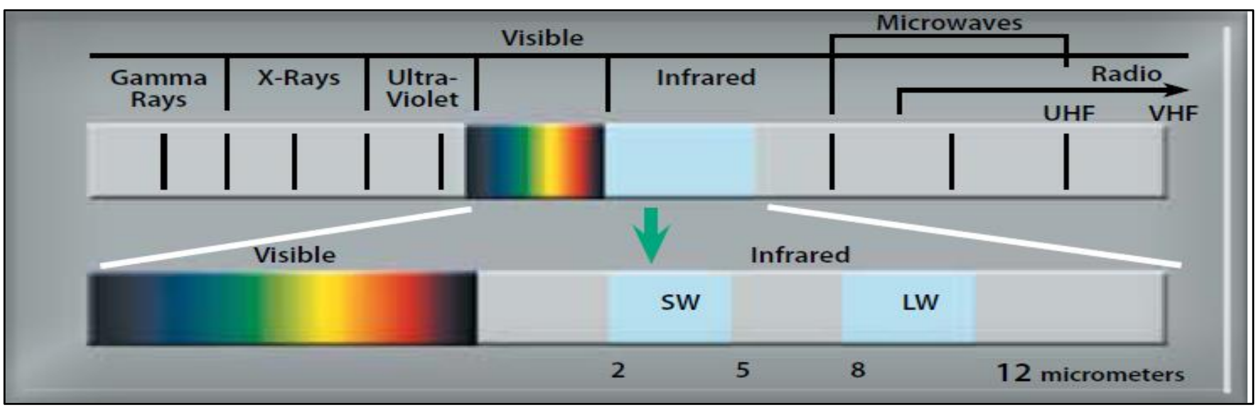


Figure 5-3. The Infrared region of the Electromagnetic spectrum

An infrared camera detects infrared energy (heat) and converts it into an electronic signal, which is then processed to produce a thermal image on a video monitor and perform temperature calculations. Heat sensed by an infrared camera can be very precisely quantified, or measured, allowing you to not only monitor thermal performance, but also identify and evaluate the relative severity of heat-related problems.

The vast majority of infrared temperature measurement is made in the range 0.2 to 20 microns. The human eye responds to visible light in the range 0.4 to 0.75 microns.

5.5.2 Emissivity

The amount of energy radiated from an object is dependent on its temperature and its emissivity. An object which has the ability to emit the maximum possible energy for its temperature is known as a Black Body. In practice there are no perfect emitters and surfaces tend to radiate somewhat less energy than a Black Body.

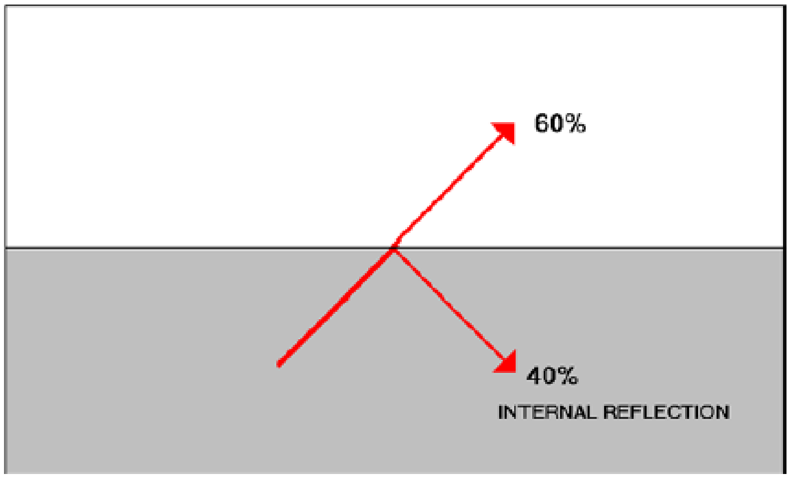


Figure 5-4. The Infrared energy reflected at a body surface

As energy moves towards the surface of an object, a certain amount is reflected back inside and never escapes by means of radiative. From this figure above, it can be seen that only 60% of the available energy is actually emitted. The emissivity of an object is the ratio of the energy radiated to that which the object would emit if it were a Black Body.

Hence emissivity is expressed as:-

$$Emissivity = \frac{Radiation\ emitted\ by\ an\ object\ at\ temperature\ T}{Radiation\ emitted\ by\ a\ Black\ Body\ at\ temperature\ T}$$

Emissivity is therefore an expression of an object's ability to radiate Infrared energy.

5.5.3 Emissivity Values of Different Materials

The value of emissivity vary from one material to another. With metals rough or oxidised surfaces usually have higher emissivity than a polished surface.

Here are some examples:

Material	Emissivity
Steel polished	0.18
Steel oxidised	0.85
Brass polished	0.10
Brass oxidised	0.61
Aluminium polished	0.05
Aluminium oxidised	0.30
Cement and Concrete	0.90

Emissivity values

For an opaque object, **Emissivity + Reflectivity = 1.0**

Hence a highly reflective material is a poor emitter of infrared energy and will therefore have a low emissivity value.

5.5.4 Effects of Emissivity

The temperature of an object cannot be determined by simply measuring its emitted infrared energy since two materials with the same temperatures and different emissivity will radiate different levels of heat hence produce different temperature readings in the infrared camera. Have the object's emissivity evaluated by a laboratory method.

The problem of emissivity can be compensated for by mathematically correcting the temperature measurement value. This is usually carried out within the signal processor of the Thermal Camera. Most modern Thermal Cameras have a compensation setting which can quickly and easily be set by the operator.

The object's emissivity must therefore be known.

The emissivity of an object can be determined as follows:

- Consult manufacturers literature (always ensure these have been evaluated at the operating wavelength of your Thermal camera as emissivity can vary with wavelength).
- Have the object's emissivity evaluated by a laboratory method.

When carrying out Thermographic (infrared) inspections, faults are often identified by comparing heat patterns in similar components operating under similar loads. This is an alternative to very precisely predicting the emissivity of each individual component and obtaining absolute temperature values.

Thermal cameras being used to inspect electrical equipment. With equal load and emissivity the temperatures of the three measurement points should be the same.

5.6 The Thermal Imagers

Thermal Imagers or Thermo-vision Cameras are sophisticated devices which measure the natural emissions of infrared radiation from a heated object and produce a thermal picture. They have motorised focus is used to obtain a clear image at different distances from the thermal imager, LCD screen for real time thermal image display. A built in memory system enables the simple capture of a large number of thermal images. Thermal images are stored on a removable compact flash memory card. This on board facility enables stored image recall to the viewfinder and selective image deletion. Several seconds of digital voice clip may be stored with each image and replayed or re-recorded on board the imager. The sound file can be replayed in by the imager or with image processing software. Temperature Measurement: Temperature measurement at single point in the scene is possible.

5.6.1 Post Processing:

This facility enables the generation of further temperature analysis in the imager viewfinder on stored images. A single movable point enables spot measurement at any point in the scene and a movable cursor generates a temperature profile trace.

5.6.2 Image Processing Software

Frames of interest may be stored as an image file for record purposes, or be subjected to a range of processing functions as follows:

- File handling: save, delete and directory facility
- Image coloring: the image may be colorized using any one of five color palettes.
- Temperature measurement: a variety of different modes are available to enable temperature measurement at any point in the scene, calculation of maximum, minimum or mean from within any defined area in the scene, profiles, histograms, and isotherms.

- Parameter changes: parameters saved with the stored image may be changed within the software. These include emissivity, and background temperature.
- Image enhancements: filtering, and zoom facility.
- The software system is menu driven making it extremely easy to use.
- Report Writer: The image processing system provides a report writing facility. This may be used to provide a hard copy record of the thermal image accompanied by an imported photograph and any other information for reference purposes.

5.7 Thermographic Inspection on Transmission Lines

With regular thermographic (Infrared) inspection on joints in transmission lines potential problems will be identified reducing downtime during maintenance and bringing unplanned outages to absolute minimum.

Thermographic inspections on transmission lines are done once in a year. It can be done in conjunction with Ground or aerial patrols.

5.7.1 Inspection Checklist for Thermographic inspections on Transmission Lines:

Inspection check list for thermal inspection include:

- Conductor Joints
- Bolted Connections
- Terminal equipment at the substation

5.7.2 Tools and Materials for thermographic inspection

- Thermal Imager/ Infrared camera
- Notebook and Pen/Pencil

5.7.3 Precautions

The absolute limit of approach according to the equipment voltage level must be kept to avoid electrocution.

5.7.4 Advantages of Thermographic (Infrared) Inspections

- Inspections can be made under full operational conditions and hence there is no loss of transmission.
- Equipment can be diagnosed hence will only be maintained if faulty. This will reduce transmission outages and also reduced the cost of downtime.
- Transmission line and Substation equipment reliability may be increased
- Repairs can be scheduled for the most convenient time since the severity of fault can be predicted
- Quality of repair work can be inspected using Thermographic inspections.

5.7.5 Priority Classification

These standards are mostly strictly adhered to and applied, although the client's subjective interpretation as to equipment criticality, existing maintenance schedules, spares availability etc., prevails.

1	> 30 DEG. C	Repair immediately
2	21 - 30 DEG. C	Schedule repair as soon as possible
3	11 - 20 DEG. C	Schedule repair during next shutdown
4	6 - 10 DEG. C	Inspect component at next opportunity
5	<6 DEG. C	Recordable indication only, no action at present

5.8 Example of Thermal Image

5.8.1 Conductor and Jumper Socket

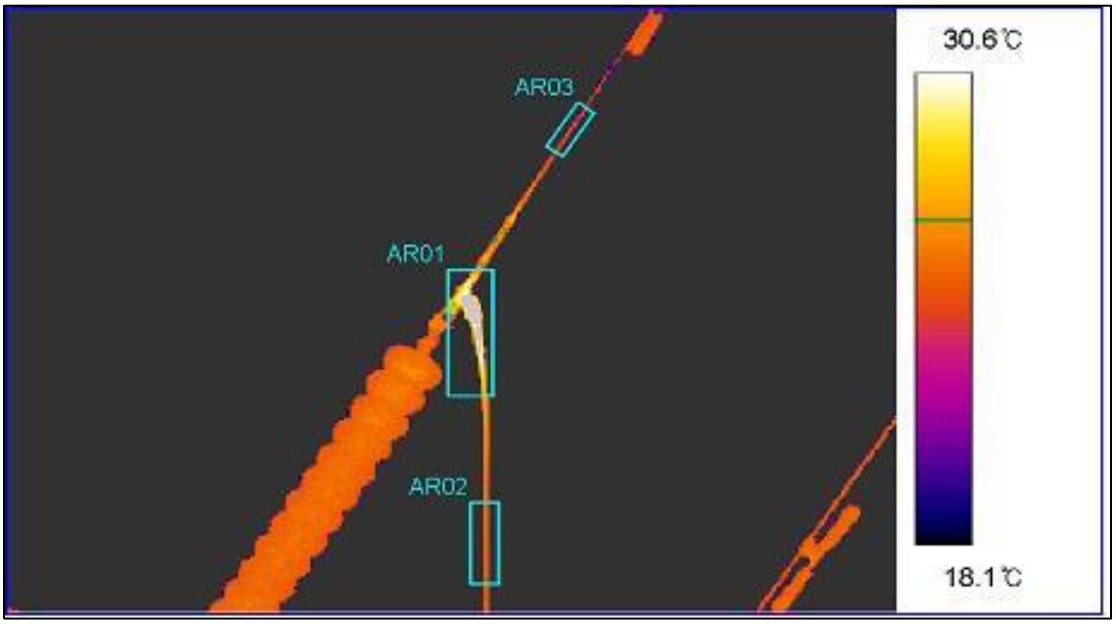


Figure 5-5. Conductor and Jumper Socket

5.8.2 Mid-span Compression Type Repair Sleeve

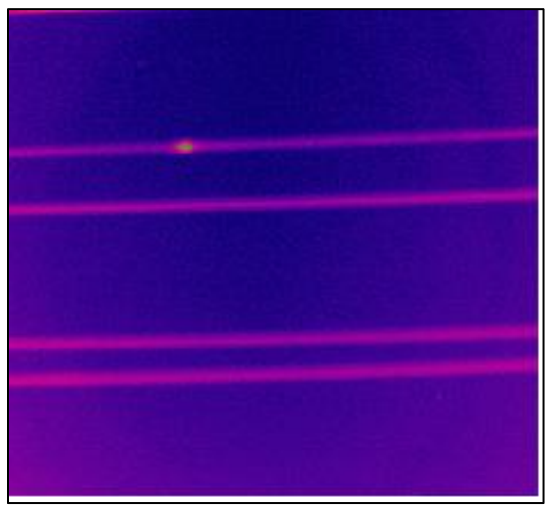


Figure 5-6. Mid-span Compression Type Repair Sleeve

M06 – EMERGENCY RESTORATION WORK

6.1 Objectives

At the end of this module participants should be able to:

- Discuss past transmission line emergencies and how they were dealt with
- Present emergency restoration plan and emergency preparedness
- Understand emergency restoration structure and its installation procedure

6.2 Introduction

Transmission line 'emergency' occurs when interruption to power transmission cannot be restored by local crew within a defined period, 24 hours or more. The restoration time may be difficult to predict when the damage is widespread or still continuing. The majority of outages on the transmission system can be effectively restored by the Area responsible using normal procedures. Abnormal weather conditions, natural disasters tower vandalism or other emergencies may create extensive damage which is beyond the capability of the Operational Areas with respect to the safe and effective restoration of service within a reasonable time period.

Such situations are considered emergencies and warrant the assistance of outside parties and the activation of an Emergency Coordination System at various levels e.g. the Area or Head Office level depending on the emergency classification.

Emergency Coordination System is activated in emergency situations only. It does not apply to normal planned or prearranged work or anything that can be looked after by the Areas. Areas requiring equipment or crew to attend to a minor outage or planned outage work should make arrangement through the normal channel.

The purpose of this module is to outline emergency organization structure and responsibilities at various levels - Head Office and Area levels and also to outline restoration procedures and use of emergency restoration structures (ERS) to construct a by-pass line. The discussions will be limited to GRIDCo emergency restoration works.

6.3 Transmission Line Emergencies

A present or imminent event that threatens business continuity due to failure of critical transmission line. Generally transmission lines emergencies are caused by natural phenomenon or are man-made

6.3.1 Emergencies Caused by Natural Phenomena

- Ice storm
- Wind Storm
- Earthquakes
- Hurricanes, Tornados
- Floods
- Avalanches/Landslides/Erosion
- Volcanic Eruption

Seasonal flooding of rivers and streams can erode tower foundations and if not checked can cause a tower to collapse. Examples of eroded tower bases on the Konongo - Kumasi 161kV transmission line is shown in Fig. 6-1 bellow.


Figure 6-1. Eroded Tower Foundation on Konongo-Kumasi (J2K) Line

Strong winds, tornadoes and hurricanes also can cause transmission line damage

Figure 6-2. Damage to Power line caused by Storm

6.3.2 Man-made Emergencies

- Vandalism
- Terrorism
- Sabotage
- Illegal Mining/Quarrying
- Vehicle Accidents

Figure 6-3. Damaged to Tower foundation by Bulldozer

6.4 Threats to GRIDCo Transmission Lines

Majority of the threats to GRIDCo's transmission lines are man-made, illegal mining within the right of way, tower vandalism, blasting and quarrying close to the transmission lines and vehicles running into the towers.

6.4.1 Illegal Mining (Galamsey)

Activities of 'galamsey' operators within the lines right-of-way (ROW) pose serious threats to the transmission lines. Their operations result in deep excavations at the bases of some towers and cause damages to the lines ROW and the tower footings. Their activities are concentrated on the Tarkwa – Takoradi, Bogosu – Prestea, Prestea – Obuasi and Tafo – Akwatia lines. Galamsey activities have also been recorded along the Bui - Sawla transmission line in northern Ghana. Damage to the right of way caused by illegal mining is shown in Fig. 6-4 bellow.

Tower base flooded by Galamsey operations

Dangerous Galamsey holes in R.O.W.

Right of way degraded by Galamsey operstors

Galamsey operation close to tower

Fig 6-4. Illegal Mining Galamsey

6.4.2 Tower Vandalism

The incidence of vandalism of transmission line towers persists and has assumed alarming proportions on some lines especially the Akosombo -Volta lines, Dunkwa – Obuasi lines and Volta-Achimota Lines. Transmission lines have been vandalized recklessly by criminals.

Large quantities of tower struts, bolts and nuts, identification nameplates, grounding cables and other tower members have been stolen from a number of towers within the transmission lines network.

ransmission lines in areas that are prone to tower vandalism have tower members either secured with anti-vandal fastener or the bolts and nuts were tack-welded to prevent the criminals from removing them. In some areas, the criminals cut the tower members secured with anti-vandal fasteners and steal them leaving the maintenance people with the task of undoing the weld and fasteners before replacing the tower members.

GRIDCo, in collaboration with national security agencies have taken various measures to control the above illegal activities. However, tower vandalism and 'galamsey' activities within the lines ROW still continue to be recorded.

Such acts of vandalism led to the collapse and damage of two (2No.) towers at Nsuta near Tarkwa on the Tarkwa – Takoradi (R1T) line in April 2005.

Another tower collapse occurred on the Akosombo-Volta transmission line in May 2006 due to Vandalism. Images of the collapsed and damaged towers are shown in Fig. 6-5 below.

Fig 6-5. Vandalized Tower Obuasi-Dunkwa

The criminal also stole almost all the tower bracings on the tower from the leg extension to the superstructure on the New Obuasi – Dunkwa line. Early detection of the theft by maintenance crew prevented another tower collapse.

Maintenance men immediately replaced the stolen members to restore the structural integrity of the tower

6.5 Some Emergencies that occurred in recent past

Acts of vandalism led to the collapse and damage of two (2No.) towers at Nsuta near Tarkwa on the Takoradi- Tarkwa (R1T) line in April 2005. The two damaged towers were replaced with four (4No.) monopoles and the line restored to service at great cost to the Authority and the nation. The damaged towers are shown below in Fig. 8 and Fig. 9

Barely a year after the R1T tower collapse another tower collapse occurred on the Akosombo-Volta transmission line in May 2006 due to tower vandalism. The damaged towers are shown in the figures below

Figure 6-6. Collapsed Tower on R1T

Figure 6-7. Collapsed Tower on Akosombo-Volta Line

6.5.1 Damaged Tower Cross-arms on 225kV Prestea – Rivera Line

Tower cross-arms were damaged on the Prestea – Rivera 225kV line when a huge tree even though it was outside the right of way landed on the conductors when it fell because it was tall enough causing a cascading failure of five tower cross-arms. (Trees of such height that they could breach the limit of approach of the line voltage or fall on the conductor if it should fall in the direction of the line are termed danger trees) One tower with a damaged cross-arm is shown in Fig 6-8 below

Figure 6-8. Damaged Cross-arm on Prestea – Rivera line

6.5.2 Restoration of Damaged R1T Transmission Towers.

Four Monopole structures were used to replace the collapsed and the damaged lattice towers. The poles were obtained from Tarkwa-New Tarkwa project spares which were available at the time. The poles were buried directly in soil stabilized with special cement mix with the soil. Polymer post insulators were used and the conductors were restrung

Figure 6-9. Excating foundation for monopole structure on R1T

Figure 6-10. Monopole Erection with crane

6.5.2.1 Disadvantages of this method

- Pole was heavy and required special truck to transport to site.
- Road was constructed to access the site.
- Crane required for erection and installation procedure was time consuming.
- Foundation excavation required.
- The location was swampy so the ground had to be stabilized.

6.5.3 Restoration of Damaged Akosombo – Volta Line

Figure. 6-11. Restoration of Damaged Line

6.5.3.1 Challenges faced with the Akosombo – Volta restoration procedure

- Spares were not readily available for the repair works.
- Traditional tower erection method was used.
- Waited for about 30 days for tower foundation concrete to cure before tower erection commenced.
- A Crane was used for tower erection so an access road was constructed to work location

6.6 Shortcoming of the Old Restoration Methods

Lack of emergency preparedness resulted in:

- No advance planning for emergency restoration
- No emergency spares and equipment
- Workers were not trained in emergency restoration work
- Improper coordination of emergency restoration works

- poor logistics and difficulties in deploying the required crew.

All the above led to prolonged restoration time

6.7 Impact of Prolonged Outages on the Transmission System

Total losses resulting from an extended outage of a key transmission line is site specific and can be considerable. A few of the utility's direct losses are:

- Cost of restoration (typically inversely proportional to the outage time)
- Higher grid losses on alternate transmission lines
- Contractual penalties for non-availability of the transmission line

  possible higher generation cost or costs for power plant reductions or shutdowns. If the transmission line failure results in power shortages at load centers, additional losses might also include:

- Lost revenue from customers contractual penalties from performance base rate-making structures

6.8 Emergency Restoration Planning

The challenges enumerated above can be avoided or minimized with Emergency Restoration Planning.

6.8.1 Advance Planning

Advance planning and preparation is necessary for the effective management of emergencies. Planning will help avoid the above problems and provide for a quick and orderly response to the emergency, while making the most effective use of internal and external resources.

The use of common procedures on Emergency Coordination is the first step towards a consistency in the organizational structure and responsibilities for the various emergency coordinating units. To be effective the plan must be up to date. Revisions must be made as changes occur.

6.8.2 General Guidelines for Advance Planning

- Define the transmission network

- Define the risks and hazards the network faces
- Identify and establish emergency management preparedness and response team
- Goals for preparedness and response planning
- Determine current capacities and capabilities
- Develop integrated plan
- Ensure thorough communication planning
- Identify resources / financing
- Identify emergency restoration spares
- Train the restoration team
- Critique and improve plan

Some of the other problems that can impede early restoration of service during an emergency even after an effective Emergency Restoration Planning are inaccessibility to the damaged line sections caused by lack of vehicular access due to overgrown vegetation, floods etc. logistics must be put in place for an early response in cases where the line sections are inaccessible.

6.8.3 Organization & Responsibilities

Classify Emergencies into three categories 1, 2 and 3 according to severity. Category 1 being the most severe

Appoint Emergency Coordinators to be responsible for each category of emergency.

- **CATEGORY 3:** This occurs when an Operational Area cannot effect safe and efficient restoration of service within a 24 hour period without requesting assistance outside the Area.
- **CATEGORY 2:** This occurs when Department cannot effect safe and efficient restoration of service within a 24 hour period without requesting assistance from outside the Department.
- **CATEGORY 1:** This occurs when GRIDCo cannot effect safe and efficient restoration of service within a 24 hour period without requesting assistance from outside GRIDCo

Restoration times may be difficult to predict initially. The damage could be widespread or continuing to develop or both in which case it is advisable to request outside assistance. The situation should be periodically reevaluated and the category upgraded if deemed appropriate.

6.8.4 Assessing the Damage Line Section

Damage assessment is one of the most important aspects of coping with a major outage. Emphasis should be placed on damage assessment since efficient restoration of power is dependent on early notification on the extent of the damage to the system. Helicopters are most useful for this activity when the location is inaccessible.

When an interruption takes place in an Area, the Area Manager or his delegated representative has the responsibility for assessing the extent of damage to the transmission system.

6.8.5 Emergency Coordinators / Responsibilities

Emergency Level	Coordinator
Category 3	Area Manager or his delegated representative
Category 2	Director SSN/NNS or his delegated representative
Category 1	Director NPD or his delegated representative

6.9 Emergency Preparedness

6.9.1 Emergency Contact List

Contacts of all Emergency Coordinators including their cell phone numbers shall be compiled and maintained. The contact list shall be updated as and when people are moved either through transfers or retirements.

A list of service providers like haulage companies, crane service providers and construction companies should also be kept and updated regularly.

6.9.2 Emergency Restoration Spares

One of the problems that impede early restoration of service after an emergency is lack of replacement spares. Advance planning and stocking of adequate spares will help avoid delays in restoration works and provide for a quick and orderly response to the emergency, while making the most effective use of internal resources.

Emergency Coordinator shall be responsible for ensuring that adequate spare are available at all times for all Category of line emergencies. For effective planning, for procurement and stocking of adequate emergency restoration spares, he shall:

- Define the transmission network – consider different types of towers, conductors, line hardware etc. in the network
- Define the risks and hazards the network faces and the extent of damage likely to occur. Consider the worst case scenario (cascading collapse of towers involving 3 km of damaged line).
- List all spares required to quickly restore the line back to service – consider the worst case scenario.
- Identify strategic locations within the system for establishing stores for emergency spares. – Consider proximity to work location, time and availability of resources to efficiently transport spares to site.
- Take regular stock of emergency spares (at least twice a year) and ensure that there are adequate spares to cover the worst case scenario of emergencies.
- Make sure that emergency spares are only used for the purpose for which they are intended. Under no circumstances shall emergency spares be used for regular maintenance.
- Replace as soon as possible spares that have been used for emergency restoration work.
- Take note of any changes that have been made to the line as a result of emergency restoration works or during regular maintenance and update spares requirement accordingly.

6.9.3 Training Periodic Drills

The timely deployment of work crew with the requisite skill and attitude could significantly reduce time spent on emergency restoration works. Advance planning and training of workmen is necessary for quick and safe restoration of power after an emergency.

The responsibility for selection and training of emergency response crew shall rest with the Emergency Coordinators.

For effective planning and quick deployment of emergency response crew to site, he shall:

- Define the types of emergency that could occur and types of work likely to be encountered e.g. line rebuilding, tower replacement, conductor repair, tree clearing, etc..
- Select staff for emergency response crews based on their experience in works identified in item 1 above.
- Ensure that the selection of staff from assisting Areas is done in such a way as not do reduce the minimum staff required for normal maintenance in the Areas.
- Liaise with the Training School and provide training for line maintenance Staff in emergency restoration works. Staffs so trained shall be issued with certificate
- Conduct mock exercises to test the readiness of crew.

6.10 Bypass Line.

When the damage assessment show that the extent of damage to the line is such that it will take considerable length of time to rebuild the damaged line section, a By-pass line is constructed to quickly restore the line back to service whiles rebuilding of the damaged section is done at a later date. Emergency restoration structures are used to construct the By-pass line. The by-pass line should be constructed some distance away from the damaged line section. This will ensure that the repair of the damaged line can be carried out very safely without line outage at a later date. Examples of single circuit and double circuit by-pass lines are shown below:

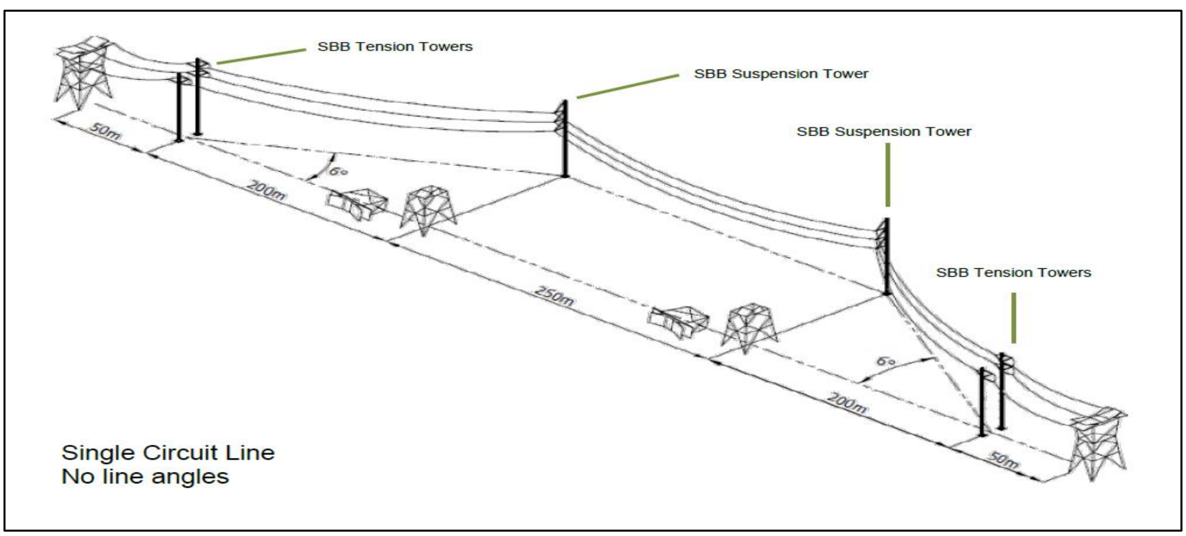


Figure 6-12. Single Circuit By-pass Line

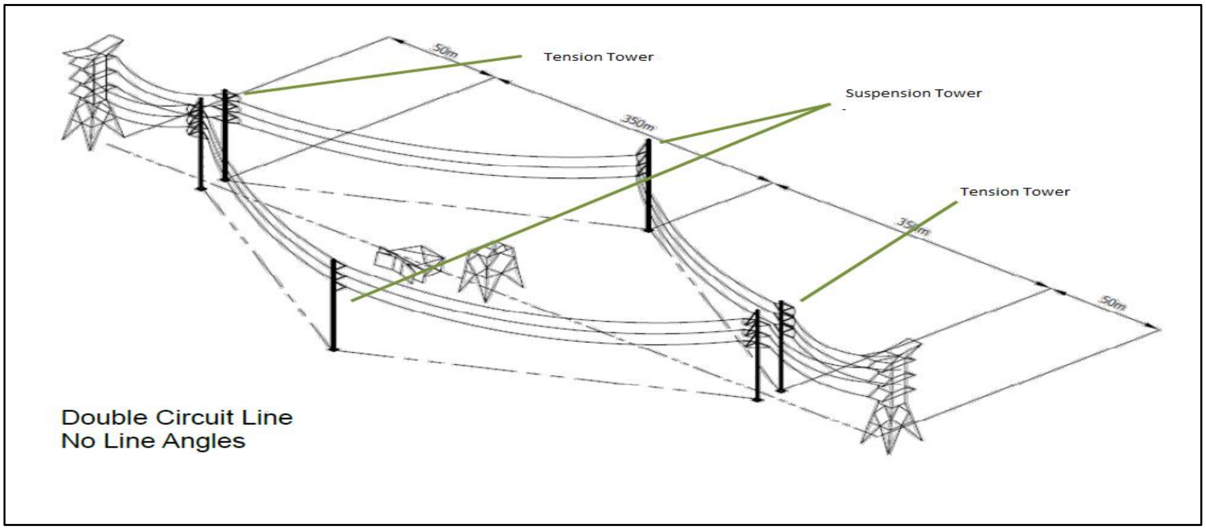


Figure 6-13. Double Circuit By-pass Line

6.11 Emergency Restoration Structures

Transmission line damage by storm, vandalism or other circumstances could impact severely on the reliability of national grid and interconnection lines. The cost resulting from loss of power supply could be substantial if the line is not restored back to service quickly.
Emergency restoration structures (ERS) are invaluable assets for timely restoration of lines back to service whiles the permanent structures are repaired or replaced. However in special cases, they are used as permanent replacement for the damaged line.
The structure must be easy to handle and quick to install. The foundation of an emergency restoration structure shall not be made of concrete which requires more time to cure.

6.12 The SBB Emergency Restoration Structures

GRIDCo procured two sets of Emergency Restoration Structures from SBB in Canada under the 330kV Aboadze-Volta and Volta-Tornu Transmission line project. SBB engineers came down to Ghana and trained selected GRIDCo staff in the installation of the ERS including the use of the structure design software.
By using SBB ERS, the transmission towers can be replaced in just a few hours by creating a by-pass and power transmission can be resumed much faster than with the traditional methods.

When the new transmission tower is installed, the SBB towers can be removed as quickly as they were installed and put back in a container until the next use.

6.12.1 Components of SBB Emergency Restoration Structure

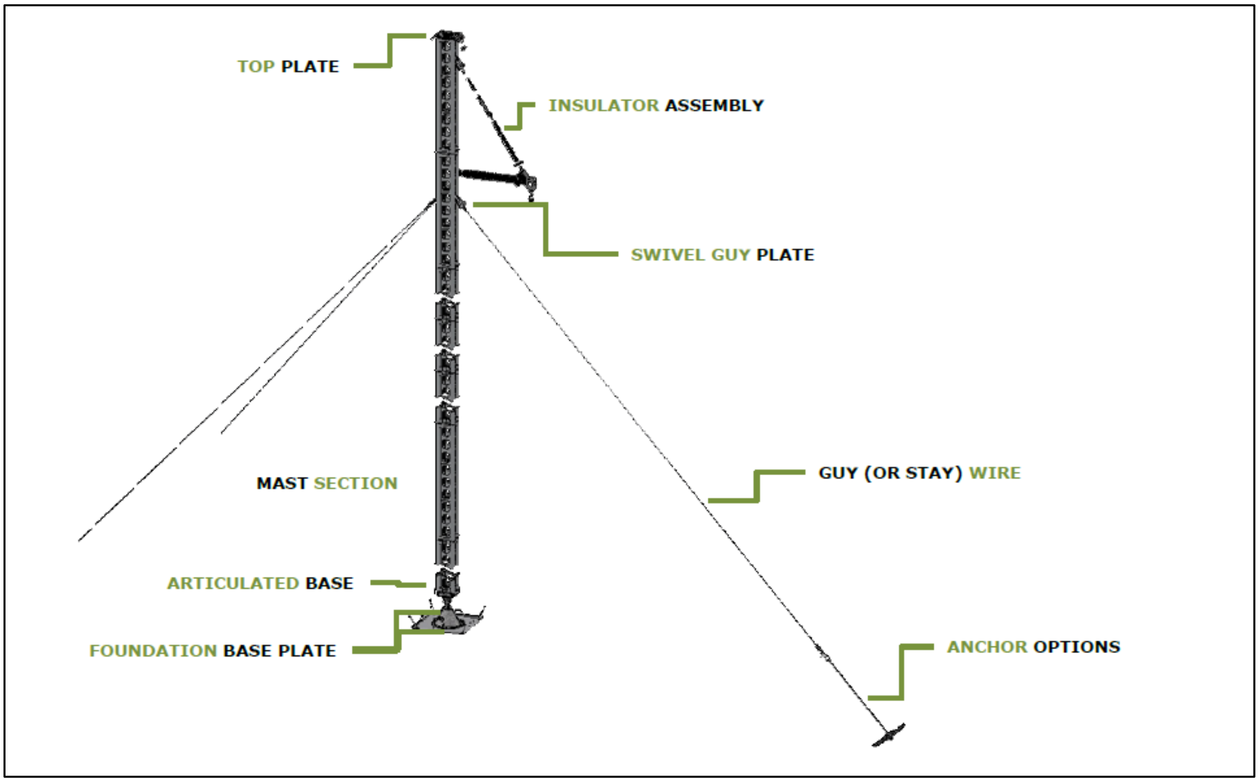


Figure 6-14. Components of SBB Emergency Restoration Structure

6.12.2 Foundation Plate (92Kg. 1.2m X 1.2m)

The foundation plate's role is to support the tower by distributing the loads evenly to the ground. It is placed directly on the ground, without the need for a concrete foundation. It is installed on a leveled ground and can also be complemented by a larger sub foundation especially designed for very soft soils with minimal bearing capacity.

6.12.3 Special Foundation for Soft Soil

In some cases soil conditions can get very challenging, with soils becoming very soft and marshy. To allow installation of our ERS towers in such conditions, a special foundation plate is used to better spread the vertical loads.

In the same cases as described above, it is also necessary to provide special anchor plates for very soft soils. Depending on the prevailing soil conditions (soft, hard, normal), different anchoring arrangements could be provided. Some examples of anchors are included above:

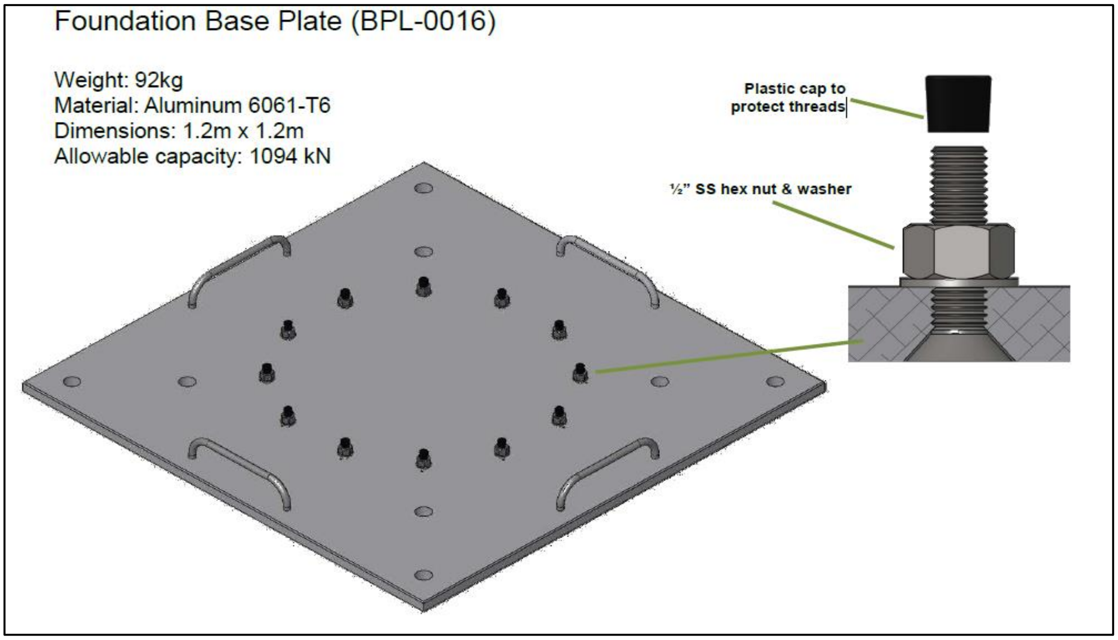


Figure 6-15. Foundation Base Plate

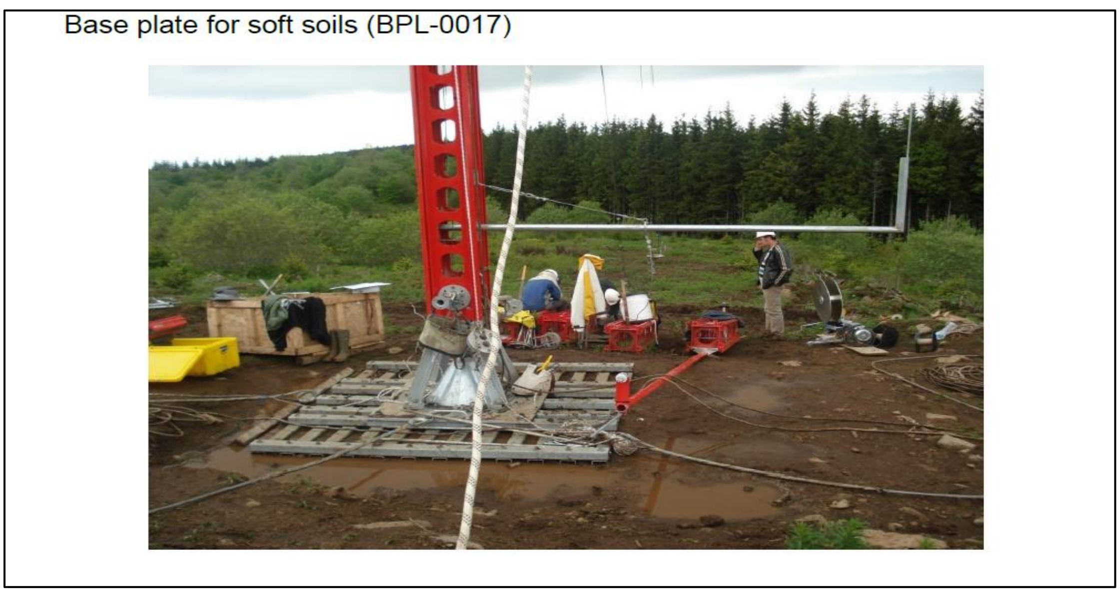


Figure 6-16. Special Foundation for Soft Soil

6.12.4 Articulated Base (133kg. 84cm X 74cm)

It consists of a fixed cone and pivoting aluminium head connecting the tower to the foundation plate. It allows the tower to move under various loads in order to avoid torsion. The design allows a rotation of 360 degrees in all directions, which also means that the tower can be erected by tilting it up using a ball joint gin pole.

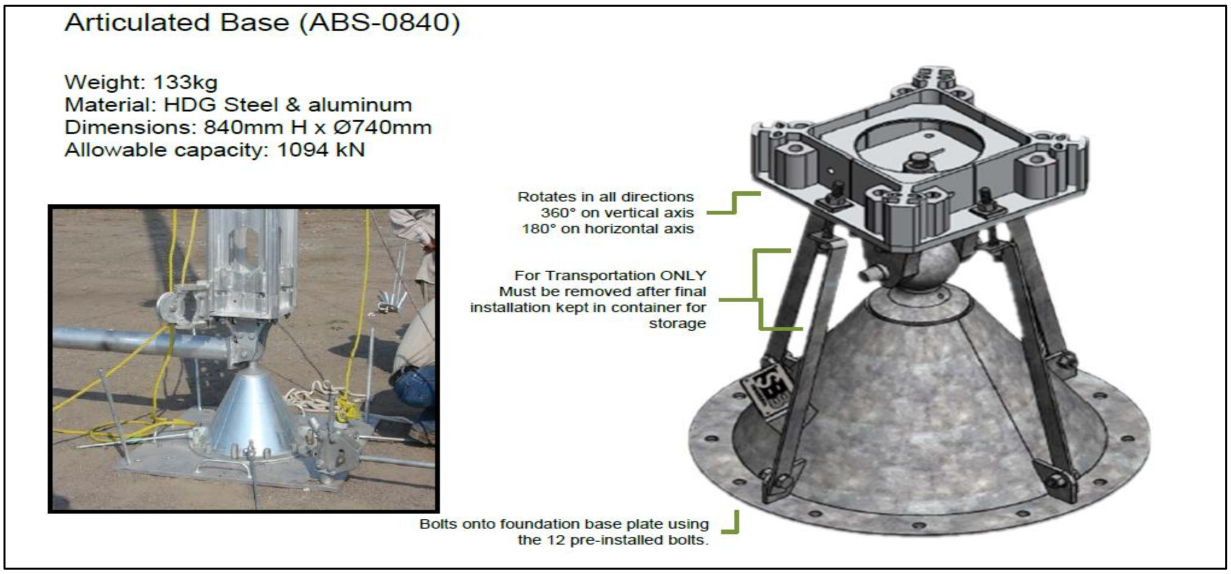


Figure 6-17. Articulated Base

6.12.5 Mast Section (135Kg. 412mm X 412mm X 2.9m)

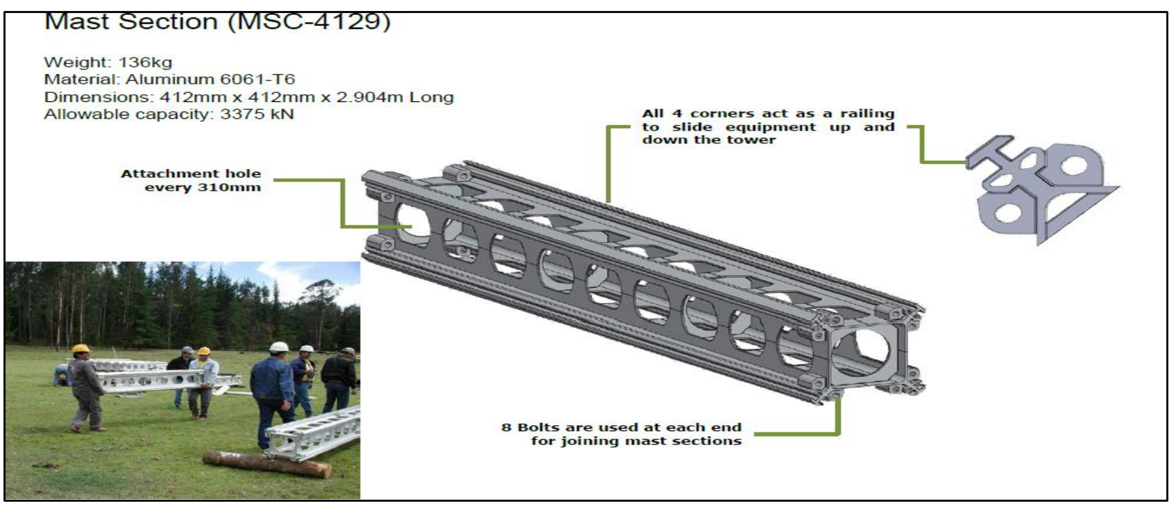


Figure 6-18. Mast Section

Each lightweight section is made of high strength aluminium alloy 6061-T6 and includes 9 openings on each side to allow attachment of a wide range of accessories (swivel guy plates, insulator brackets, platforms, etc.).

Sections also include an integrated rail system on each corner, which allows the sliding gin pole and the fall arrest device to slide from bottom to top of the tower without interruption or disassembly, even with guy wires installed.

6.12.6 Swivel Guy Plate

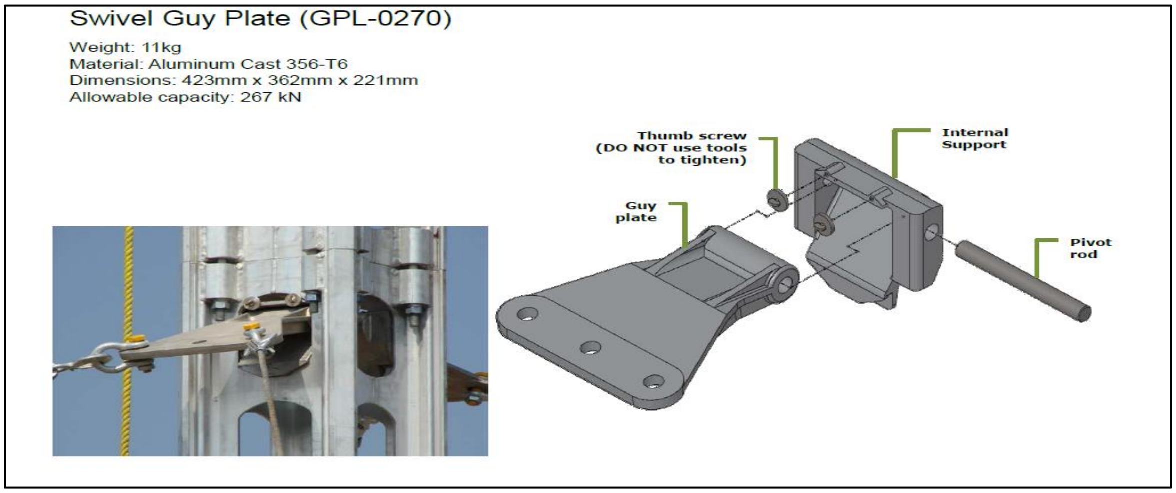


Figure 6-19. Swivel Guy Plate

The aluminium guy plate is used to attach guy wires, brace of line post insulators and strain insulators to the tower. It is designed to be installed anywhere on the tower, in less than 30 seconds. The swivel allows a perfect alignment with the guy wires.

6.12.7 Suspension Insulator Assembly

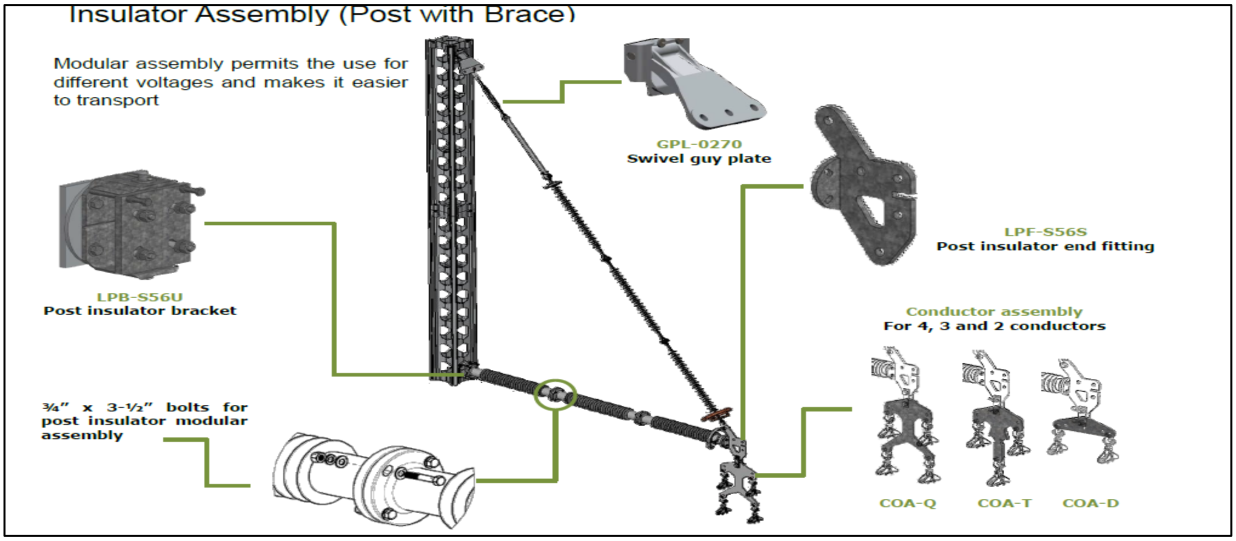


Figure 6-20. Insulator Assembly(Post with Brace)

6.12.8 Tension Insulator Assembly

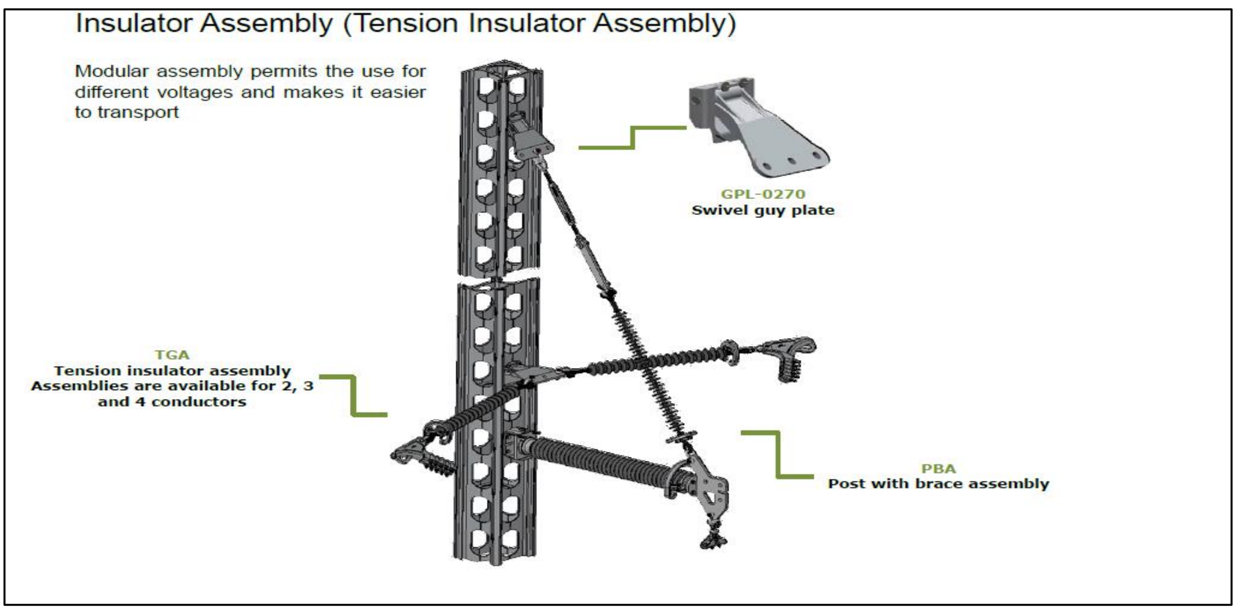


Figure 6-21. Insulator Assembly(Tension Insulator)

Modular assemblies of polymer insulators simplify the work in the field. Modular assemblies allow the use of the same insulator for different line voltages. For example, by using a 2 x 220kV insulator assembly on a 400kV line, customers can avoid storing 400kV insulators in addition to the 220kV insulators. Moreover the 220kV insulators are easier to manipulate than 400kV insulators considering length, weight.

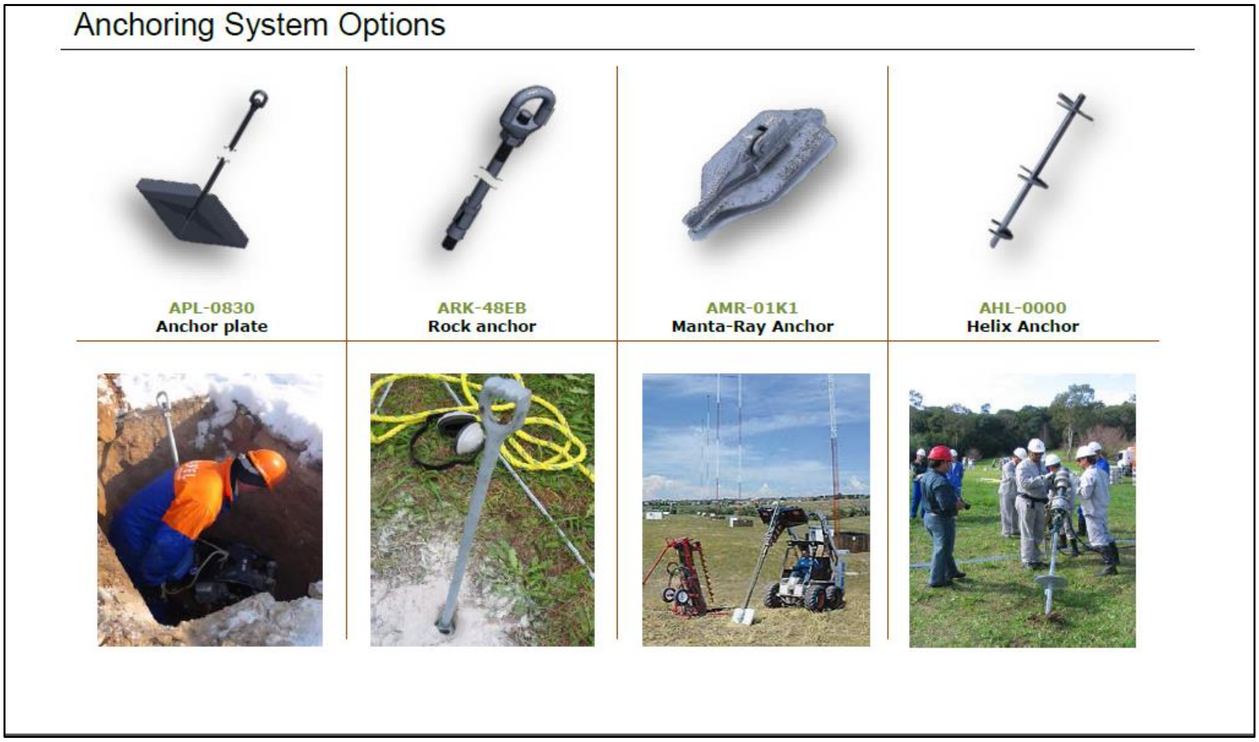


Figure 6-22. Anchorng System Options

6.13 Tools and Equipment for Installation SBB ERS

6.13.1 Sliding Gin Pole

The sliding gin pole attaches to the rails of the tower and is used to raise and lower the mast sections and all the other components up and down the tower.

By using the gin pole, customers no longer need to have a crane available on site. The gin pole can be operated manually or using the small portable winch supplied with the ERS

6.13.2 Sliding Gin Pole

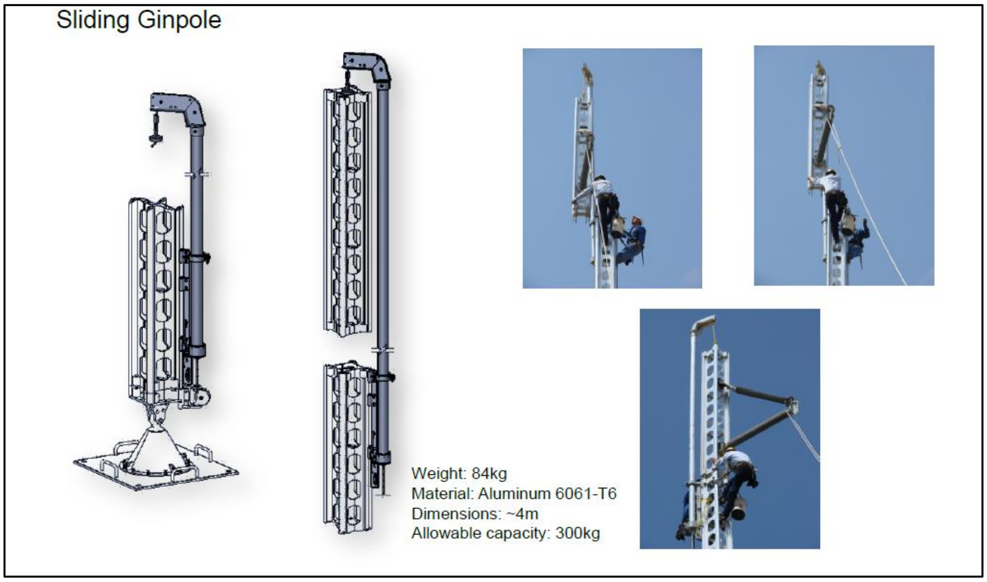


Figure 6-23. Sliding Ginpole

6.13.3 Ball – Joint Ginpole

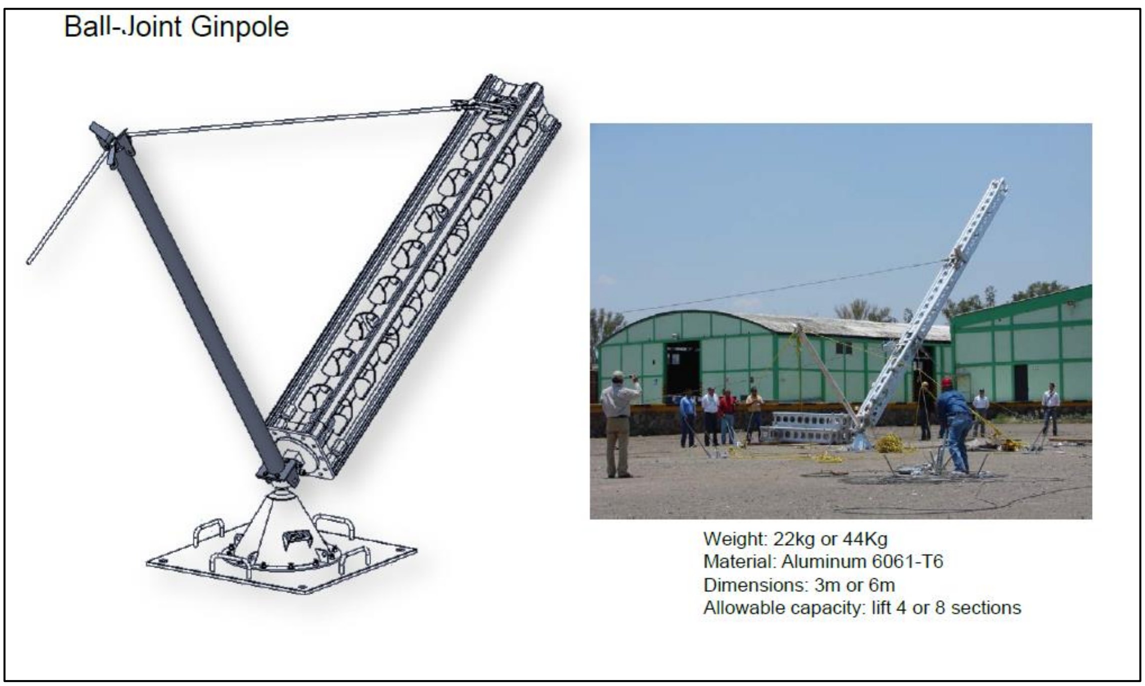


Figure 6-24. Ball-Joint Ginpole

6.13.4 Ball – Joint Gin Pole (22kg or 44kg)

This device, measuring 3m or 6m in length, can be used to tilt up to 6 mast sections from a horizontal to a vertical position, without using a crane. It can be used in conjunction with either a grip puller or a 4×4 vehicle on-site that will provide the pulling power.

Once the mast sections are in a vertical position, they will be secured with anchors and guy wires, then continue building a higher tower by using the sliding gin pole.

6.13.5 Working Platform (101kg, 122kg or 142kg)

This platform is used to help linemen reach insulators when working on the tower (for stringing operations for example). It is designed to be lightweight, yet easy to operate by one person only, which is critical, especially when working several meters off the ground.

The platform is made to different lengths in order to adapt to voltages up to 765kV: 2.5m, 4.5m and 6.5m.

Figure 6-25. Working Platform

6.13.6 Resting Platform (3.3kg)

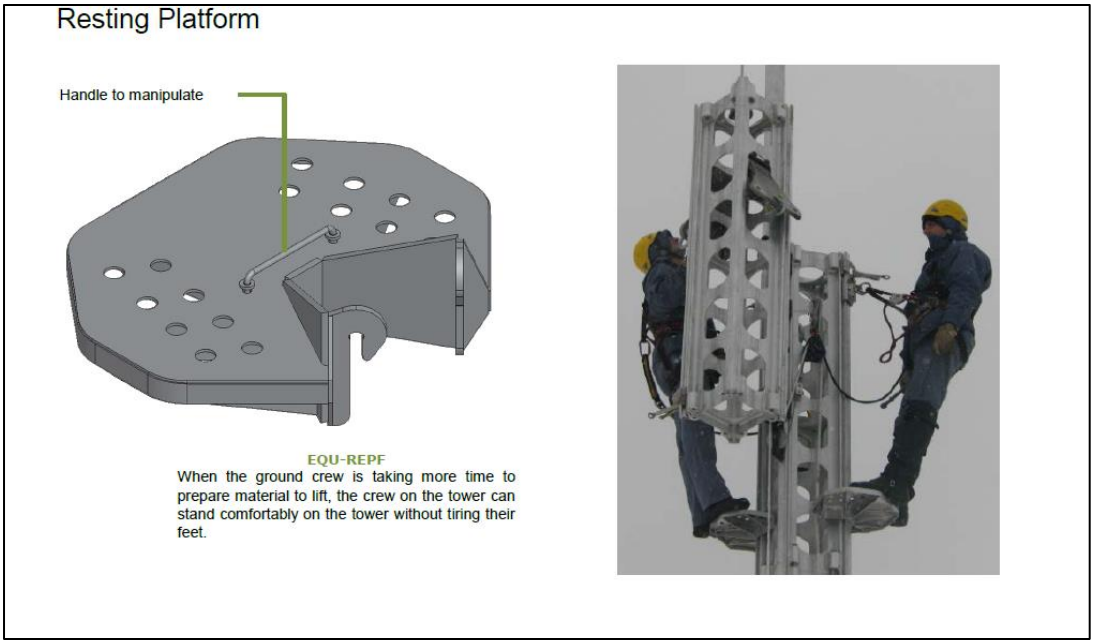


Figure 6-26. Resting Platform

This platform helps linemen to stand with both feet flat while working on the tower for a longer period. It is made light enough to be transported on the linemen's tool belts.

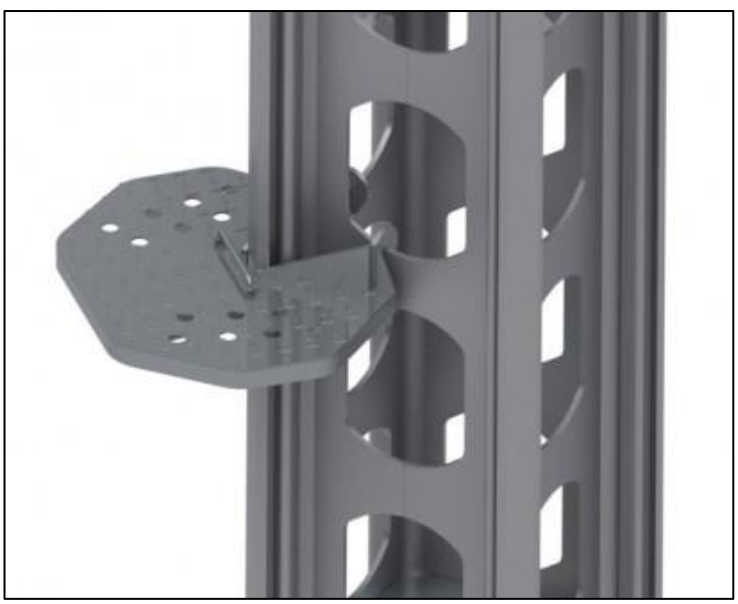


Figure 6-27. Resting Platform

6.13.7 Alignment Tool

This is a necessary tool to hold 2 sections together while they are being bolted and ensure perfect alignment. This also helps ensure that accessories that use the rails can slide flawlessly.

Figure 6-28. Alignment Tool

6.13.8 Portable Winch (19kg)

Figure 6-29. Portable Winch

This is a gasoline powered winch that is used to raise tower components and accessories up to tower by providing pulling power in order to avoid using cranes or other heavy equipment.

It is specifically designed to be used with SBB ERS and with a weight of just 19kg and a lifting capacity of 250kg, it is truly portable and extremely user-friendly.

6.13.9 Cobra Combi (27kg)

Figure 6-30. Cobra Combi

This gasoline-powered tool is used to drive steel rods in the ground by acting as a jackhammer but also to drill holes in the rock for the rock anchors.

6.13.10 Certified Fall Arrest Device

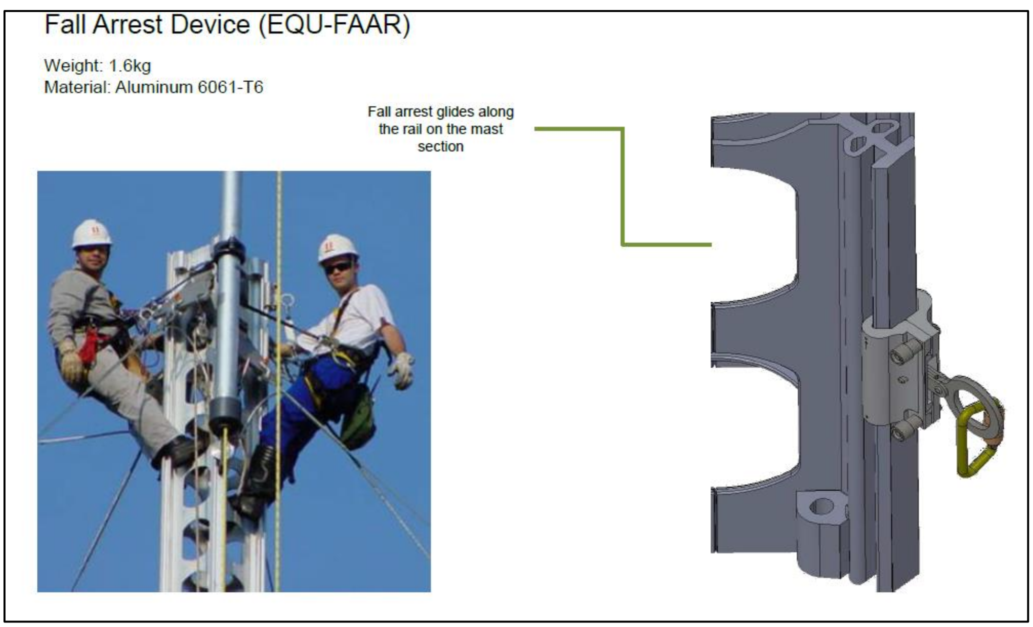


Figure 6-31. Fall Arrest Device

The fall arrest device is designed to be attached on the side rails of the tower and slide from bottom to top, without interruption. It allows free movement when climbing up on the tower but will lock in position when pulled suddenly in the opposite direction (lineman falling). Because of its full integration in the tower design, the fall arrest device is a very efficient safety measure for linemen.

6.14 Analysis Software

The software is supplied with the SBB ERS components at request. It prepares configurations for general use with the aid of the PLS-CADD/LW+MAST software from Power Line Systems (PLS). You will be able to make simple modifications on a typical SBB configuration using this tool to validate an SBB ERS tower for specific usage with fast Structure Checks.
A minimum knowledge or experience in transmission lines is required to understand the inputs and outputs of the software.

6.14.1 PLS-CADD LITE

This is the main program in which the impact of outside conditions on the tower is analyzed. The following parameters are integrated directly into the PLS-CADD/LITE:

- Weather cases
- Type, number and tension of conductor, OPGW and shield wire
- Safety factors, load factors, strength factors, etc
- Span, lines angle and clearances

It is a streamlined version of PLS-CADD and is very useful to quickly model a few spans.

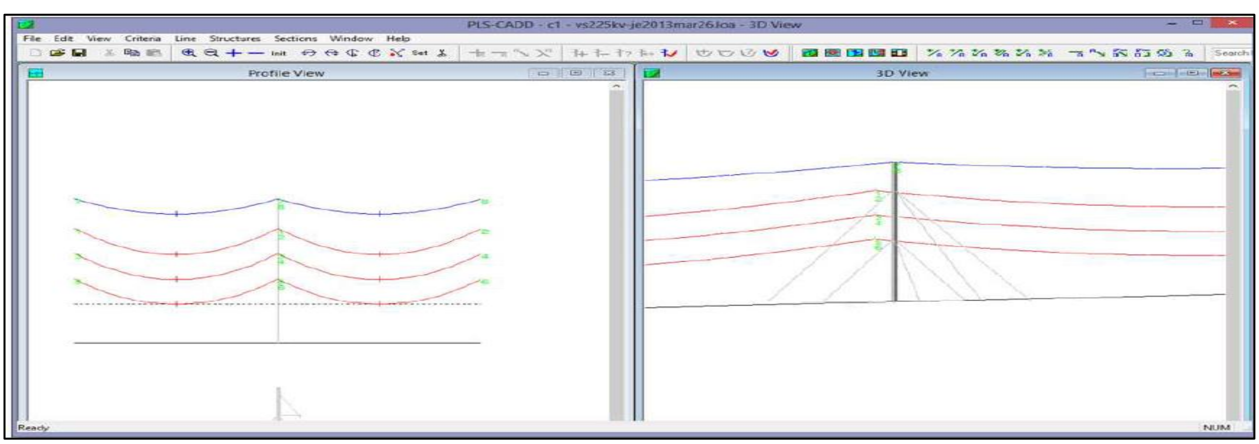


Figure 6-32. PLS-CADD

6.14.2 PLS-POLE/LW + MAST

This is a module to define the ERS tower design including the capacity of tower components, the number of guy wires, the mechanical capacities of the insulators, the geometrical characteristics of the elements, etc.

The following parameters are integrated directly into the PLS-POLE/LW+MAST:

- Geometry and physical properties of the tower
- Insulator data
- Guying details
- Conductor connections, etc

Both modules are from the world-renowned PLS suite, used by most utility companies worldwide, and were developed specifically for ERS use.

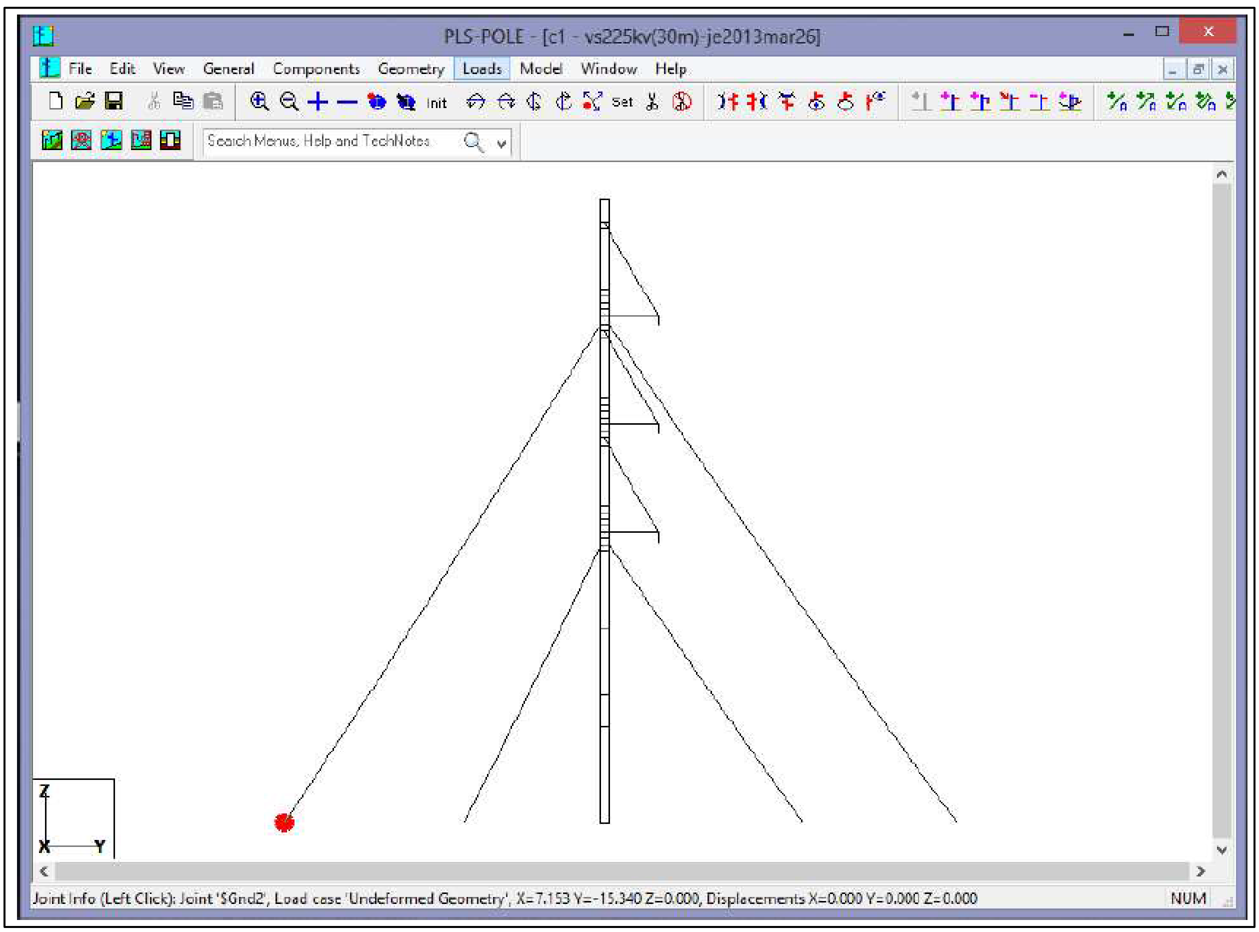


Figure 6-33. PLS-POLE/LW + MAST

6.15 ERS Installation Method

Before proceeding with assembly, it is essential to do a general revision with the field staff of the tower erection details; guy wires installation as well as the use of equipment. Usually, the Supervisor is responsible for organizing such meetings. It is recommended that there be an inspector present at all times on the field in order to ensure the compliance of the installation of the tower components.

To start, the tower foundation and the guy anchors are installed on the site according to the plans and specifications. Their installation must be done by following the instructions by the tower designer or the suppliers. The guy anchors' layout is the object of a structural study by an engineer, member of a recognized. Professional order. It is thus essential to respect the positions and tolerances prescribed in order to guarantee the integrity of the structure.

To erect an SBB tower, it is possible to choose from four different erection methods:

Sliding Gin Pole, Ball-joint Gin Pole, and a combination of either methods or an erection using special equipment, such as a helicopter, boom truck or crane. Usually, a combination of both the ball-joint and the sliding gin poles proved to be efficient, but in certain cases this method may present some disadvantages.

Figure 6-34. Installing the Base Plate

Figure 6-35 . Installing Anchor Plate

Figure 6-36. Erecting the first section

Figure 6-37. Erecting sections

6.15.1 Guying of Tower

Conventionally, the guying sequence is as follows:

- The number and the positions of the permanent guys are governed by the plans and specifications of the tower
- As the sections are installed, there should never be more than four sections that are not guyed at the top end of the tower. The temporary guys are used in this
- The temporary guys must never be removed unless one superior level of the guys (temporary or permanent) is installed safely.
- When the tower is secured by the permanent guys, the underlying temporary guys are removed by the linesmen.

6.15.2 Temporary Guying

It is recommended to use a set of four (4) temporary guys in order to maintain the tower in vertical position during assembly.

A set of temporary guys usually includes:

Four (4) Tirfor with steel cable equal or longer than the superior guy with preformed loop attachment at one end;

- Four (4) guy plates;
- Four (4) anchor shackles.

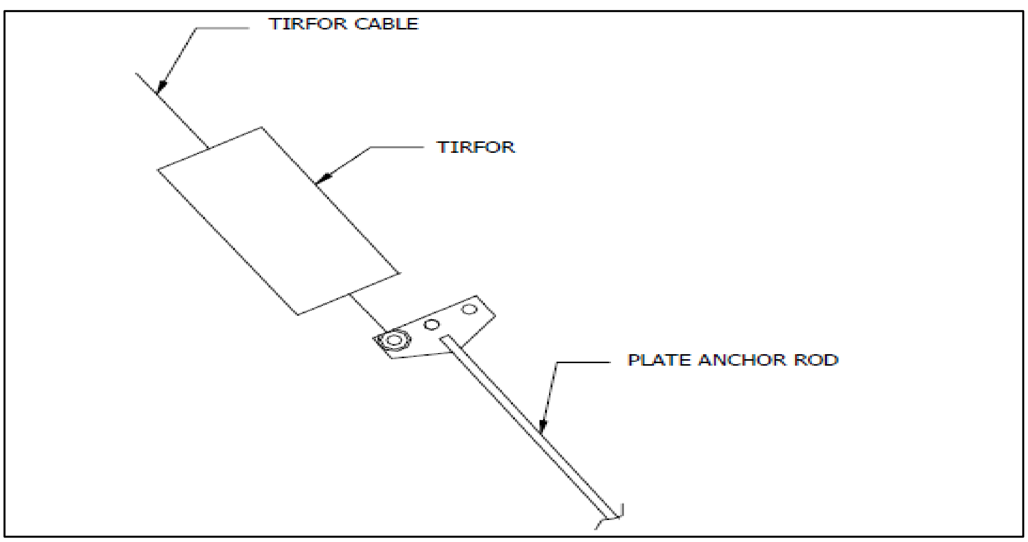


Figure 6-38 . Detail of installation of temporary guy on the permanent anchor

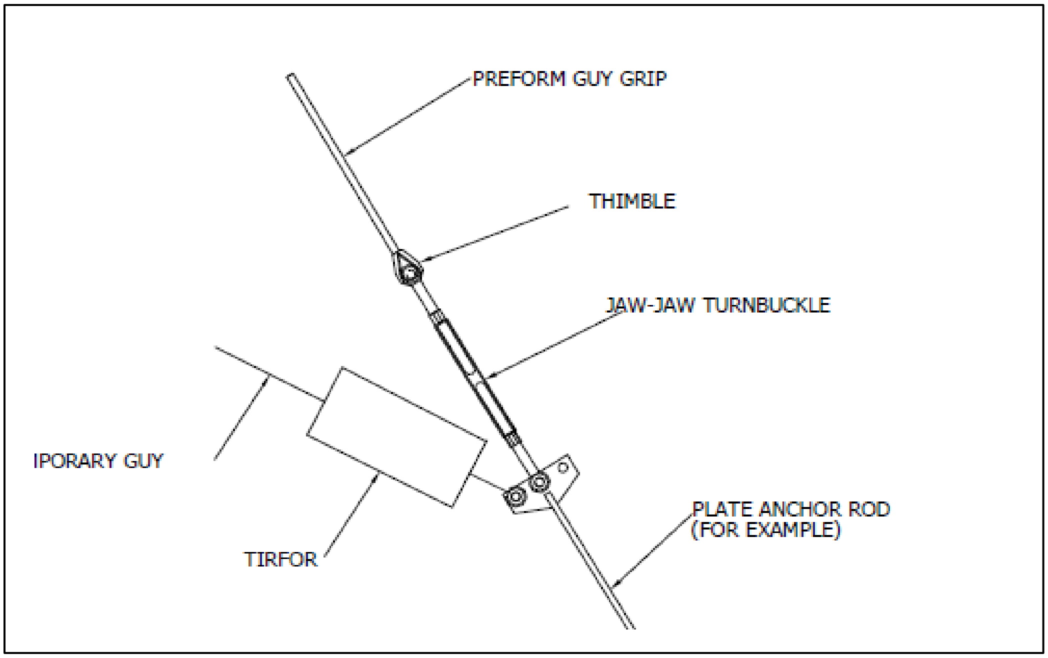


Figure 6-39 . Detail of the initial tensioning of the permanent guy cable

6.15.3 Insulator Installation

The post insulator connects to the tower through a bracket assembly. It is composed of two major parts: post insulator bracket and its support

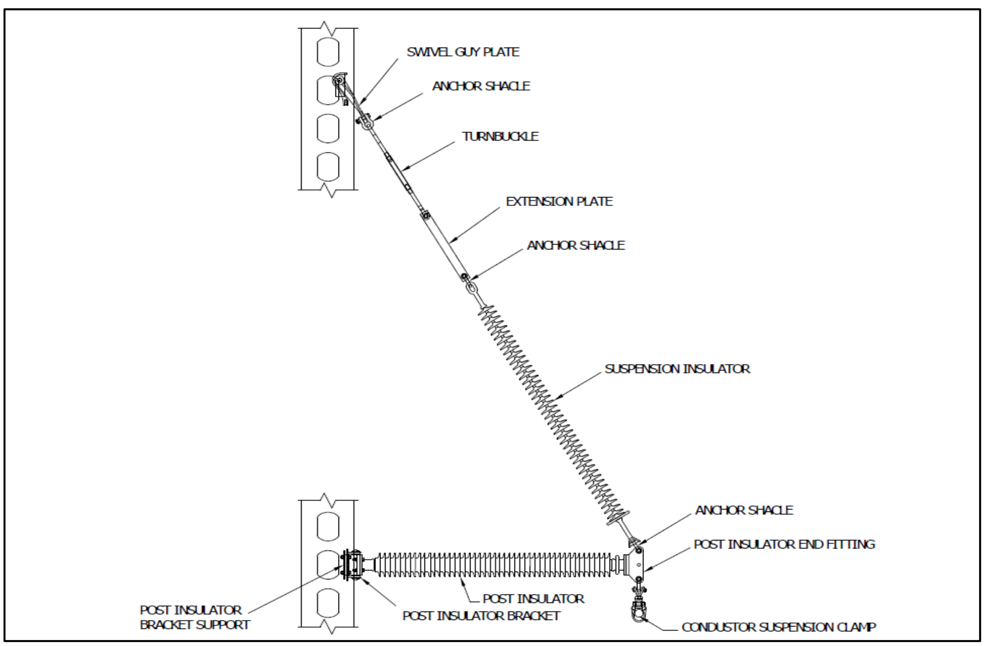


Figure 6-40 .Suspension Insulator

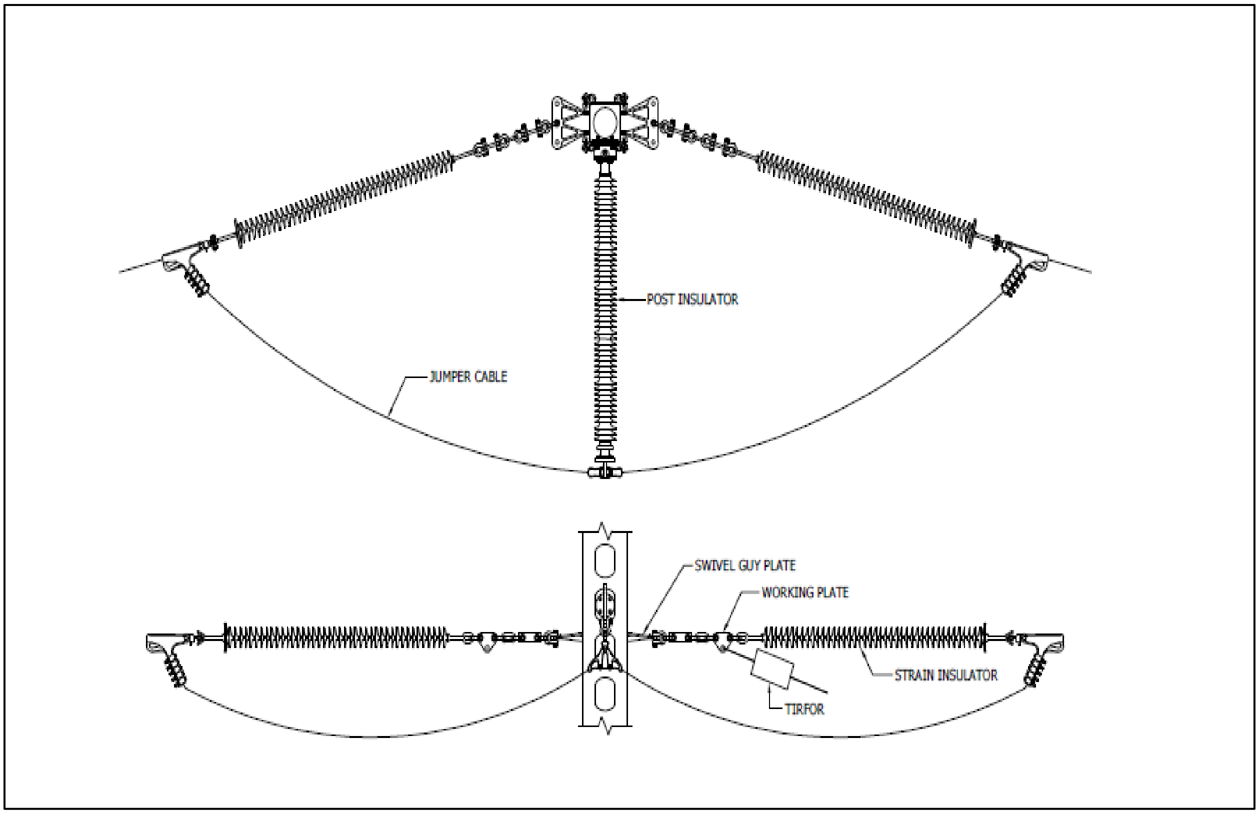


Figure 6-41. Strain insulator in anchor configuration

6.16 Advantages of Emergency Restoration Structures

- All sections have the same length and the same width so they are easy to store on top of one another and fit perfectly in a 20ft container.
- The sections are made in aluminum alloy, which means they will not rust if scratched, stored in a humid place or exposed to salty water.
- A section only weights about 135 kg so it is easy to carry by 2 people on short distances or 4 people on longer distances.
- The Container Storage System (CSS) allows neat organization of all the ERS components in the shipping containers
- Easy to erect and dismantle
- The sliding gin pole accelerates erection of the tower and allows a team as small as 6 people to build a 30m tower in few hours.

- No heavy equipment is required to build or dismantle a tower. SBB supplies all the tools and the training necessary.
- Safe and Comfortable to Work On
- Linesmen are always attached to the tower thanks to the SBB fall arrest device that slides along the rails on the side of the tower. They don't need to unbuckle to go over obstacles.
- Comes with several accessories to help linesmen to be comfortable while maintaining productivity: working platform (to help installation of conductors), resting platform (to rest while off the ground), lifting hook, lifting arm, etc…
- Stronger than other Towers
- More resistant in compression tests.
- They can resist winds of over 240km/h or 150km/h combined with heavy ice as well as any harsh conditions (high heat or high humidity)

6.17 Safety

- It is mandatory that the Team leader and the installation team read and understand the directions given in the installation manual provided by the supplier.
- The team leader should ensure the safety of his team at all time during the installation of a tower.
- Each component or equipment should be verified for any deficiencies by the team leader prior to use.
- Prior to the tower assembly, all the permanent anchors should be pull-tested.
- At any time during installation of a tower, a close look should be put on the anchors to make sure those are stable and safe.
- Never climb the tower before securing the stay wires or guys wires adequately.
- Always use the lineman safety device when climbing and working on the tower.
- During erection of the tower, never install more than 4 mast sections without guys (permanent or temporary).
- Each component or equipment should be used according to manufacturer's recommendations and documentation.
- Never stand near the tower base while linemen are working above

6.17.1 Work protection Code

It is essential that during emergency conditions all Work Protection Code procedures are strictly adhered to in all instances. With the existence of unfavourable working conditions, coupled with the presence of many unfamiliar outside work crews, it must be ensured that all requirements are met in this regard.

6.17.2 Safety Supervisor

A Safety Supervisor must be appointed and assigned responsibilities for the general safety of all workmen and the public. His duties and responsibilities shall be the same as those specified in the Standard Protection Code.

M07– INTRODUCTION TO GEOGRAPHIC INFORMATION SYSTEM (GIS)

7.1 Objectives

At the end of this module participants should be able to:

- Define the concept and basic functions of Geographic Information System
- Understand various applications in the electric power sector

7.2 Introduction

This module aims to give a general view of Geographical Information System and their possible use in specific electric power system problems in changing business environment, where the customer satisfaction has a direct bearing on the profitability of a utility. The GIS medium integrates both landbase and the electrical network maps. The GIS overlays single line diagrams of the power network with updated power network for system planning, data analysis and reporting. Asset management, network analysis, customer management can be accomplished by GIS functionality. GIS also provides seamless environment for applications like transient stability, load flow, short circuit analysis and load forecasting.

7.3 Geographic Information System(GIS)

Geographical Information System (GIS) is an automated information system that is able to compile, store, retrieve, analyze and display geographically referenced data. GIS system combines various layers of information about a place for better understanding and depending on the purpose, different layers can be put together for better analysis. The requirements of the different layers include, finding the best location for new facilities, analyzing environmental damage, keeping an overview of the electrical grid and so on.

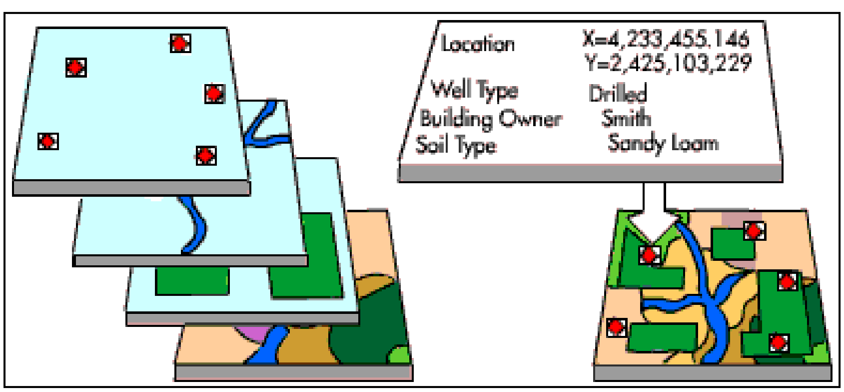


Figure 7-1. Combining various layers of information

The power of a GIS over paper maps is its ability to select the information needed depending upon the intended application. The features of GIS are being introduced into power systems for developing better working models of various aspects like:

- Fault Location determination based on Geo-referencing.
- Topology Analysis & Fault Isolation
- Requirement Analysis
- Resource Allocation --- Tools, Manpower
- Generate Work Order
- System Restoration

The literature reveals that, a well-designed GIS based transmission and distribution network may help minimize loss of electricity and enable pooling of supply and demand in order to maximize efficiency of the electric power system and reduce environmental impacts of power generation. Map data used by GIS are collected from existing maps, aerial photos, satellites, and other sources. A digitizer or similar device is used to convert compiled map data to a digital form in order to make it computer compatible. This transformation allows the storage, retrieval, and analysis of the mapped data to be performed by the computer. Maps produced by a GIS are typically displayed on computer monitors or are printed on paper. The power of GIS lies in its ability to analyze the data and to present the results of that analysis as more meaningful information than any other traditional systems.

The GIS database contains both map data (spatial data depicting location of geographical objects) and attribute data (non-spatial data describing physical characteristics of each object). During a GIS analysis, site (map) data is linked with situation (attribute) data for each object mapped. It is this link, which is automatically performed by the GIS software that gives GIS its analytical power. Another advantage of GIS is its interface with GPS, which provides the location of features spatially on the earth surface.

7.4 Global Positioning System

The Global Positioning System (GPS) is one of the main building blocks, helping in creation of any GIS system. It is a location system based on a constellation of about 24 satellites orbiting the earth at altitudes of approximately 11,000 miles. GPS satellites are orbited high enough to avoid the problems associated with land based systems, yet can provide accurate positioning 24 hours a day, anywhere in the world. The GPS is made up of three parts: satellites orbiting the Earth; control and monitoring stations on Earth; and the GPS receivers owned by users. GPS satellites broadcast signals from space that are picked up and identified by GPS receivers. Each GPS receiver then provides three-dimensional location (latitude, longitude, and altitude) plus the time. GPS can provide at any point on the earth a unique address (its precise location). A GIS is basically a descriptive database of the earth (or a specific part of the earth). GPS tells you that you are at point X,Y,Z while GIS tells you that X,Y,Z is an oak tree, or a spot in a stream with a pH level of 5.4. GPS tells us the "where". GIS tells us the "what". The "what" is the object or objects which will be mapped. These objects are referred to as "Features", and are used to build a GIS. It is the power of GPS to precisely locate these Features which adds so much to the utility of the GIS system. On the other hand, without Feature data, a coordinate location is of little value. The accuracy of currently available GPS devices varies from around 3m to millimetres , depending on the configuration of these systems.

7.5 Applications for Electric Power Systems

A GIS allows the operator to:

(1) Incorporate (import) data from outside sources,

(2) Easily update and alter data

(3) Ask data-related questions on (or query) the database.

The database management system (DBMS) software that is a part of a typical GIS provides these capabilities. Geographical Information System (GIS) based systems in engineering applications has advantages which improves the performance, since GIS takes the inputs of the spatial and nonspatial data, monitors and analyzes with higher reliability in space and time dimensions. Geographic Information Systems can be used for mapping of complete electrical network including low voltage system and customer supply points on satellite imagery and/or survey maps. Layers of information are contained in these map representations. The first layer may represent the distribution network coverage. The second layer may be used for land background containing roads, landmarks, buildings, rivers, railway crossings etc. The next layer could contain information on the equipment viz poles, conductors, transformers etc. Most of the electrical network/equipment have a geographical location and the full benefit of any network improvement can be had only if the work is carried out in the geographical context. Processes such as network planning, repair operations and maintenance connection and reconnection must be based around the network model. Even while doing something as relatively simple as adding a new service connection; it is vital to know that existing users of the system are not affected by this addition. GIS in conjunction with system analysis tools helps to do just this. GIS when integrated with real time SCADA can help in sending the right signals to the communication network. Outages can be isolated faster than even before and maintenance crews dispatched with critical information including location of the fault.

GIS can be used in power systems management for:

- Fault Management
- Routine maintenance can be planned.
- Network extensions and optimization
- Network reconfiguration
- Improved revenue management
- SCADA can be integrated with GIS
- Rights of way and compensation

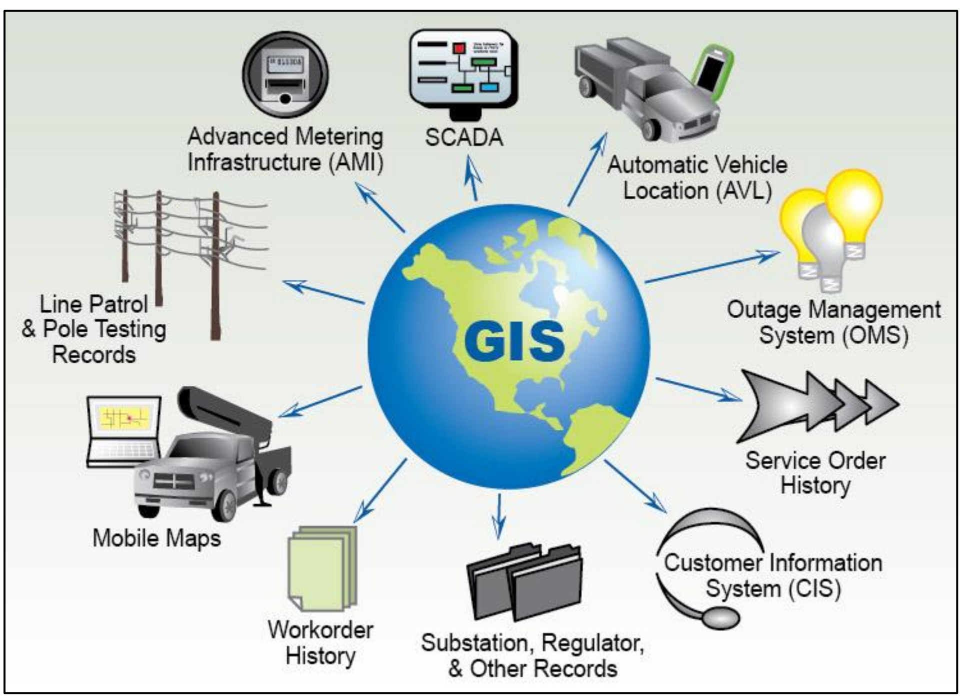


Figure 7-2. Multiple uses of GIS

7.5.1 Transmission Line Routing using GIS

GIS application for the transmission Line Routing problem, where we are giving more insight into the electric problem, explain in a better way how GIS use can help in resolving the unseen problems, which is not easy to solve unless we integrate spatial concept with traditional/conventional/available routing solutions. The transmission line routing is highly complex, as transmission lines are not aesthetically pleasing, and people are concerned about health issues due to the electric and magnetic fields, especially from high voltage transmission lines. GIS is used in transmission line routing as a technical tool.

During the route selection for a transmission line, a straight route with minimum curves is desirable as it gives the best engineering and economic solution. In order to achieve this route the line may have to pass through certain places which are already inhabited by people or areas that are unsuitable for locating the transmission towers. Depending upon the population density and other factors, either the community is relocated or the route of the transmission line needs to be changed. GIS can be used to analyse the selection of suitable areas for transmission lines, so that there is minimal environmental disruption such as minimizing the number of trees that are cut down when transmission lines are to be positioned across a forest area, implement optimal routing algorithms based on electrical and material properties in addition to locational characteristics, visualize the network on a map and help make appropriate decisions and reduce cost escalations (due to re-routing, etc) during the implementation phase.

Electromagnetic fields (EMF) occur independently of one another as electric and magnetic fields at the 50-Hz frequency used in transmission lines, and both are created by electric charges. Electric fields exist when these charges are not moving. Magnetic fields are created when the electric charges are moving. The magnitude of both electric and magnetic fields fall off rapidly as the distance from the source increases (proportional to the inverse of the square of distance).

To estimate the maximum fields, calculations will be performed at mid-span where the conductor is positioned at its lowest point between structures (the estimated maximum sag point). The magnetic fields are computed at 1 meter above ground. Buffer zone concept from spatial informatics can help in routing the high tension transmission line near to a populated area, where spatial buffer zone will protect the inhabitants from strong electric and magnetic field effects.

Another example of utilization of buffer zone concept in electric power systems can be visualized in the transformer installation plan during an electrical network expansion. If an engineer needs to know the date of installation of a transformer all that he needs to do is click on the transformer symbol on the map and a table will appear detailing all the information on that particular transformer. If he wants to know how many transformers are installed in a given locality, the GIS will process the network data within the buffer zone of the desired locality and provides the results.

7.5.2 Asset Management

Asset management jobs require information from multiple sources within and outside a utility. This may include information on right of way and public utility easements or external subscriptions on climate zone, weather & traffic conditions, land topography and environment data. In combination with the knowledge on the location of the respective assets, GIS helps in building a timely response mechanism to address the issues of repair, recovery and replacement of these assets, thus providing for an uninterrupted and reliable supply.

7.5.3 Disaster Management and Locating Faults

GIS (Geographic Information Systems) enhance visualization of power systems by associating spatial data with transmission assets, such as contouring and animation, making them attractive platforms for displaying geographically referenced real time power system data such as the voltage and line loading contours. GIS information is stored in geographical map layers making it easy to relate transmission network conditions with other relevant information such as weather, vegetation growth, and road networks. Real time weather data integrated in GIS increases the operator′s situational awareness. For example, with the help of such a system, the identification of a weather front moving towards a given area enables operators to quickly pinpoint transmission facilities with increased risks of outage. In conjunction with SCADA/ EMS data, the operator can then initiate dispatching orders to protect the system against potential cascading failures. GIS vegetation maps can be combined with real time line loading information to identify lines with increased risk of flashovers and faults due to sagging. Such lines can then be considered candidates in the EMS contingency analysis. Conversely, if the GIS vegetation map shows negligible growth, operators can push more power through a corridor with line sag constraints. Contour mapping of voltage, load or generation profiles can be used to visualize the system-wide operating conditions, such as overloaded components, and help operators pinpoint trouble spots in the grid with just a glance at the screen. Based on a quick localization, more detailed numerical displays can be opened to further investigate the source and possible solution to an abnormal network situation. In a contour plot, the color indicates the severity of the threat and the locations in the contour maps correspond to the geographic location of the problem area. Once a trouble spot has been located on the contour map, an operator can take preventive action to ensure an abnormal situation does not progress into a system-wide outage.

7.6 Conclusion

The capability of GIS for displaying and analyzing information from diverse sources provides for a powerful interface for multifaceted understanding of the problems/issues, thus providing a framework for development of suitable and appropriate solutions. In case of power systems, GIS enhances its visualization by associating spatial data with transmission and other assets. To take proper decisions, information must be collected and analyzed to its full extent. Information on the facilities, their condition and their connectivity is important in taking control decisions. With the use of GIS, power companies can collect and store a large amount of data that can be readily accessed and analyzed. Hence, GIS and its applications play an important role in modern power system planning, analysis and control.

** REFERENCE : Application of Geographical Information System and Spatial Informatics to Electric Power Systems [A. Nagaraja Sekhar, K. S. Rajan, and Amit Jain, Member IEEE, 2008]*

4. UNDERGROUND TRANSMISSION SYSTEM

Ghana Grid Company

M01 – FUNDAMENTAL CONCEPT

1.1 Objectives

At the end of this module participants should be able to:

- Identify the concept of underground transmission line construction
- Understand the Advantage and Disadvantage of underground transmission line

1.2 Introduction

This module contains information about electric transmission lines which are installed underground, rather than overhead on poles or towers. Underground cables have different technical requirements than overhead lines and have different environmental impacts. Due to their different physical, environmental, and construction needs, underground transmission generally costs more and may be more complicated to construct than overhead lines.

Figure 1-1. Underground Transmission Cables

The design and construction of underground transmission lines differ from overhead lines because of two significant technical challenges that need to be overcome.

1) Providing sufficient insulation so that cables can be within inches of grounded material
2) Dissipating the heat produced during the operation of the electrical cables.

Overhead lines are separated from each other and surrounded by air. Open air circulating between and around the conductors cools the wires and dissipates heat very effectively. Air also provides insulation that can recover if there is a flashover.

In contrast, a number of different systems, materials, and construction methods have been used during the last century in order to achieve the necessary insulation and heat dissipation required for undergrounding transmission lines.

1.3 The definition of the Underground transmission lines

Many people ask if transmission lines can be placed underground rather than overhead. Currently, there are no underground 500-kV lines of significant length in the world. While many lower voltage, local electric distribution lines are placed underground, particularly in newer neighborhoods, almost all high-voltage electric transmission lines are overhead for four general reasons:

- Environmental impact,
- Cost considerations,
- Construction measures and
- Operational issues.

Because of these issues, underground transmission lines typically are justified only where there is no viable overhead corridor, such as in densely populated urban areas or in the vicinity of airports.

1.4 Underground lines can have greater environmental impact

While lower voltage distribution lines that connect to homes and businesses can be buried directly in the ground with less invasive construction, underground transmission lines require substantial underground infrastructure and design considerations. we acknowledge that there are different environmental impacts of underground and overhead lines based on the environmental setting and construction techniques and works to propose projects that minimize environmental impacts.

1.5 Cost considerations are significant

Insulated cables, underground surveying and excavation, splicing vaults and concrete-encased conduits to protect lines from dig-ins contribute to higher costs. The lifespan of underground lines is 30 to 35 years, about half that of overhead lines.

Installation costs for underground transmission lines can range from 5 to 10 times the cost of an equivalent 500-kV overhead line. A major part of this cost is associated with the massive amount of excavation required for underground trenches. Factors influencing the cost include, but are not limited to, the following:

- **Routing -** Right-of-way, easement and permitting costs and whether the line will be placed in the road right-of-way
- **Terrain and obstacles -** Other underground utilities, streams and railroad crossings, embankments, bridges, major roads, traffic and soil conditions
- **Permitting -** Traffic and lane restrictions, noise, time of day and other construction restrictions
- **Design -** Mitigating soil thermal characteristics

1.6 Specific construction measures are required

Building an underground transmission line requires many special considerations. Underground cables have to be spliced many times along a transmission line route since there are limitations on how long sections can be manufactured and weight limitations on shipping. For example, A 500-kV underground cable is typically 5.5 to 6 inches in diameter and will weigh more than 25 pounds per foot.

Cables are typically installed in conduits, and rough terrain would limit the amount of cable that can be pulled at one time. Conduits are grouped in duct banks and encased in concrete. The duct bank would then be buried under about 4 feet of thermal fill to dissipate the heat to the surrounding ground. Cables are spliced in vaults to allow access for any needed testing and repairs. These vaults would be located in every 800 to 2,300 feet, depending on terrain. Each high-voltage direct current cable would be spliced in a separate vault to limit heat generation and risk of a splice failure affecting the other cable. The vaults would be around 10 feet wide by 10 feet high by 35 feet long.

Additionally, when a high-voltage transmission line transitions from overhead to underground, a transition station is required. These would appear similar to a substation with a large steel structure to hold high-tension conductors, a control house for line monitoring, protection equipment, terminations to connect the overhead conductors to the underground cable and security fencing around the perimeter. A typical transition station would cover about an acre.

1.7 Operational issues, outage times significantly different

All electric lines produce heat and therefore have a limit on the amount of power that they can carry. Underground lines cannot dissipate heat as well as overhead lines. Factors such as electrical insulation, the type of surrounding soil, adjacent underground utilities and the depth of installation all affect the wires ability to dissipate heat.

New underground lines can have higher thermal ratings than outdated overhead lines they are replacing; however, there is far less flexibility to make improvements as needed on underground lines. When lines are above ground, replacing wires or making other improvements can often be done without significant disruption. In contrast, repairing an underground line requires excavation, which significantly disrupts the surface landscape.

Failures on underground transmission lines are infrequent. However, when they occur, they are extremely costly and time-intensive to repair. Line outages can last up to a month or more as a result of the difficulty in determining the exact location that needs repair and the logistics of long lead times for replacement materials. In contrast, required repairs to overhead lines can usually be completed within 24 hours.

1.8 Underground Construction Considerations

Underground construction could be a reasonable alternative to overhead in urban areas where an overhead line cannot be installed with appropriate clearance, at any cost. In suburban areas, aesthetic issues, weather-related outages, some environmental concerns, and the high cost of some ROWs could make an underground option more attractive.

Underground transmission construction is most often used in urban areas. However, underground construction may be disruptive to street traffic and individuals because of the extensive excavation necessary. During construction, barricades, warning and illuminated flashing signs, are often required to guide traffic and pedestrians. After each day's work, steel plates will cover any open trench. All open concrete vaults will have a highly visible fence around them. When the cable is pulled into the pipe, the contractor should cordon off the work area. There may be time-of-day or work week limitations for construction activities in roadways that are imposed for reasons of noise, dust, and traffic impacts. These construction limitations often increase the cost of the project.

The trenching for the construction of underground lines causes greater soil disturbance than overhead lines. Overhead line construction disturbs the soil mostly at the site of each transmission pole. Trenching an underground line through farmlands, forests, wetlands, and other natural areas can cause significant land disturbances.

Many engineering factors significantly increase the cost of underground transmission facilities. As the voltage increases, engineering constraints and costs dramatically increase. This is the reason why underground distribution lines are not uncommon; whereas, there is just short miles of underground transmission currently in the world.

1.8.1 Construction Impacts in Suburban and Urban Areas

The construction impacts of underground lines are temporary and, for the most part, reversible. They include dirt, dust, noise, and traffic disruption. Increased particles in the air can cause health problems for people who live or work nearby. Particularly sensitive persons include the very young, the very old, and those with health problems, such as asthma. If the right-of-way is in a residential area, construction hours and the amount of equipment operating simultaneously may need to be limited to reduce noise levels. In commercial or industrial areas, special measures may be needed to keep access to businesses open or to control traffic during rush hours.

1.8.2 Construction Impacts in Farmland and Natural Areas

Most underground transmission is constructed in urban areas. In non-urban areas, soil compaction, erosion, and mixing are serious problems, in addition to dust and noise. During construction, special methods are needed to avoid mixing the topsoil with lower soil horizons and to minimize erosion. The special soils often placed around an underground line may slightly change the responsiveness of surface soils to farming practices. Post-construction, trees and large shrubs would not be allowed within the right-of-way due to potential problems with roots. Some herbaceous vegetation and agricultural crops may be allowed to return to the right-of-way.

1.8.3 Costs

The estimated cost for constructing underground transmission lines ranges from 4 to 14 times more expensive than overhead lines of the same voltage and same distance. For example, A typical new 69 kV overhead single-circuit transmission line costs approximately $285,000 per mile as opposed to $1.5 million per mile for a new 69 kV underground line (without the terminals). A new 138 kV overhead line costs approximately $390,000 per mile as opposed to $2 million per mile for underground (without the terminals).

These costs are determined by the local environment, the distances between splices and termination points, and the number of ancillary facilities required. Other issues that make underground transmission lines more costly are right-of-way access, start-up complications, construction limitations in urban areas, conflicts with other utilities, trenching construction issues, crossing natural or manmade barriers, and the potential need for forced cooling facilities. Other transmission facilities in or near the line may also require new or upgraded facilities to balance power issues such as fault currents and voltage transients, all adding to the cost.

While it may be useful to sometimes compare the general cost differences between overhead and underground construction, the actual costs for underground may be quite different. Underground transmission construction can be very site-specific, especially for higher voltage lines. Components of underground transmission are often not interchangeable as they are for overhead. A complete in-depth study and characterization of the subsurface and electrical environment is necessary in order to get an accurate cost estimate for undergrounding a specific section of transmission. This can make the cost of underground transmission extremely variable when calculated on a per-mile basis.

1.9 Choosing Between Underground and Overhead

There are different advantages and disadvantages for underground transmission lines. When compared with overhead transmission lines, the choice to build an underground transmission line instead of an overhead line depends on a number of factors.

The most non-debatable reason for choosing underground is in highly urban areas, where acquiring ROW that meets National Electrical Safety Code requirements is difficult or impossible. This makes the added cost of undergrounding acceptable to not being able to route the new line at all.

Choosing underground for reasons of aesthetics, may be justified because it is assumed that following the disruption of construction, the entire line would be out-of-sight. However, considerations must be made for the disruption caused by the trench construction and the ancillary facilities that would be above ground, such as transition structures (risers), pressurizing stations, and transition stations.

In general, underground lines are significantly more expensive than overhead lines. There are operational limitations and maintenance issues that must be weighed against the advantages. For some projects only a portion of a line may be constructed underground to avoid specific impacts. Every project must be assessed individually to determine the best type of transmission line for each location segment.

M02 – UNDERGROUND TRANSMISSION COMPONENTS

2.1 Objectives

At the end of this module participants should be able to:

- Define the basic structure of underground transmission line
- Understand the function of each components in underground transmission line

2.2 Introduction

The purpose of this module is to provide information about the fundamental components of the underground transmission line, compared with installing overhead lines. Overall, there are a number of issues that make the underground transmission option more technically challenging and expensive. However, despite the costs and technical challenges, there are circumstances in which underground transmission lines are a more preferable option than overhead transmission lines. This module explains about the basic components of the underground transmission line.

2.3 Underground Cable

There are two main types of underground transmission lines currently in use. One type is constructed in a pipe with fluid or gas pumped or circulated through and around the cable in order to manage heat and insulate the cables. The other type is a solid dielectric cable which requires no fluids or gas and is a more recent technological advancement. The common types of underground cable construction include:

- High-pressure, fluid-filled pipe (HPFF)
- High-pressure, gas-filled pipe (HPGF)
- Self-contained fluid-filled (SCFF)
- Solid cable, cross-linked polyethylene (XLPE)

The detailed information will be followed in the next module about underground cables.

2.4 Ancillary Facilities

Different types of cables require different ancillary facilities. Some of these facilities are constructed underground, while others are aboveground and may have a significant footprint. When assessing the impacts of underground transmission line construction and operation, the impacts of the ancillary facilities must be considered, as well.

2.5 Vaults

Vaults are large concrete boxes buried at regular intervals along the underground construction route. The primary function of the vault is for splicing the cables during construction and for permanent access, maintenance, and repair of the cables. The number of vaults required for an underground transmission line is dictated by the maximum length of cable that can be transported on a reel, the cable's allowable pulling tension, elevation changes along the route, and the sidewall pressure as the cable goes around bends. XLPE cable requires a splice every 900 to 2000 feet, depending on topography and voltage. Pipe-type cables need a splice at least every 3,500 feet. The photos in Figure 4 show examples of vault construction.

Vaults are approximately 10 by 30 feet and 10 feet high. They have two chimneys constructed with manholes which workmen use to enter the vaults for cable maintenance. Covers for the manholes are designed to be flush with the finished road surface or ground elevation. Vaults can be either prefabricated and transported to the site in two pieces or constructed onsite. Excavations in the vicinity of the vaults will be deeper and wider. Higher voltage construction may require two vaults constructed adjacent to each other to handle the redundant set of cables.

Figure 2-1. Vault Construction

- Left: 345 kV XLPE project – Cement vault visible with two chimneys extending up to be level with the future road surface.
- Right: 138 kV XLPE project – Bottom half of pre-constructed vault positioned in trench.

Fig 2-2. 138 kV XLPE project – Pre-fabricated top half of vault being lowered into trench.

2.6 Transition Structures

For underground cables less than 345 kV, the connection from overhead to underground lines require the construction of a transition structure, also known as a riser. Figures 5 and 6 depict sample transition structure designs. These structures are between 60 and 100 feet tall. They are designed so that the three conductors are effectively separated and meet electric code requirements.

The insulated conductor of the overhead line is linked through a solid insulator device to the underground cable. This keeps moisture out of the cable and the overhead line away from the supporting structure.

Figure 2-3. 138 kV Underground to Overhead Transition Structures

Lightning arrestors are placed close to where the underground cable connects to the overhead line to protect the underground cable from nearby lightning strikes. The insulating material is very sensitive to large voltage changes and cannot be repaired. If damaged, a completely new cable is installed.

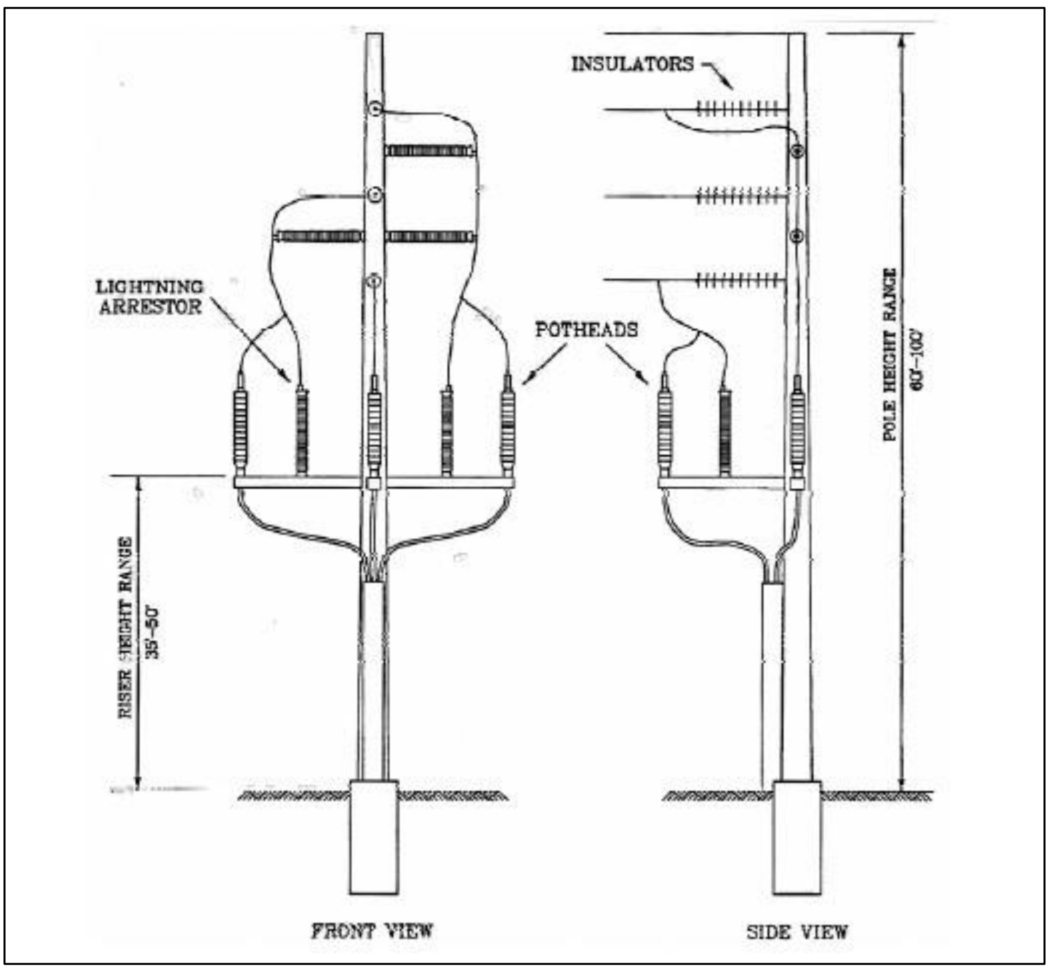


Figure 2-4. Diagram of a Typical Transmission Riser Structure

2.7 Transition Stations

High voltage (345 kV or greater) underground transmission lines require transition stations wherever the underground cable connects to overhead transmission. For very lengthy sections of underground transmission, intermediate transition stations might be necessary. The appearance of a 345 kV transition station is similar to that of a small switching station. The size is governed by whether reactors or other additional components are required. They range in size from approximately 1 to 2 acres. Transition stations also require grading, access roads, and storm water management facilities. Figure 5 is a photo of small transition station.

Figure 2-5. Small Transition Station

2.8 Pressurizing Sources

For HPFF systems, a pressurizing plant maintains fluid pressure in the pipe. The number of pressurizing plants depends on the length of the underground lines. It may be located within a substation. It includes a reservoir that holds reserve fluid. An HPGF system does not use a pressurizing plant, but rather a regulator and nitrogen cylinder. These are located in a gas-cabinet that contains high-pressure and low-pressure alarms and a regulator. The XLPE system does not require any pressurization facilities.

2.9 Joint bays

For most installations, joints are required at intervals along the route. This is because the cable is supplied in fixed lengths dictated by the cable drum diameter, the diameter of the cable itself and the maximum weight that can be transported.
For directly buried cables, joints will be approximately every 500–1,000m. In tunnels this spacing has to be consistent so it complies with National Grid safe working practices.
XLPE joints are prefabricated off site and assembled on site. With fluid filled cables, the majority of the joint is constructed/assembled on site. For both options, joint bays are required, which can be up to 40m in length and 5m in width. In these joint bays it is essential that suitable clean conditions are established and that they have the provision of temporary power supplies and de-humidification in order to achieve satisfactory jointing.

2.10 Stop joints

Stop joints are only required for fluid filled cables where the length of cable and/or gradient necessitates joints to retain fluid pressure. The fluid is provided in a closed system via pressure tanks at the stop joint positions. Above ground kiosks with fluid pressure monitoring equipment are situated next to the stop joints/fluid tanks. The fluid tanks significantly increase the required land take of the cable route at the stop joint locations. Depending on where they are located, these tanks can either be buried or above ground. Generally, a stop joint bay is significantly longer than a standard straight joint bay.

2.11 Water cooling

In some cases plastic/aluminum pipes filled with water are laid alongside underground cables so that the heat generated by the cables can be transferred to the water flowing through the pipes. The water is then cooled in heat exchangers every 3km or so.
Buildings to house the water pumping equipment and heat exchangers are required above ground and these must be carefully sited to minimize the impact of fan and pump noise on the locality.
Where space is limited and a reduced land take is necessary, this type of cooling enables closely spaced cables to achieve a higher rating.

2.12 Reactive compensation

Reactive compensation to compensate for the changing current drawn by long lengths of high voltage cable may be required for lengths of cable greater than 5km. Reactive compensation equipment would be installed within a substation.

M03 – UNDERGROUND TRANSMISSION CABLE

3.1 Objectives

At the end of this module participants should be able to:

- Define the basic structure of each type of the underground transmission cable.
- Understand the function of each part which consists the cable.

3.2 Introduction

The use of underground cables for transmission of power dates back centuries. However, the usage of these cables has remained relatively low in different regions of the world. The basic idea behind the use of underground cables is that electrical power can be transmitted in two main ways: by use of overhead electrical cables or underground ones.
Since the use of underground transmission is expected to continue growing in popularity, it is important for you to understand what underground electric transmission cables are, their nature and usage.

3.2.1 Advantages of Underground Cables

There are several advantages that are associated with the laying of specific types of cables under the ground for purposes of transmitting electricity. The following is a brief outline of these advantages.

- Compared to overhead cables, underground cables are much safer. This is because underground electrical cables are not exposed to the many dangers that overhead power cables are exposed to
- It is cheaper to maintain underground cables over the course of time as compared to overhead ones. In practice, the cost of installing underground cables far exceeds what is associated with the installation of overhead ones. But once the underground cables have been installed, it is highly unlikely that they will have to be repaired every now and then as it is the case with overhead electrical cable types.
- Underground transmission of electricity is associated with reliability. This is because instances of constant disruption in the supply of power as a result of storms or faults that are associated with overhead transmission lines are not common when power transmission lines are laid underground.

3.2.2 Use of Underground Cables

There are several issues that are usually taken into consideration in relation to the use of underground cables.

- The first one is the actual manner in which the cables are laid underground. In practice, there are three main methods that are used: placing the cables in concrete-reinforced troughs, directly burying the cables and placing the cables in underground tunnels. The choice of any of these methods is usually based on the geographical features of the area in which the grounding is supposed to be done.
- The second issue is related to the actual type of cables that are used in the process. There are different types of cables that can be laid underground and used to transmit electricity. What is important to note is that the choice of the cables is largely determined by the type of installation that has to be done. For example, plastic cables, also known as XLPE and fluid-insulated cables are used when only a small portion of the transmission line has to be put underground. On the other hand, HVDC cables are regarded as heavy-duty underground cable types and they are used for main transmission lines.

3.3 Insulating underground cable

Conductors that transmit electricity need to be electrically insulated. One major difference between overhead lines and underground cables is the way they are insulated. Overhead lines are insulated by air, while underground cable conductors are wrapped in layers of insulating material. Air is the simplest and cheapest insulation and the heat produced by the electricity flowing through the bare overhead conductors is removed by the flow of air over the conductors. When conductors are buried underground, robust insulation is needed to withstand the very high voltage. The insulation method depends upon the type of cable used. Underground cables, because of the insulation and surrounding environment, tend to retain the heat produced in the copper/aluminum conductor. This heat then has to be dissipated to the surrounding environment. To compensate for this, underground cables are generally bigger to reduce their electrical resistance and heat produced. How the heat produced is dissipated will depend upon the cable installation method.

For direct buried cables each cable needs to be well-spaced from others for good heat dissipation. To match overhead line thermal performance for a 400kV double circuit, as many as 12 separate cables in four separate trenches may be needed, resulting in a work area up to 65m wide.

In addition, water cooling may be used. For cables installed in deep bore tunnels, cable cooling is provided by forced air ventilation or water cooling.

When designing a cable system, there are a number of factors to consider relating to the physical environment of the cable, which will help optimize their electrical performance.

These include ensuring:

- Adequate heat dissipation to prevent overheating and subsequent reduction in its capacity for carrying current (cable rating).
- Adequate physical protection to protect the cable from damage and to ensure it is not a potential danger to people while in service.
- Proper access for maintenance crews to the cable to inspect, repair or replace it.

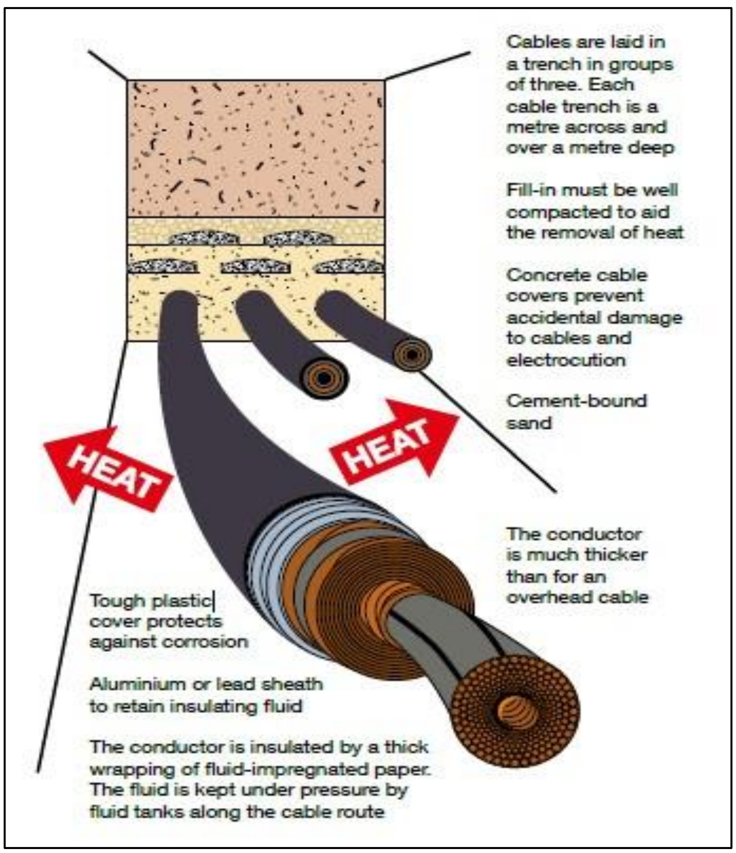


Figure 3-1. A typical cable installation method

3.4 Types of Underground Electric Transmission Cables

There are two main types of underground transmission lines currently in use. One type is constructed in a pipe with fluid or gas pumped or circulated through and around the cable in order to manage heat and insulate the cables. The other type is a solid dielectric cable which requires no fluids or gas and is a more recent technological advancement. The common types of underground cable construction include:

- High-pressure, fluid-filled pipe (HPFF)
- High-pressure, gas-filled pipe (HPGF)
- Self-contained fluid-filled (SCFF)
- Solid cable, cross-linked polyethylene (XLPE)

3.4.1 High-Pressure, Fluid-Filled Pipe-Type Cable

A high-pressure, fluid-filled (HPFF) pipe-type of underground transmission line, consists of a steel pipe that contains three high-voltage conductors. Figure 2 illustrates a typical HPFF pipe-type cable.

Each conductor is made of copper or aluminum; insulated with high-quality, oil-impregnated kraft paper insulation; and covered with metal shielding (usually lead) and skid wires (for protection during construction).

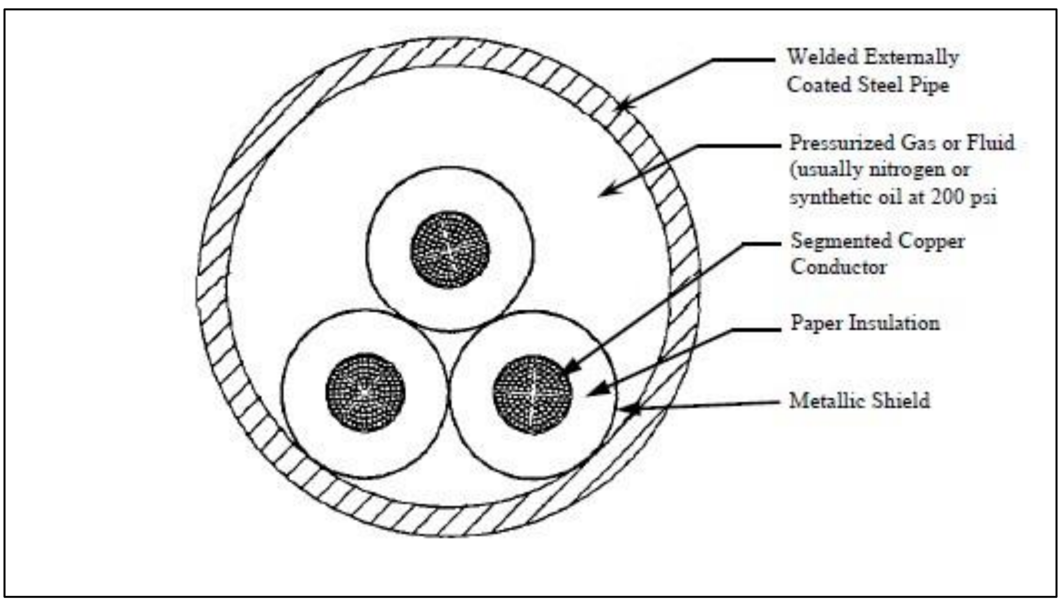


Figure 3-2. HPFF or HPGF Pipe-Type Cross Section

Inside steel pipes, three conductors are surrounded by a dielectric oil which is maintained at 200 pounds per square inch (psi). This fluid acts as an insulator and does not conduct electricity. The pressurized dielectric fluid prevents electrical discharges in the conductors' insulation. An electrical discharge can cause the line to fail. The fluid also transfers heat away from the conductors.

The fluid is usually static and removes heat by conduction. In some situations the fluid is pumped through the pipe and cooled through the use of a heat exchanger. Cables with pumped fluids require aboveground pumping stations, usually located within substations. The pumping stations monitor the pressure and temperature of the fluid. There is a radiator-type device that moves the heat from the underground cables to the atmosphere. The oil is also monitored for any degradation or trouble with the cable materials.

The outer steel pipe protects the conductors from mechanical damage, water infiltration, and minimizes the potential for oil leaks. The pipe is protected from the chemical and electrical environment of the soil by means of a coating and cathodic protection.

Problems associated with HPFF pipe-type underground transmission lines include maintenance issues and possible contamination of surrounding soils and groundwater due to leaking oil.

3.4.2 High-Pressure, Gas-Filled Pipe-Type Cable

The high-pressure, gas-filled (HPGF) pipe-type of underground transmission line (see Figure 1) is a variation of the HPFF pipe-type, described above. Instead of a dielectric oil, pressurized nitrogen gas is used to insulate the conductors. Nitrogen gas is less effective than dielectric fluids at suppressing electrical discharges and cooling. To compensate for this, the conductors' insulation is about 20 percent thicker than the insulation in fluid-filled pipes. Thicker insulation and a warmer pipe reduce the amount of current the line can safely and efficiently carry. In case of a leak or break in the cable system, the nitrogen gas is easier to deal with than the dielectric oil in the surrounding environment.

3.4.3 Self-Contained, Fluid-Filled Pipe-Type

The self-contained, fluid-filled (SCFF) pipe-type of underground transmission is often used for underwater transmission construction. The conductors are hollow and filled with an insulating fluid that is pressurized to 25 to 50 psi. In addition, the three cables are independent of each other. They are not placed together in a pipe.

Each cable consists of a fluid-filled conductor insulated with high-quality kraft paper and protected by a lead-bronze or aluminum sheath and a plastic jacket. The fluid reduces the chance of electrical discharge and line failure. The sheath helps pressurize the conductor's fluid and the plastic jacket keeps the water out. This type of construction reduces the risk of a total failure, but the construction costs are much higher than the single pipe used to construct the HPFF or HPGF systems.

3.4.4 Solid Cable, Cross-Linked Polyethylene(XLPE)

The cross-linked polyethylene (XLPE) underground transmission line is often called solid dielectric cable. The solid dielectric material replaces the pressurized liquid or gas of the pipe-type cables.

XLPE cable has become the national standard for underground electric transmission lines less than 200 kV. There is less maintenance with the solid cable, but impending insulation failures are much more difficult to monitor and detect. The diameter of the XLPE cables increase with voltage (Figure 3).

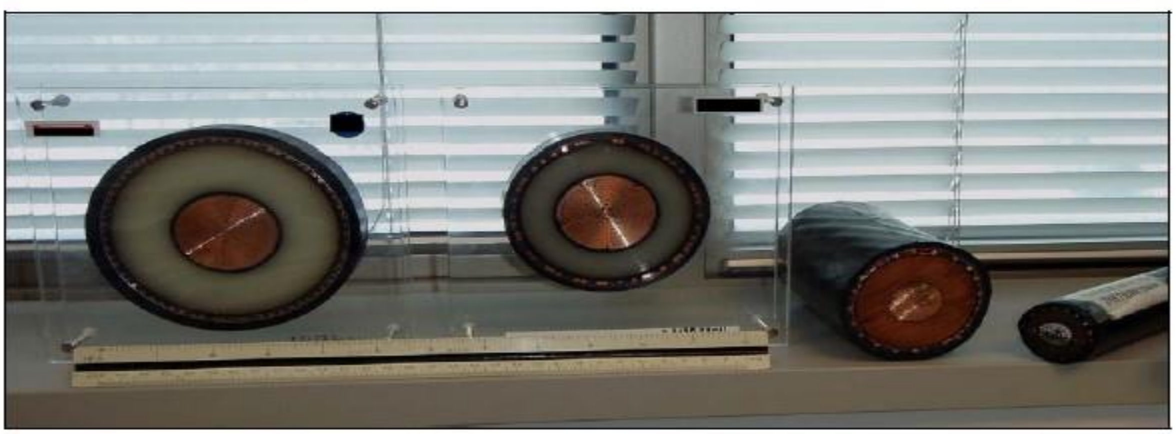


Figure 3-3. XLPE Cables with Different Voltages

Underground XLPE cables left to right: 345 kV, 138 kV, 69 kV, and distribution

Each transmission line requires three separate cables, similar to the three conductors required for aboveground transmission lines. They are not housed together in a pipe, but are set in concrete ducts or buried side-by-side. Each cable consists of a copper or aluminum conductor and a semi-conducting shield at its core. A cross-linked polyethylene insulation surrounds the core. The outer covering of the cable consists of a metallic sheath and a plastic jacket.

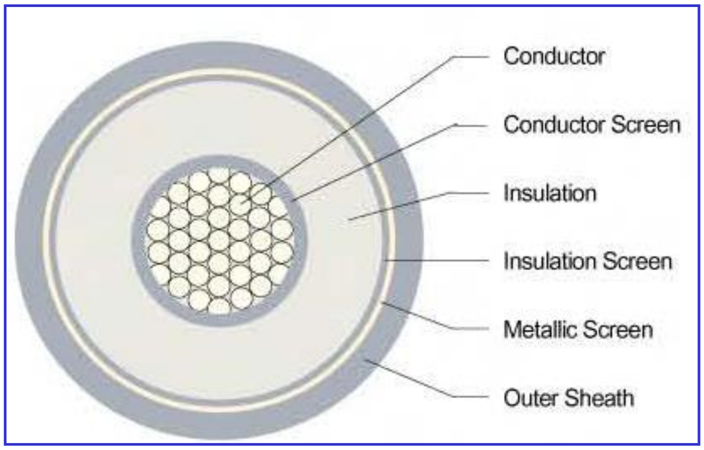


Figure 3-4. XLPE Cable Cross-Section

3.4.4.1 Conductor

The conductor consists of annealed copper or hard aluminum stranded wires and classified into three (3) major types of concentric, compacted circular and segmental compacted circular.

3.4.4.2 Conductor Screen

The conductor screen consists of an extruded semi-conducting polyethylene to minimize electrical stresses due to the stranded configuration of the conductor. The semi-conducting material used for conductor screen has no deleterious effect on the conductor. Semi-conducting tape is sometimes applied as a separator.

3.4.4.3 Insulation

The insulation material is extruded cross-linked polyethylene. The conductor screen, the insulation and the insulation screen mentioned to the following clause are extruded simultaneously in one process to ensure that the screen and insulation are intimately bonded together and free from all possibilities of voids between layers. The extrusion process is carried out under strictly controlled atmospheric conditions.

3.4.4.4 Insulation Screen

The insulation screen is provided over the insulation by extruding the semi-conducting compound concentrically and circularly to minimize the possibility of ionization on the outer surface of the dielectric.

3.4.4.5 Metallic Screen

The metallic screen consists of the wire shield, the corrugated aluminum sheath or the lead sheath. The corrugated aluminum sheath and the lead sheath is also adopted where the surface of duct is poor and where moisture is high.

3.4.4.6 Outer Sheath

Outer Sheath is to protect the metallic sheath from electrical or chemical corrosion, it is covered by PE or PVC.

3.5 Cable installation method

There are a number of different cable installation methods available. The method used depends upon a range of factors including land use and each will have different environmental factors. The various options are described below.

3.5.1 Direct buried cables

The traditional means of cable installation for high voltage cables in urban and rural areas is by direct burial. Trenches approximately 1.5m wide and 1.2m deep are required for each single cable circuit. A thermally stable backfill of cement bound sand is used to ensure a known thermal conductivity around the cables in order to maintain the cable rating (capacity to carry current).

A large cable swathe is normally required which can be up to 65m in width depending on the number of circuits and size of conductor to be installed. Joint bays are necessary at intervals of approximately 500–1,000m to allow for the jointing of the individual sections of cable. In these areas a widening of the easement corridor may be required for the arrangement of joints.

Direct burial of cables involves excavating trenches into which the cables are installed on a bed of selected sand or cement bound sand with the use of winches or power rollers. Sheet piling or timber is used to support the sides of the trenches. Reinstatement of the excavated trench is then carried out using approved backfill material placed directly around the cables with protection covers placed above the cables in the excavation. All backfill materials such as cement bound sand/ selected sand must be carefully compacted around the cables to ensure no air pockets exist.

The presence of any air pockets will degrade the cable system rating. Regular tests are carried out during this process to ensure the correct level of compaction is achieved. There are safety and environmental issues associated with the installation of direct buried cables. These include disruption to traffic, excessive noise, vibration, visual intrusion and dust generation. The use of heavy plant and construction traffic will also be a factor. Working alongside open excavations with heavy plant and construction equipment also imposes various safety risks.

Direct burial is normally the cheapest method for the installation of underground cables where restrictions on land use are not an issue. Where there is a requirement to cross major roads or through urban areas the costs of this type of major excavation in terms of traffic management, construction and legal restrains can be considerable.

Figure 3-5. Direct buried cable installation in a rural area

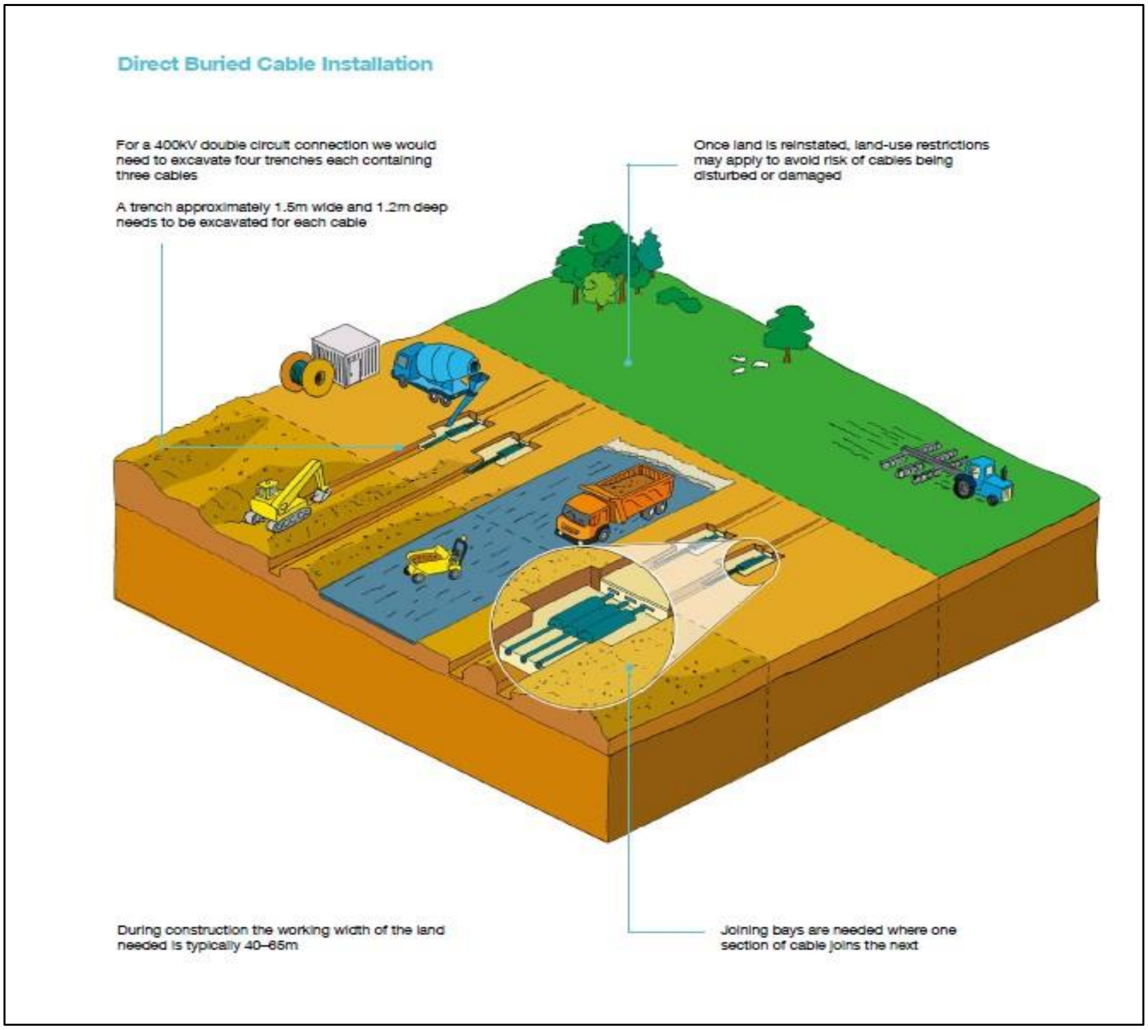


Figure3- 6. Direct Buried Cable Installation

3.5.2 Ducted method

An alternative, but more expensive method to direct burial is installation using ducts. The advantage of a ducted installation is that the ducts can be installed in shorter sections along the cable route leaving shorter sections of exposed trench, reducing risk and disruption to the general public.

Most cable systems have specific cable designs and therefore cable can only be manufactured once the contract has been agreed. This may cause long delays. Installing ducts has the advantage of saving installation time as all the ducts can be installed before the cable delivery.

3.5.3 Surface troughs

For surface trough installation, a trench is excavated and a concrete base is laid in the bottom of the trench to support the troughs. The troughs are laid at a depth so that only the trough cover is visible. The cables are laid directly within the troughs, which are capped with reinforced concrete covers. Troughs provide mechanical protection for the cables and improved thermal conductivity; however, the level of rating available may be restricted.

Surface troughs are not normally suitable for routes with heavy vehicle traffic or where there is a high risk of thieves and vandals. Therefore, on National Grid's network, they are normally only used in secure areas such as substations, although historically they can also be found beside canals. In rural locations, direct bury cables are less visually intrusive than this option. Environmental impacts are relatively minimal and are likely to include noise, dust and access restrictions during the construction and subsequent maintenance phases.

Figure 3-7. 275kV cables installed in surface troughs along tow path

3.5.4 Deep bore tunnels

Tunnel installation is generally used in urban locations where direct bury installation would cause unacceptable disruption. The method of excavation and tunnel design is largely dependent on the size of the tunnel required and the type of ground in which it is to be bored. Tunnels are lined with bolted segments and sealed using gaskets.

Detailed ground condition surveys are required to determine the most appropriate design.

The depth of a tunnel is typically around 25–30m and maintains a fall (slope) of 1:1,000 to provide free drainage. Tunnel construction requires a significant amount of land – around 3,000m_2 at the primary construction site, where a 12m diameter shaft is needed. A tunnel requires a minimum of two head house buildings to provide access for maintenance and for installation of the cables at each end. Head house buildings are around 16m x 16m x 7m in height. In addition, tunnels of significant length require inspection and emergency access and exit points along the route to ensure escape from the tunnel within safe limits.

A tunnel with a diameter of around 4m would be required to provide sufficient room for up to 12 cable cores and joint bays. Within the tunnel a rail mounted access vehicle may be required to provide safe emergency exit and allow inspection, maintenance and repair. Cable cooling is provided by forced air cooling from electrically driven fans. If necessary additional cooling can be provided by a water cooling system.

The advantages of using deep tunnels are that underground services such as water and sewerage are unaffected, and river or railway crossings can be made. Also, because of limited surface land take, normal development can take place at ground level and along the route of the tunnel there is minimal disruption during construction and maintenance. However, these result in significant costs associated with planning consent, land acquisition and planning and constructing a route to avoid major surface and underground structures. In addition, development at the primary construction site is likely to generate environmental impacts, such as disruption to traffic, noise, vibration and dust for the duration of the development.

Figure 3-8. Tunnel head house building

Figure 3-9. XLPE cables installed in a deep bore tunnel

3.5.5 Cut and cover tunnels

For cut and cover tunnels, a tunnel is constructed using pre-formed concrete sections, which are laid in a pre-excavated deep open trench. The depth at which they are laid is dependent on ground conditions and proposed future land use.

The tunnel sections require a head house at each end to provide the ventilation fans for forced air cooling and entry points to the tunnels. Emergency access/exit points may also be required along a tunnel route depending upon its length. The tunnel must be of sufficient size to provide adequate space for the installation and operation of the cables, the ventilation for removal of heat and safe access for personnel during cable installation and maintenance. The land above the tunnel can be developed, but depending on its depth, certain restrictions may apply. The environmental impacts from the installation of a cut and cover tunnel are considerable. They include noise, vibration, construction/delivery traffic, visual intrusion, dust generation and deposition due to the excavation of trenches along the route.

Figure 3-10. Cut and cover tunnel installation in mainland Europe

M04 – OPERATION & MAINTENANCE OVERVIEW

4.1 Objectives

At the end of this module participants should be able to:

- Define the basic procedures for maintaining underground transmission system
- Understand the basic considerations for operation and maintenance

4.2 Introduction

Cables have an asset life of around 60 years. During their lifetime regular inspection and testing is carried out to ensure that cable insulation and joints are operating correctly. At the time of installation, equipment is put in place that monitors the performance of the cable and its insulation. Over the lifetime of a cable significant refurbishment and repairs to ancillary equipment, such as fluid tanks, may require more significant excavations at joint bays and stop joints. Vehicular access to strategic areas of the cable route, such as joint bays, is required at all times.

If a fault occurs on an underground cable, it is on average out of service longer than overhead lines. This is due principally to the long time taken to locate, excavate and undertake the repair works These maintenance and repairs also cost significantly more.

The majority of faults on cables are caused by fluid leaks, faulty joints and accessories, sheath faults, water cooling failures and, most commonly, third party damage. Under fault conditions, several weeks can be required to locate the fault or fluid leak and repair the cable. During this period excavations may be required which can result in road closures and traffic management measures. In some cases, the excavations could be in the order of 4m x 30m. Underground cables are generally matched to the rating of the overhead line route in which they are installed; this also determines the cable design and any necessary cooling. Where an increase in the rating of an overhead line is required it can usually be achieved relatively easily by using different or larger conductors. Where there is an underground cable installed as part of a route the up-rating can only be achieved at considerable expense, for example, by re-excavation and the installation of larger or more cables or with additional cooling.

4.3 Underground Operating Considerations

Post-construction issues such as aesthetics, electric and magnetic fields (EMF), and property values are usually less of an issue for underground lines. Underground lines are not visible after construction and have less impact on property values and aesthetics.

Apart from cost and construction issues, there are continued maintenance and safety issues associated with the right-of-way. The right-of-way must be kept safe from accidental contact by subsequent construction activities. To protect individual ducts (for SCFF and XLPE lines) against accidental future dig-ins, a concrete duct bank, a concrete slab, or patio blocks are installed above the line, along with a system of warning signs ("high-voltage buried cable"). Additionally, if the cables are not constructed under roads or highways, the ROW must be kept clear of vegetation with long roots such as trees that could interfere with the system.

4.4 Cable Repairs

Repair costs for an underground line are usually greater than costs for an equivalent overhead line. Leaks can cost $50,000 to $100,000 to locate and repair. A leak detection system for a HPFF cable system can cost from $1,000 to $400,000 to purchase and install depending on the system technology. Molded joints for splices in XLPE line could cost about $20,000 to repair. Field-made splices could cost up to $60,000 to repair.

A fault in a directionally drilled section of the line could require replacement of the entire section. For example, the cost for directional drilling an HPGF cables is $25 per foot per cable. The cables in the directional drilled section twist around each other in the pipe so they all would have to be pulled out for examination. The newer XLPE cables tend to have a life that is one half of an overhead conductor which may require replacing the underground every 35 years or so.

Easement agreements may require the utility to compensate property owners for disruption in their property use and for property damage that is caused by repairing underground transmission lines on private property. However, the cost to compensate the landowner is small compared to the total repair costs. Underground transmission lines have higher life cycle costs than overhead transmission lines when combining construction repair and maintenance costs over the life of the line.

4.5 Potential Fluid Leaks

Although pipe-type underground transmission lines require little maintenance, transmission owners must establish and follow an appropriate maintenance program, otherwise pipe corrosion can lead to fluid leaks.

Both HPFF and SCFF lines must have a spill control plan. The estimate for potential line leakage is about one leak every 25 years. Soil contaminated with leaking dielectric oil is classified as a hazardous waste. This means that contaminated soils and water would have to be remediated. The types of dielectric fluid used in underground transmission lines include alkylbenzene (which is used in making detergents) and polybutene (which is chemically related to Styrofoam). These are not toxic, but are slow to degrade. The release and degradation of alkylbenzene could cause benzene compounds, a known carcinogen, to show up in plants or wildlife.

A nitrogen leak from a HPGF line would not affect the environment, but workers would need to check oxygen levels in the vaults before entering. Fluid leaks are not a problem for solid dielectric cables.

4.6 Electric and Magnetic Fields

Electric fields are created by voltage. Higher voltage produces stronger electric fields. Electric fields are blocked by most objects such as walls, trees, and soil and are not an issue with underground transmission lines. Magnetic fields are created by current and produced by all household appliances that use electricity. Magnetic field strength increases as current increases so there is a stronger magnetic field generated when an appliance is set on "high" than when it is set on "low". Milligauss (mG) is the common measurement of magnetic field strength. Typically, a hair dryer produces a magnetic field of 70 mG when measured one foot from the appliance. A television produces approximately 20 mG measured at a distance of one foot. The strength of the magnetic field produced by a particular transmission line is determined by current, distance from the line, arrangement of the three conductors, and the presence or absence of magnetic shielding. Underground transmission lines produce lower magnetic fields than aboveground lines because the underground conductors are placed closer together which causes the magnetic fields created by each of the three conductors to cancel out some of the other's fields.

This results in reduced magnetic fields. Magnetic fields are also strongest close to their source and drop off rapidly with distance (Table 1). Pipe-type underground lines can have significantly lower magnetic fields than overhead lines or other kinds of underground lines because the steel pipe has magnetic shielding properties that further reduce the field produced by the conductors.

Table 1 shows sample magnetic field measurements at different distances from underground and overhead lines. Maximum magnetic field strengths of underground transmission lines typically do not exceed a few mG at a distance of 25 feet.

Voltage	Construction	Amperes	Distance	mG
69 kV	Underground - XLPE	252	Centerline at surface	34.20
			50 feet from Centerline	0.90
69 kV	Underground - Pipe-type	204	Centerline at surface	0.80
			50 feet from Centerline	0.10
69 kV	Overhead	167	Centerline	23.00
			40 feet from Centerline	7.00
138 kV	Underground - Pipe-type	467	Centerline at surface	0.21
			50 feet from Centerline	0.05
138 kV	Overhead	710	Centerline at surface	190.00
			50 feet from Centerline	46.00

Table 4-1. Sample Magnetic Field Strength of Various Transmission Lines

4.7 Heat

Heat produced by the operation of an underground transmission cable raises the temperature at the surface above the line, a few degrees. This is not enough to harm growing plants, but it could cause premature seed germination in the spring. Heat could also build up in enclosed buildings near the line. Transmission routes that include other heat sources, such as steam mains, should be avoided.

Electric cables should be kept at least 12 feet from other heat sources, otherwise the cable's ability to carry current decreases.