# Design a 161 kV transmission line system from Huwara to Jenin


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الاهداء

الى وطننا فلسطين

الى شهداء فلسطين

الى الاسرى والمعتقلين

الى ينبوع العطاء والحنان .. اباؤنا وامهاتنا

اخواننا واخواتنا

زملائنا وزميلاتنا

معلمينا وكل محبي العلم والمعرفة والى كل من ساهم في انجاح
هذا العمل

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## الملخص


هـذا المشروع يقـوم عـلى عمـل تصـميم لخـط نقـل كهربائي للضـفة الغربيـة بالكامـل مـن الشـمال الى الجنـوب. حيـث يقـوم هـذا المشروع بعمـل تصـميم للابـراج ،وخطـوط النقـل الكهـربائي والعـوازل وانظمـة الحمايـة المناسـبة لهـذا التصـميم مـع الاخـذ بعـين الاعتبـار الاحـمال المسـتقبليه للمنطقـه الخاصـه بالمشروع في الفـتره الواقعـه مـا بـين(2015-2040).وتم ايضـا عمـل تصـميم محطـة لـكل مدينـة سـوف يعـبر مـن خلالهـا الخـط، وتم الحصـول عـلى المعلومـات التفصـيليه الخاصـه بالشـبكه وتم عمل محاكاه للمشروع باستخدام برنامج E-TAP .

# Abstract

The idea of the project is to design transmission line system for all of the west bank from north to the south. The appropriate design for towers, conductors, insulators has been done as well as for protection system, considering future loads for the area of the project in the period of (2015-2040), and we designed substation for each city that the transmission line across it, and after collecting the specific information of the network the project synchronization built using E-TAP program.

# CHAPTER ONE

# Introduction

## 1.1 Overview

We designed a transmission line of electric power from Huwara to Jenin, this line feeds the substation transformers in the north west Bank, and the line will transfer 1 GW in conductors, we are depending on the information from the Statistics Center.

The design taking into account the load growth up to 2040.

## 1.2 The objectives of project

- Study the load growth of the north of the west bank up to the year 2040.
- Complete design of 161 kv transmission line system from Huwara to Jenin.
- Design substation from (161-33) kv for each city in the north of the west bank.
- Simulation of the design system using electromagnetic transients program (E-TAP) program.

## 1.3 Motivations

Due to increase in an electrical power system, all developing countries attempting to electricity independent. So, Palestinian government is attempt to self-sufficient from Israeli occupation so, this motivates us to design a new transmission line system to achieve this aim.

## 1.4 Approach

1. Collect the need and appropriate data by statistics center.
2. Collect the need and appropriate data by Palestinian power authority.
3. Estimate the load growth during 20 years.
4. Design all components of the transmission line and the substation.
5. Collect the standard measurements depending on the national electrical safety code $NESC_{2007}$.

## 1.5 Importance of the project

This project can be used as a guide for design a transmission line and substation, if we apply this project in a west bank we can pass up the Israeli transmission line.

# Chapter two

## Load growth

## 2.1 The number of population (2010-2040)

To depend the information of Palestinian statics center. it explains the number of population in the period between (2010-2040) and the range of power consumption

Per each one in these south cities (Nablus-Tulkarm-Jenin). our worked to define the equation. And we were able to draw a curve.

The curve explains the relation between the ratio of increases the number of population and the power consumption yearly per each one.

### 2.1.1 Power consumption per each person.

We have used the information from the Palestinian central of statistics for the work area for our project. We were able to define equation which has been used to create the load growth curve (2010-2040).

| YEAR | NABLUS | TULKARM | JENIN |
|---|---|---|---|
| 2010 | 0.38 | 0.35 | 0.35 |
| 2011 | 0.37 | 0.37 | 0.41 |
| 2012 | 0.43 | 0.36 | 0.47 |
| 2013 | 0.4 | 0.36 | 0.46 |
| 2014 | 0.4 | 0.29 | 0.44 |
| 2015 | 0.42 | 0.39 | 0.46 |

Table2.1: max power consumption per each person at (MW).

## 2.2 The average load growth (2010-2040)

Considering on these equations and curves, we do forecasting.

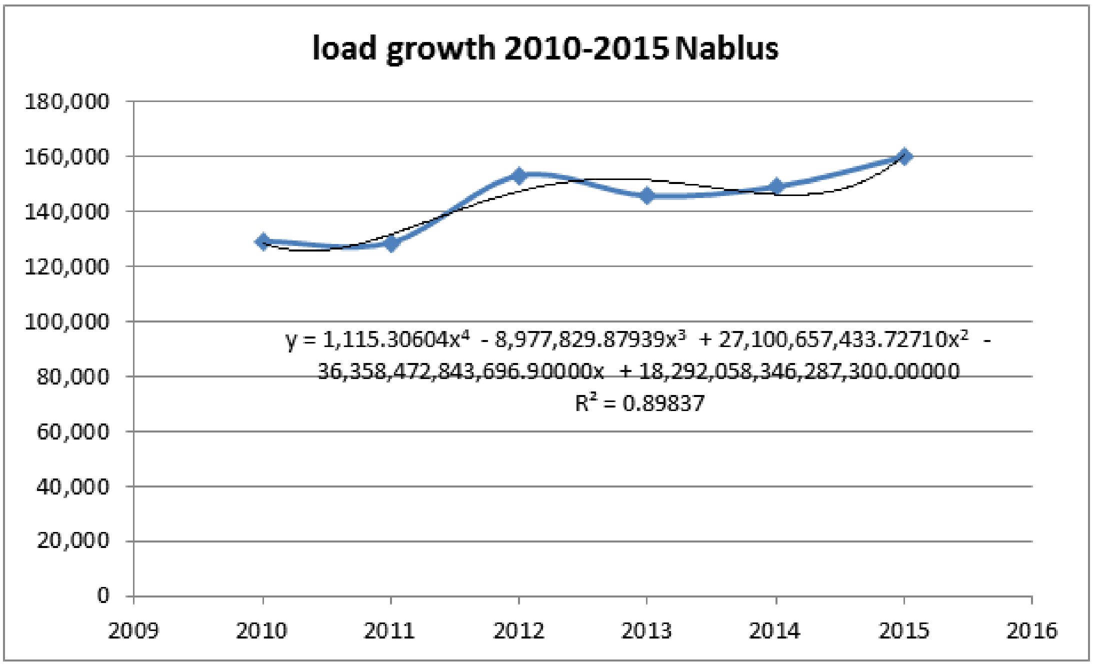


Figure 2.1: Average Load Between (2010-2015) for Nablus

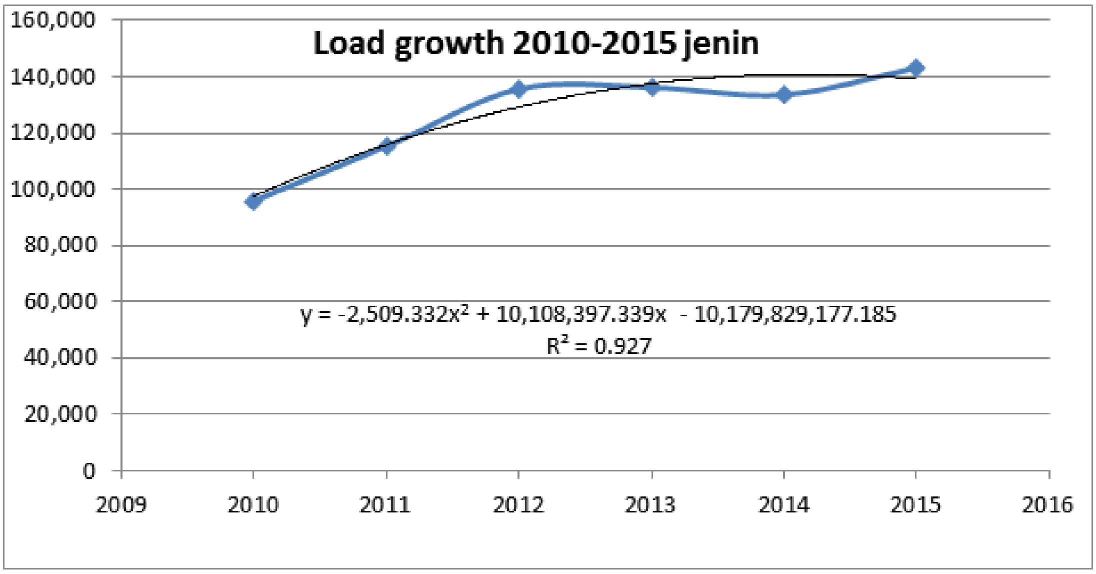


Figure 2.2 Average Load Between (2010-2015) for Jenin

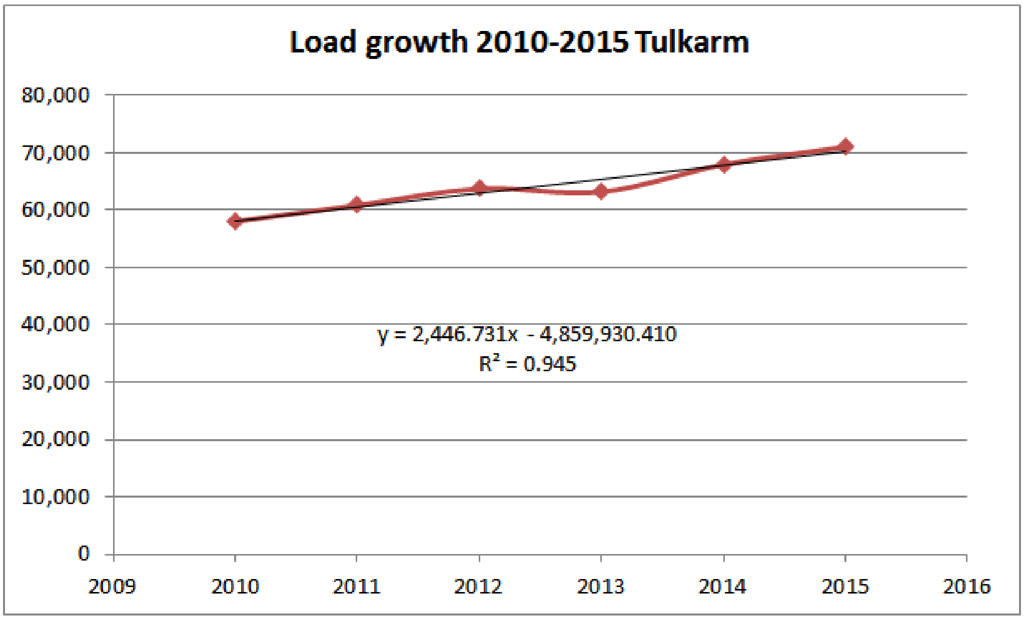


Figure 2.3: Average Load Between (2010-2015) for Tulkarm

## 2.3 The load growth (2010-2040)

The curve below explains the ratio between the number of population and the power consumption per person in the south west, it includes (Nablus-Tulkarm - Jenin), and we assume this equation to determine this curve by excel program.

$$Y = 6765.56756\,x - 13377271.42145$$

$$R^2 = 0.98647$$

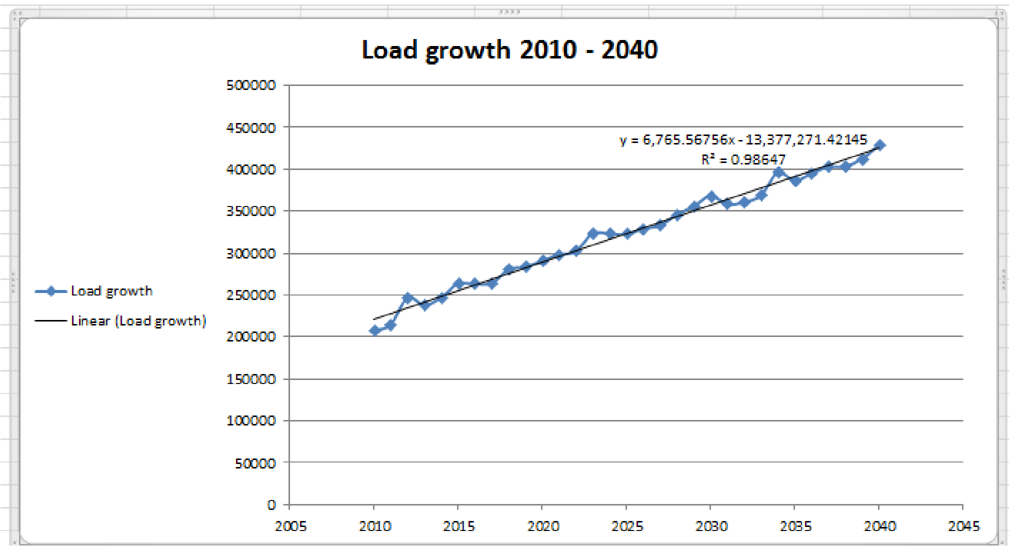


Figure 2.4: load growth in south west bank

| District | Pf | angle | Pmax(MW) | Q max(MVAR) | S MAX(MVA) |
|---|---|---|---|---|---|
| JENIN | 0.8 | 36.8 | 46.3 | 34.64 | **57.824** |
| TULKARM | 0.8 | 36.8 | 53.6 | 40.1 | **66.94** |
| QALQILIA | 0.8 | 36.8 | 24.3 | 18.18 | **30.34** |
| NABLUS | 0.86 | 30.68 | 96.2 | 57.1 | **111.85** |
| RAMALLAH | 0.85 | 31.78 | 136.4 | 84.5 | **160.45** |
| JERICHO | 0.85 | 31.78 | 25.6 | 15.86 | **30.11** |
| JERUSALEM | 0.85 | 31.78 | 167.1 | 103.5 | **196.57** |
| BETLAHIM | 0.85 | 31.78 | 93.7 | 58.05 | **110.22** |
| HEBRON | 0.85 | 31.78 | 142.7 | 88.5 | **167.86** |
| SALFIT | 0.85 | 31.78 | 9.6 | 5.95 | **11.29** |
| TOUBAS | 0.85 | 31.78 | 13.5 | 8.36 | **15.88** |
| TOTAL | | | 809 | 514.63 | |

Table 2.2 loads data of the districts of the WEST BANK

# Chapter three

## Design and Data Analyses

3

## 3.1 Introduction

We design the appropriate component for the transmission line towers, conductors, protection and insulators as it required in the national electrical safety code $NESC_{2007}$.

## 3.2 Towers Design

### 3.2.1 Introduction

It’s the main unit for supporting the overhead transmission lines, towers have to carry transmission conductor at safe height from ground.

### 3.2.2 The main parts of transmission towers are:

- Peak of transmission tower.
- Cross arm of transmission tower.
- Cage of transmission tower.
- Transmission Tower Body

### 3.2.3 Design of transmission towers

**When we design, transmission tower this point should be considered in mind:**

- The minimum ground clearance of the lowest conductor point above the ground level.
- The minimum clearance to be maintained between conductors.
- The distance between the first circuit and, the second circuit.

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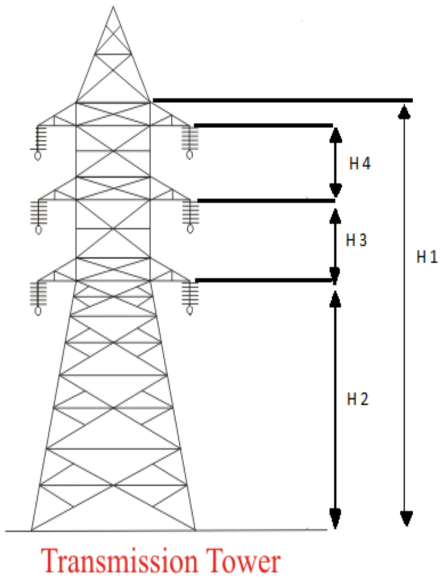


Figure3.1: transmission tower heights.

In our project, we will work on 161-kv towers, these towers under national electrical standards $NCSC_{2007}$.

We will work in our design on this tower.

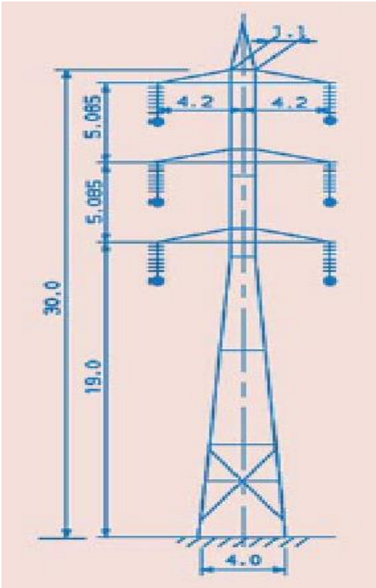


Figure3.2: dimensions of transmission tower

- The vertical distance between the first cross-arm and the second cross-arm = 5.085 m.
- The vertical distance between the second cross-arm and the third cross-arm = 5.085 m.
- The vertical distance between the third cross-arm and the ground = 19 m.
- The horizontal distance between the first circuit and, the second circuit = 1.1 m.
- The horizontal distance from the end of cross arm to the tower cage = 4.2 m.
- The height of the tower = 30 m.
- The horizontal distance between the tower legs = 4 m.
- Weight of the tower =2570kg.

The normal span between towers is 350 m.

$$\text{Number of towers} = \frac{disnance}{span\ between\ towers + horizantal\ tower\ base} \tag{3.1}$$

$$= \frac{55\ km}{350m + 4\ m}$$

= 155 tower.

So, we will put 155 tower will be distributed to:

- Suspension towers.
- Tension towers.
- Angle towers.
- End tower.

#### 3.2.3.1 Tension

$$T = \frac{w.g.L^2}{8.S} \tag{3.2}$$

w= weigh of conductor per unit length (kg/m)

L= span of the conductor (m)

g = gravitational constant (1kgf = 9.81 N)

S= sag (m)

w=926.5kg/km

L=350m

g=9.81N

For the sag, we take the min. sag which gives the max. tension.

So, we take the min. sag = 3m.

So, the tension.

$$T = \frac{\frac{926.5\text{kg}}{\text{km}} \cdot \mathbf{9.81} \cdot \mathbf{350^2}}{\mathbf{8.3}}$$

= 46.39 kN for each conductor

#### 3.2.3.2 Guy and stay wire

Stay wires or guys wire are galvanized steel wire strands that are used for sustaining mechanical load. Generally, they are made up of 6 wires stranded around 1 wire, twisting 7 wires together. A common use for stay wires is in the electricity industry, using the wire to stay power poles and tower structures.

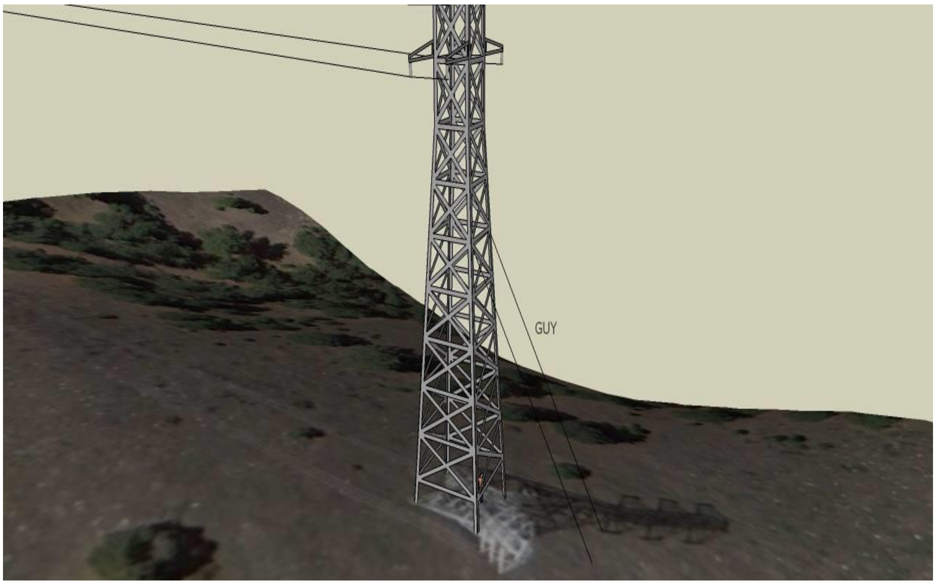


Figure 3.3 Guy-loading diagram

$$T_h = \frac{1}{h_g} \left( T_1 \times h_1 + T_2 \times h_2 + T_3 \times h_3 \right) \tag{3.3}$$

Where,

*Th* is the horizontal component of guy wire tension.

$T1$ is the horizontal load at height $h1$.

$T2$ is the horizontal load at height $h2$.

$T3$ is the horizontal load at height $h3$.

$hg$ is the height of attachment point of guy.

$h1$ is the height of horizontal load $T1$.

$h2$ is the height of horizontal load $T2$.

$h3$ is the height of horizontal load $T3$.

$$=\frac{1}{15}\ (46.39 \times 29 + 46.39 \times 24 + 46.39 \times 19\ )$$

$$=222.672 \text{ kN}$$

$$\tan\beta = \frac{h_g}{L} \tag{3.4}$$

$$\tan\beta = \frac{15}{5} = 3.$$

$$\beta = \arctan\left(\frac{h_g}{L}\right) \tag{3.5}$$

$$=71.5^{o}$$

Where $L$ is the lead of the guy. Then, the tension in the guy wire is

$$T_g = \frac{T_h}{cos\beta} \tag{3.6}$$

$$=\frac{222.672kN}{COS\ 71.5}$$

$$=701.7 \text{ kN}$$

This tension will be for the first guy for the first circuit, we will use two guy wires for the tower who will have tension from one side or, tension from two sides but, with angle between them.

#### 3.2.3.3 Tower base

First case: when we have tension from one side.

a. For rocky soil.

The dimension for this base is (6.5×6.5) m in X-Y, with depth 3.5 m.

b. For sandy soil.

The dimension for this base is (7.5×7.5) m in X-Y, with depth 4 m.

Second case: when we have tension from two side.

a. For rocky soil.

The dimension for this base is (5×5) m in X-Y, with depth 2.5 m.

b. For sandy soil.

The dimension for this base is (6×6) m in X-Y, with depth 3 m.

We used for the two cases, reinforced concrete type 350B.

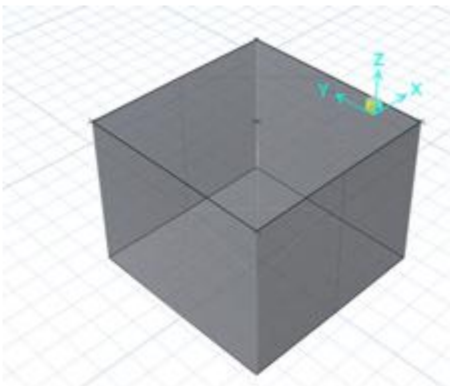

Figure 3.4 Tower Base

#### 3.2.3.4 Tower grounding

- Used to reduce earth wire potential and stress on insulators at the time of stroke and also for safety.

Tower footing resistance will be 10Ω and shouldn't be more than 20Ω under any condition throughout the year.

Earth resistance depends upon soil resistivity (general 100 Ω-m).

1. **Buried conductor**

   One or more conductor is connected to towers legs and buried in back filled of tower foundation.

   Used where soil resistivity is low.

2. **Counterpoise wire**

   A length of wire of 50 m is buried horizontally at depth of 0.5 m below ground. This wire is connected to tower legs.

   Used when earth resistance is very high and soil conductivity is mostly confined to upper layer.

## 3.3 Conductor Design

### 1.5.1 Introduction

The temperature of the conductor increases with increasing heat produced by the current through it, it is sometimes possible to increase the power handling capacity (uprate) by changing the conductors for a type with a lower coefficient of thermal expansion or a higher allowable operating temperature.

$$\mathbf{P} = \boldsymbol{I}^{2} \times \boldsymbol{R} \tag{3.7}$$

### 3.3.2 Calculation for conductors

We want to transfer 1GW at rated voltage 161KV from huwara to Jenin

$$\text{Current} = \frac{p}{\sqrt{3}.Vkv.cos\emptyset} \tag{3.8}$$

P = 0.5 GW per each circuit.

Voltage equal 161 kV.

And let the maximum power factor equal 1.

$$\text{I} = \frac{0.5\ GW}{\sqrt{3}.161\ KV\ .1}$$

I = 1793.013 A

This is the current of each circuit at

First phase = 1793.013A , and the phase shift angle equal 0.

Second phase = 1793.013A , and the phase shift angle equal -120.

Third phase = 1793.013 A , and the phase shift angle equal 120.

The bundle of three sub conductors has been selected.

$$I_{LINE} = \frac{current\ of\ bundle}{3} \tag{3.9}$$

$$= \frac{1793.013}{3} I_{line}$$

=*597.67 A*

We choose the Lark type depends on the data sheet for conductors.

The cross-sectional area for each line equal 201.24 $mm^2$

The rated current equal 594A

The weight of conductor 926.5 $\frac{k_g}{km}$

For ground wire $I_g$ =I/2 =295.1 A.

We choose the Pigeon type depends on the data sheet for conductors.

The cross-sectional area for each ground line equal 85.03 $mm^2$

## 3.4 Sag in transmission line:

Sag calculations have an importance in the electrical transmission lines. because through these calculations can be determine the amount of clearance between the wire and the ground to identify whether it conforms to the terms of security and safety. Also, because sag affects the amount of tensile posed to the wire, it must adjust the clearance when installing the conductors so as not to exceed the permitted value of tensile strength even when a wire faces the worst cases of mechanical loading as possible.

In standard case:

If the two points are in the same level, the maximum sag is in the middle of the distance of conductors between towers.

### 3.4.1 The value of the sag depends on:

1-The distance between two towers, the sag increases if the distance as increase.

2-The tension of conductor's. if the tension increase the sag decrease.

3- Environmental effects (ice, wind…)

4-Tempreture, if the temperature increase, the sag is increase

5- The weight of conductor. If the weight increase the sag increase installing the right system will cut energy costs and keep the temperature more comfortable.

#### 3.4.1.1 Sag calculations between the same level towers

When the towers are identical the suspension points of the conductor are being at the same height and maximum sag occurs in the midway between two suspension wires and takes the form of a curve suspension chains.

$$D = \frac{L^2 \times W_C}{8T} \tag{3.10}$$

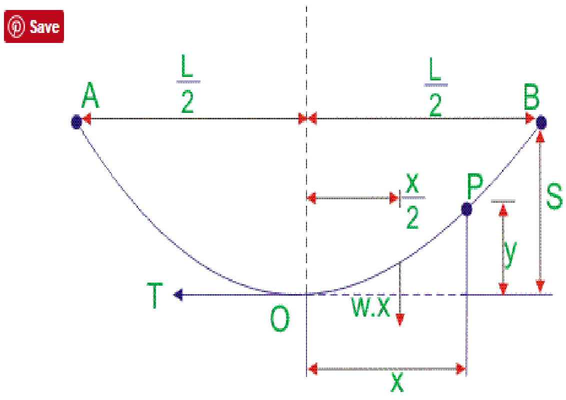


figure 3.5 sag between same tower level

D: the sag

L: The distance between towers per meter.

$w_c$ : The weight of conductor per each meter $k_g/m$

T: The tension on conductor N/m.

In this case the distance between conductor and the earth:

C = H-D

H: suspension point height from earth surface.

#### 3.4.1.2 How ice effects on the sag

When we have accumulation of snow layer with thickness (t) on the surface of the conductor, it is working to increase the weight of conductor and that weight impact to the bottom and to calculate the weight, firstly calculate the thickness of the layer accumulated:

The size of the accumulated snow / m (vi):

$$V_i = \frac{\pi}{4}\ ((d+2t)^2 - d)^2 \quad (3.11)$$

$$V_i = \frac{\pi}{4}\ (2d+2t).2t \quad (3.12)$$

$$V_i = (d+t)\pi\ .2t \quad (3.13)$$

Where d is the diameter of conductor.

The weight of ice ($W_i$)

$$= V_i \times \rho \quad (3.14) W_i$$

$$W_i = (d+t)2t\ .\pi.\rho \quad (3.15)$$

Since the weight of the snow affects vertically downwards in the same direction with the weight of conductor, so it is added to the weight of conductor directly, so the actual weight become the conductor weight plus the weight of accumulated snow, this weight enters in the sag calculation:

$$W_e = W_i + W_c \quad (3.16)$$

#### 3.4.1.3 Wind effects on the sag

When the conductors face a pressure winds of$k_g/m^2$, then this pressure make a force affected by it horizontally, its amount equal to the product of the wind pressure and the projected area of conductor per meter.

The force acting on the conductor as a result of wind pressure:

$$W_w = \ A_P \,.\, p = d \,.\, P \quad \frac{k_g}{m} \tag{3.17}$$

$$W_e = \ \sqrt{{W_c}^2 + \ {W_w}^2} \tag{3.18}$$

This total weight is used for sag calculation:

$$D_e = \ \frac{W_e \, L^2}{8T} \tag{3.19}$$

In this case the sag is not vertically but inclined with an angle (Ø):

$$\emptyset = \tan^{-1}\left(\frac{W_w}{W_c}\right) \tag{3.20}$$

The vertical sag (D) and sprains horizontal for conductor (Dh) are two components *De*

In vertical and horizontal directions:

$$D = \ D_e \, COS(\emptyset) \tag{3.21}$$

$$D_h = \ D_e \sin(\emptyset) \tag{3.22}$$

In case of which the line face the wind pressure in addition to snow:

$$W_e = \ \sqrt{(W_c + \ W_i)^2 + W_w} \tag{3.23}$$

$w_c$ : *the weight of conductor* $\frac{k_g}{m}$.

$w_i$ : *the weight of ice on conductor* $\frac{k_g}{m}$.

$w_w$ : *the force of pressure of wind* kg/$m^2$.

#### 3.4.1.4 Sag calculations between the same level towers

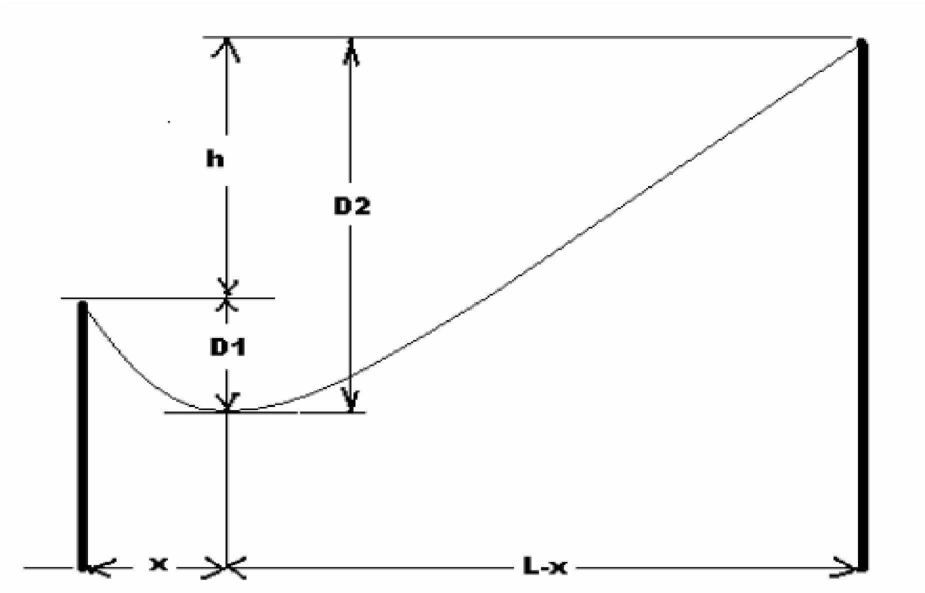


Figure 3.6 sag between different tower level

$$X = \frac{L}{2} - \frac{Th}{W_c L} \tag{3.24}$$

This equation determines the point of maximum sag of the short tower If it < X calculate the sag D1.

Using sag known equation. And the clearance between conductor and the earth in this case equal to the difference between the height of the short tower and the sag:

$$D_1 = \frac{W_c \,. X^2}{2T} \tag{3.25}$$

If the point > X it means that fewer low in the wire is the height of the short tower and the clearance between conductor and the earth is the height of short tower.

We use this equation in excel program to assume the values of sag at any span,

| w [kg/m] | T[kg] | L [m] | S [m] |
|---|---|---|---|
| 0.911 | 18546.754 | 50.000 | 0.015 |
| 0.911 | 18546.754 | 100.000 | 0.061 |
| 0.911 | 18546.754 | 150.000 | 0.138 |
| 0.911 | 18546.754 | 200.000 | 0.246 |
| 0.911 | 18546.754 | 250.000 | 0.384 |
| 0.911 | 18546.754 | 300.000 | 0.553 |
| 0.911 | 18546.754 | 350.000 | 0.752 |

Table 3.1 calculation sag at same level towers.

| density of ice[ kg/cm3] | d [cm] | t [cm] | wi[kg\m] | Ww [kg\m] | Wt [kg/m] | Cos Θ | S | Sv |
|---|---|---|---|---|---|---|---|---|
| 0.009 | 2.046 | 1.000 | 0.088 | 158.376 | 1.025 | 0.989 | 0.017 | 0.017 |
| 0.009 | 2.046 | 1.000 | 0.088 | 158.376 | 1.025 | 0.989 | 0.069 | 0.068 |
| 0.009 | 2.046 | 1.000 | 0.088 | 158.376 | 1.025 | 0.989 | 0.156 | 0.154 |
| 0.009 | 2.046 | 1.000 | 0.088 | 158.376 | 1.025 | 0.989 | 0.276 | 0.273 |
| 0.009 | 2.046 | 1.000 | 0.088 | 158.376 | 1.025 | 0.989 | 0.432 | 0.427 |
| 0.009 | 2.046 | 1.000 | 0.088 | 158.376 | 1.025 | 0.989 | 0.622 | 0.615 |
| 0.009 | 2.046 | 1.000 | 0.088 | 158.376 | 1.025 | 0.989 | 0.847 | 0.837 |

Table 3.2: Effect of Ice and wind on Sag

| **H[m]** | **X1** | **X2** | **S1** | **S2** |
|---|---|---|---|---|
| *10.000* | *-4047.181* | *4097.181* | *402.233* | *412.233* |
| *10.000* | *-1986.091* | *2086.091* | *96.866* | *106.866* |
| *10.000* | *-1282.394* | *1432.394* | *40.385* | *50.385* |
| *10.000* | *-918.045* | *1118.045* | *20.697* | *30.697* |
| *10.000* | *-689.436* | *939.436* | *11.672* | *21.672* |
| *10.000* | *-528.697* | *828.697* | *6.864* | *16.864* |
| *10.000* | *-406.740* | *756.740* | *4.063* | *14.063* |

Table 3.3 calculation sag at different heights.

Where

L = length of the span

w is the weight per unit length of the conductor

T is the tension in the conductor

y is the height from point O to point P

x2is the distance of support at the upper level point B from O

h is the difference in height level between two supports

x1 is the distance of support at the lower level point A from O

t: distance of ice over cable

d: diameter of cable

Density of ice = 0.9340g= 0.009340Kg at 0.0

### 3.4.2 Clearances

Measurement of Clearance and Spacing unless otherwise stated, all clearance shall be measured from surface to surface and all spacing's shall be measured center to center. For clearance measurement, live metallic hardware electrically connected to line conductors shall be considered a part of the line conductors. Metallic bases of potheads, surge arresters, and similar devices shall be considered a part of the supporting structure.

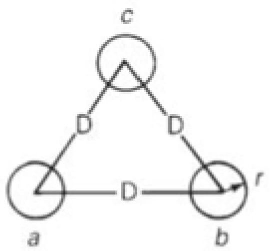


Figure 3.7 three-phase three-wire with equal phase spacing

$$D = \left(\frac{V.PU.a}{500K}\right)^{1.667} .bc(m) \tag{3.26}$$

Where:

V = maximum ac crest operating voltage to ground or maximum dc operating voltage to ground in kilovolts;

PU = maximum switching-surge factor expressed in per-unit peak voltage to ground and denned as a switching -surge level for circuit breakers corresponding to0.98probability the maximum switching surge generated per breaker operation does not exceed this surge level, or the maximum anticipated switching-surge level generated by other means, whichever is greater;

a = 1.15, the allowance for three standard deviations;
b = 1.03, the allowance for nonstandard atmospheric conditions;

c = 1.2, the margin of safety;

K = 1.15, the configuration factor for conductor-to-plane gap.

$$v = \frac{161}{\sqrt{3}} = 92.95kv\ , pu = 2.35pu$$

D = 0.31m = 31cm

## 3.5 Corona effect

$$v_{d0} = g_0 \delta m_0 r\ ln\frac{d}{r} \qquad (3.27)$$

$$= 69.6\ kv$$

Where:

d= 31 cm

r= 1.023cm

$g_0 = \frac{30}{\sqrt{2}} = 21.12\ kV(rms)$

$m_0 = 0.98$

$\delta = \frac{3.92\ .\ 73}{273+25} = 0.960$

In this calculation, the corona doesn't show of conductor. And we want to explain methods to reduce corona effect.

Methods of reducing corona effect

- By increasing conductor size.
- By increasing conductor spacing.
- Minimum spacing
- d= 1.6 cm

## 3.6 Insulators

The purpose of the insulator is to generate a safe clearance between insulating Circuit and other plant. There is also one other task what insulator must do:

Conductors are supported to the tower with the help of insulator.

The insulator is fastened to the cross arm.

The material of an insulator is porcelain or glass.

Cast resin (medium voltage) and, composite insulators (higher voltages) have also been used in recent years.

An insulator can be a line post insulator which is used from 1.5 kV to 145 kV.

In the higher voltages insulator strings are usually used.

A composite insulator is used in situations where there are demands of the huge mechanical strength, danger of vandalism, required, light weight and dirty installation environment.

The chosen insulator type is an insulator string which includes all necessary components such as cap and pin insulator and brackets.
There are two different kinds of insulator string which are named V- and I-strings.

In this project, we use the porcelain for insulating, and glass insulator for tension.

## 3.7 Protection

### 3.7.1 Introduction for the power system protection

Protection is the art and sciences of the application of devices that monitor the power line currents and voltages (relays) and generate signals to de energize faulted sections of the power network using circuit breakers. The goal is to minimize the damage of the equipment’s and property that would be caused by system faults, if residues, and maintain the delivery of electrical energy to the consumers. Many types of protective relays are used to protect power system equipment, they are classified according to their operating principles; over current relay senses the extra (more than set) current considered dangerous to a given equipment, differential relays compare in and out currents of the protected element, while impedance relays measure the impedance of the protected piece of planet. For a good performance of a relay in a power system it must have the following characteristics; dependability, security, selectivity, sensitivity, and high speed for protection.

### 3.7.2 Symmetrical components and fault analysis

**Faults Classification.**

Faults have two main types according to the symmetry of the system:

**A. Symmetrical Faults.**

In the balanced system, the system impedance in each phase are identical and the three-phase voltages and currents through the system are completely balanced.

**Faults under symmetrical conditions are caused in the system accidently through:**

1. Insulation failure of equipment.
2. Flash over of lines initiated by lighting stroke.
3. Accidental faulty operation.

**B. Asymmetrical Faults.**

Unbalanced system can result due to unsymmetrical faults, then system operation may also become unbalanced when load not balanced. Most faults in the system are unsymmetrical so it's very important to pay attention.

**The asymmetrical faults can be classified as follow:**

**I. Shunt Type Faults:**

1. Single line to ground fault (L-G).
2. Line to line fault (L-L).
3. Double line to ground fault (L-L-G)

**II.** Series Type Fault:

It is the open conductor fault.

Figure shows these types of faults.

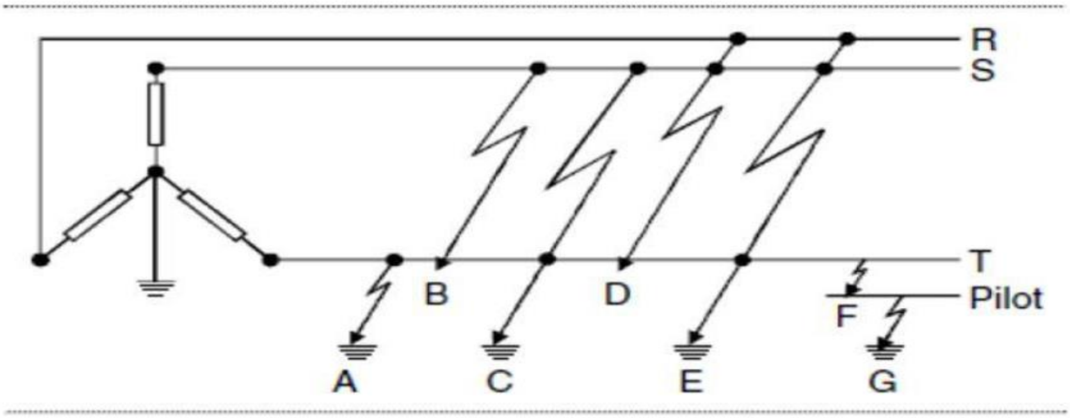


Figure 3.8 How Faults Occur

Faults may occur as a cross country fault. Phase to earth fault has a current that depends on the earthing system. Most faults on the transmission lines are caused by lightning which results in the hash over of insulations.

### 3.7.3 Symmetrical Components

In normal mode of operation, the three-phase system is symmetrical, so to analyze this system we analyze one of the phases, the obtained results are the same for each phase but shifted by 120.

In case of faults we cannot apply the previous method to analyze the system due to the asymmetry, and we have to analyze each phase independently; but this method is long and hard to apply, so we use the symmetrical components and Fortescue's theorem.

The symmetrical components are positive sequence, negative sequence, and zero sequence; these sequences are shown in figure

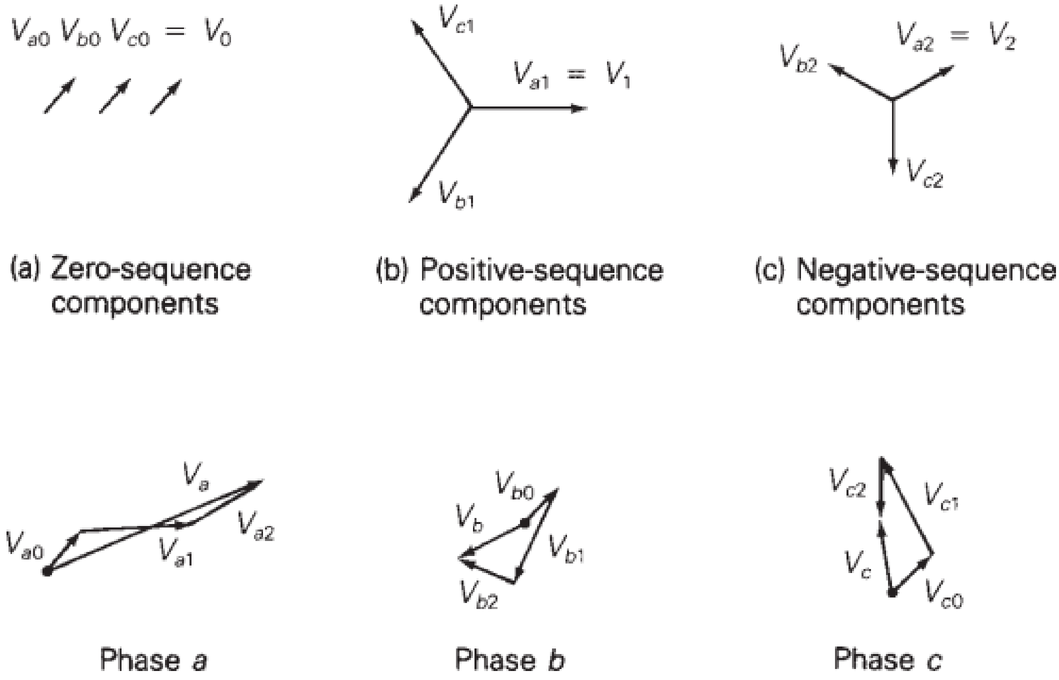


Figure 3.9 Symmetrical Components

### 3.7.4 Types of protection devices

#### 3.7.4.1 Circuit breaker

The circuit breaker is one of the most important devices that used in the protection system. The circuit breakers are generally classified based on the way of extinguish the spark resulting from arc. Accordingly, there are four varieties of circuit breakers are:

1. Oil circuit breakers
   The oil circuit breaker is widely used in industrial fields. This type used the oil in the process of extinguish the electrical spark when the electric arc occurrence of bubbles forming working to extinguish the sparks.

**Advantages**

- By connecting several interrupting mechanisms in series, the voltage rating of the breaker can be increased.
- By careful design the interrupting capacity rating can be increased up to 26,000 MVA.
- Quiet operation

**Disadvantages**

- The breaker contains flammable oil, consequently should be located outdoors.
- Oil breakdown at high temperatures forms carbon which gets dissolved in the oil. This increases the oil conductivity. To keep the oil insulating properties at an acceptable level, it must be purified after a predetermined number of breaker operations. This requires oil treatment equipment on site.
- may become an environmental hazard if spillage occurs

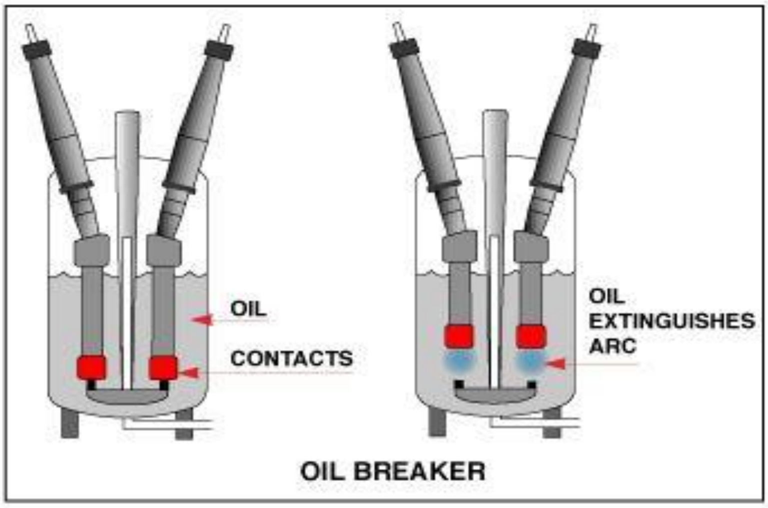


Figure 3.10 oil circuit breaker

2. Air-blast circuit breakers
   These circuit breakers used mainly in the high voltage applications. When the fault happens, cause separate the contacts then the electric arc is formed and this leads to rush of air which acts to cool the spark and thus extinguish.

3. Sulphur hexafluoride circuit breakers
   This type of circuit breakers used SF6 gas, which has a great tendency to gain electrons are negative. Upon separation of the gas starts to flow contactors transforms gas to negative ions. Lost electrons lead to the weakening of the electric arc and thus extinguish the spark.

   The properties of SF6 gas are superior to other interrupting mediums as follows:

1- High dielectric withstand characteristic. For example, SF6 gas at absolute pressure has twice the dielectric strength of air and at 3 barites is comparable to oil.

2- High thermal conductivity and short thermal time constant (1000times shorter than air) resulting in better arc quenching.

3- Arc voltage characteristic is low thus resulting in reduced arc-removal energy.

4-At normal conditions, SF6 is inert, non-amiable, non-corrosive, odorless and nontoxic.

4. Vacuum circuit a breaker

   In this type of circuit breakers uses a vacuum that could be up to 10-7 Tor. This vacuum provides a very high isolation. This isolation leads to extinguish the spark too quickly.

Table 3.3 comparison of insulating method of CBs

| Property | air | oil | Sf6 | vacuum |
|---|---|---|---|---|
| **Number of operation** | medium | low | Medium | high |
| **"soft " break ability** | Good | Good | Good | Fair |
| **Monitoring of medium** | N/A | Manual test | automatic | Not possible |
| **Fire hazard risk** | None | High | None | none |
| **Health hazard risk** | None | Low | Low | None |
| **Economical voltage range** | Up to 1 kv | 3.3_22kv | 3.3_800kv | 3.3_36kv |

Table 3.4 highlights the features for different types of circuit breakers.

| factor | Oil breakers | Air breakers | Vacuum/sf6 |
|---|---|---|---|
| **safety** | Risk of explosion and due to increase in pressure during multiple operation | Emission of hot air and ionized gas to the surroundings | No risk of explosion |
| **size** | Quite large | Medium | Smaller |
| **maintenance** | Regular oil replacement | Replacement of arcing contacts | Minimum lubrication for control device |
| **Environmental factors** | Humidity and dust in the internal properties | The atmosphere can change and effect the dielectric | Since. Sealed no effect due to environment |
| **endurance** | Below average | Average | Excellent |

We will use the SF6 circuit breaker in the high voltage side and vacuum circuit breaker in the medium voltage side.

### 3.7.4.2 Auto recloser

Is a self-controlling circuit breaker equipped with mechanism to being able to reconnect the circuit after separating because of a fault in the system.

### 3.7.4.3 Current transformer CT

This type of transformer is used within the system of equipment protection. This transformer works to step down the current that flowing in it for measurement processes and also protect protection devices where this transformer connect is series with an electrical system.

### 3.7.4.4 Voltage transformer VT

Like the current transformer, this transformer works to step down the voltage between its parties for different measurement processes where the transformer is connected in parallel with the system.

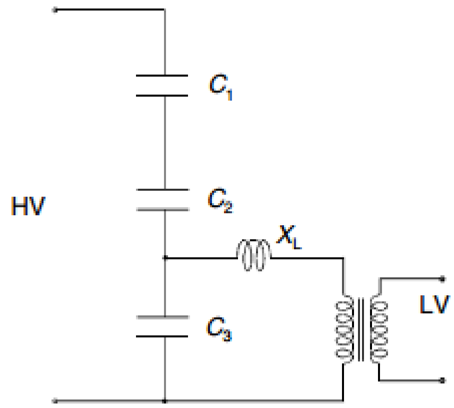


Figure 3.11 voltage transformer

#### 3.7.4.5 Surge arrester

Surge arresters are equipment used to eliminate the sudden impact of the lightning on the system.

Surge arresters used to protect a variety of devices and equipment in the transmission system such as transformers.

#### 3.7.4.6 Relays

Relays are developed and installed to protect the lines. The transmission line protection Relays, in the industry, are based on the fundamental frequency components of the voltages and currents.

## Principle of Operation

The basic circuit of a simple protection system can be shown as in Figure:

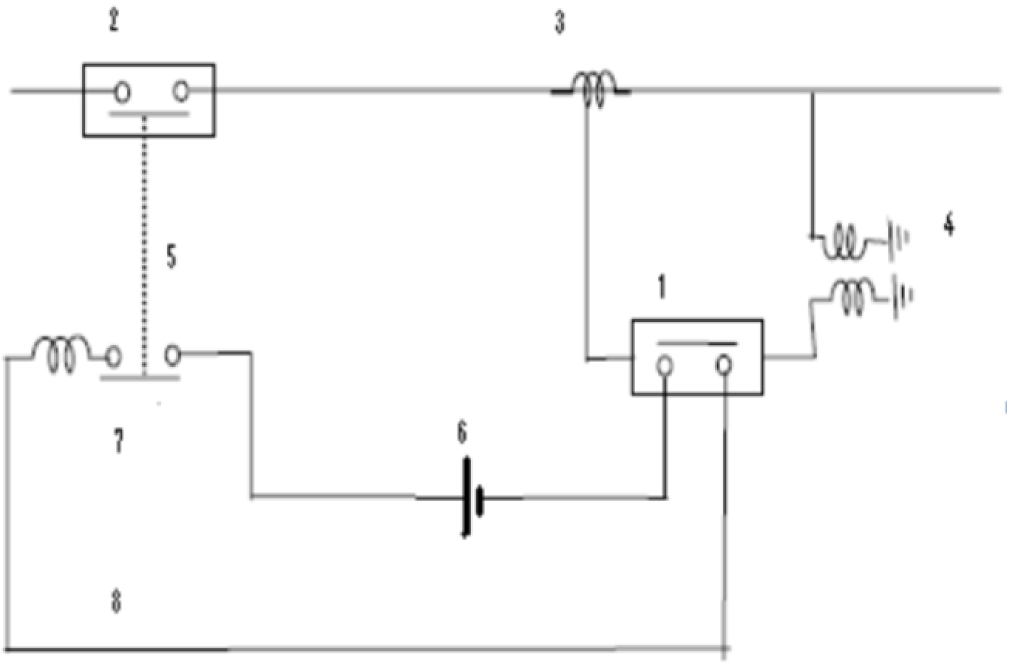


Figure 3.12 principle operation of relay

Where;

1. Protective relay.
2. Circuit breaker (CB).
3. Current transformer (CT).
4. Voltage transformer (VT)
5. Coil of tripping the CB.

6. Battery.
7. Auxiliary switch.
8. Circuit of tripping the CB

## Protection zone:

As mentioned before, the aims of the power system is to generate, transmit, and distribute the electrical energy, these aims need several equipment such as generators, transformers, transmission lines, etc. all these equipment are important so we have to protect it to provide a continuity and safety supplying. We cannot protect it randomly, so we divide the system into zones each zone called protection zone.

The figure below shows a simple power system divided into protection zones.

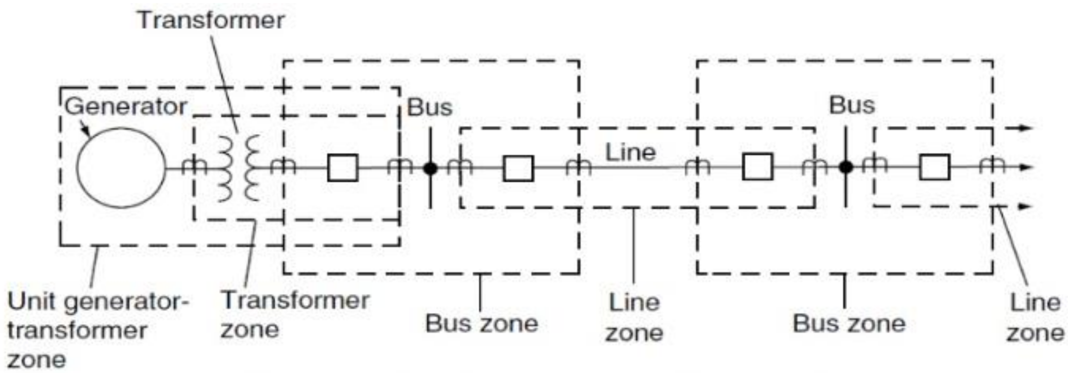


Figure 3.13 protection zones

### 3.7.4.7 Differential protection

This protection system is use the current difference as criteria. The differential protection system consisting of:

1. Current transformer (CT).
2. Relay.

The differential protection is used for the very high devices cost such as power transformer which have rating higher than 5MVA because the cost of this system is very high and there are two type of this protection:

### 1. Balanced current

The principle of this type of protection system is shown in the figure. The current transformers are connected in series with the system. The Relay connected across the midpoint between them and the voltage on the relay is equal zero. When the fault occurs outside the protective zone, there is no current flow through the relay. So, the differential relay does not activate.

In the case of the fault occurs inside the protective zone, the difference between the current that flow in the CTs is flow through the relay then the relay interrupted the circuit as shown in the figure.

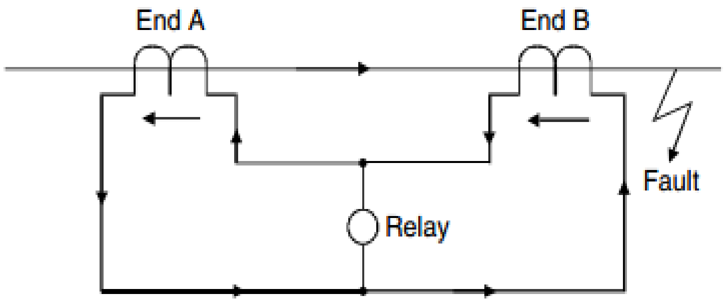


Figure 3.14 External fault

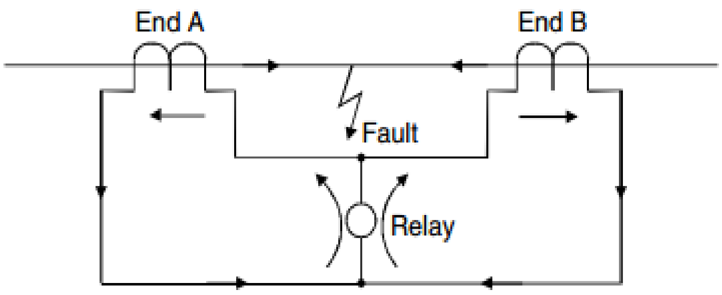


Figure 3.15 Internal fault

### 2. Balanced voltage

In this type of differential protection, the current flow the current transformers produce a voltage on the relays. The voltage on the two relays is equal when the occurrence of the fault is outside the protective zone. Accordingly, the Relay does not activate. But if the fault occurs inside protective zone there is difference in the value of current in the secondary of CTs. And therefore, the relay activates and make interruption in the circuit as shown in the figure.

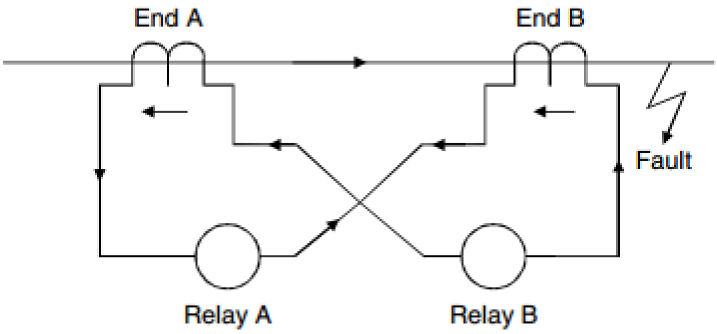


Figure 3.16 External fault

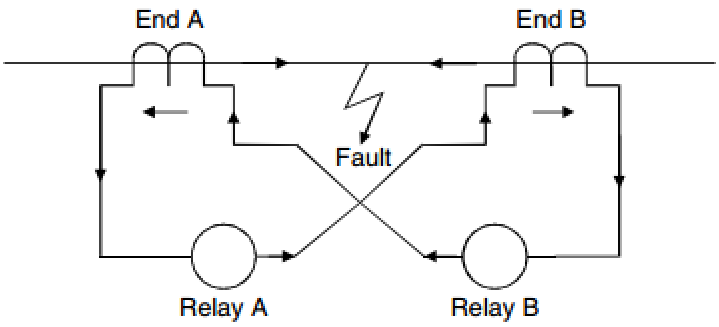


Figure 3.17 Internal fault

### 3.7.5 Requirements of protection system

**A. Sensitivity**

It means the ability of the protection system to detect all faults and abnormal conditions in the protective zone where the detection needed for the minimum fault current. In this requirement, there are three cases:

**B. Selectivity:**

The circuit breaker must be able to detect and isolate the fault item only.

**C. Fast operating:**

It means the ability of the protection system to isolate the faulty part quickly, which leads to minimize the effect of the fault and increase the stability of the power system.

**D. Reliability:**

It means the dependability, in other word we can depends in the protection system in all cases such as the arc rare, and it must operate even after years of operation.

**E. Economical**

It means obtaining the maximum protection with lower cost, but we have to use a high-quality protection devices which means more cost needed.

**F. Simplicity**

The protection system must be simple to help us during maintenance, but the protection level increase the complexity of the protection system.

In summary, the basic function of protection is to detect faults and to clear them as soon as possible. It is also important that in the process the minimum amount of equipment should be disconnected.

Faults cause large amounts of currents to flow in the components that would burn out if current flows are not promptly interrupted. The voltages of the faulted phases decrease on the occurrence of a fault.

### 3.7.6 Substation

Substation planning considers the location, size, voltage, sources, loads, and ultimate function of a substation. If the planning process was not based on scientific foundations, it leads to high cost of establishing the plant and also a lot of problems that need to find solutions.

The substation may be categorized as:

1. Distribution Substations

A distribution substation is a combination of switching, controlling, and voltage step-down equipment.

2. Switching Substations

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

3. Transmission Substations

   A transmission substation is a combination of switching, controlling, and voltage step-down equipment arranged to reduce transmission voltage to sub transmission voltage for distribution of electrical energy to distribution substations. Transmission substations frequently have two or more large transformers.

## Transmission Substations

Transmission substations are usually characterized by primary and secondary voltages of 161 kV to 33 kV. The transmission substation has distribution substations and large loads, reliability of service and flexibility of operation are extremely important. Facilities normally allow equipment maintenance without circuit interruption. Multiple bus arrangements and extensive use of circuit breakers for switching provide added system flexibility.

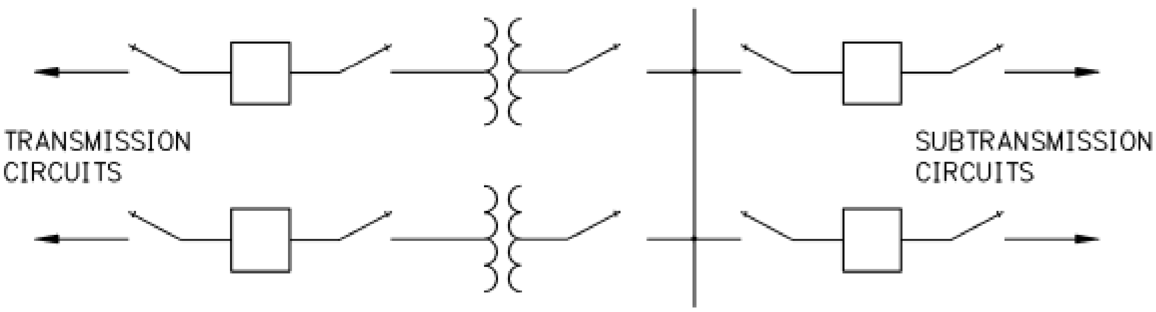


Figure 3.18 Basic Transmission Substation

Power circuit breakers are included in the two transmission circuits to help prevent complete substation shutdown for line faults. The circuit breakers have disconnected switches on both source and load sides to permit isolation during maintenance or other periods requiring complete deenergization. These switches are normally of the three-pole, single-throw, group-operated type, mounted on separate stands.

The power transformers commonly used are three-phase autotransformers, usually with tertiary windings. Three-phase two-winding transformers are used when phase relationships have to be sustained between the primary and the secondary systems. The disconnect switches on the low-voltage sides of the power transformers allow de-energization of one transformer while maintaining service to both low-voltage circuits from the other transformer.

**The components of substation:**

1. Power transformers
2. Current transformers & Voltage transformers
3. Circuit Breaker
4. Surge Arresters
5. Bus bars
6. Isolators
7. Potential transformer
8. Wave trap
9. Insulator
10. Earth switch
11. Earthing system
12. Control panel
13. Cables
14. Capacitors
15. Autorecloser

### 3.7.7 Basic of substation design

**<u>selection of the location</u>**

To design substation there is very important factor and the location is one of these factors. The selection of the location is depending on:

1. Location of present and future load center
2. Alternative land use considerations
3. Location of existing distribution lines
4. Soil resistivity
5. Atmospheric conditions: salt and industrial contamination
6. Public safety

**<u>Selection of substation equipment:</u>**

**1.** Selection of transformers

- The size of transformer may be selected from power ratings given below to supply present and future loads

**2.** Ratings of Circuit Breakers

- Rated voltage, rated frequency, rated current, and rated short-circuit breaking capacity of circuit breaker must be determined.

**3.** Ratings of Switch Disconnectors (Load-break switches)

- Rated voltage, rated current, and allowed short-circuit current must be determined.
- Switch disconnectors must withstand thermally and mechanically against the short circuits

**4.** Ratings of Isolators (Disconnectors)

- Rated voltage, rated current, and allowed short-circuit current must be determined
- Switch disconnectors must withstand thermally and mechanically against the short circuits

**5.** Characteristics of Voltage Transformers

**6.** Characteristics of Current Transformers

# Chapter 4 : Substation design

## 4.1 The proper scheme of the substation:

### Double breaker–double bus

We choose The double breaker–double bus configuration consists of two main buses, each normally energized. Electrically connected between the buses are two circuit breakers and, between the breakers, one circuit, Two circuit breakers are required for each circuit.

In the double breaker–double bus configuration, any circuit breaker can be removed from service without interruption of any circuits. Faults on either of the main buses cause no circuit interruptions. Circuit breaker failure results in the loss of only one circuit.

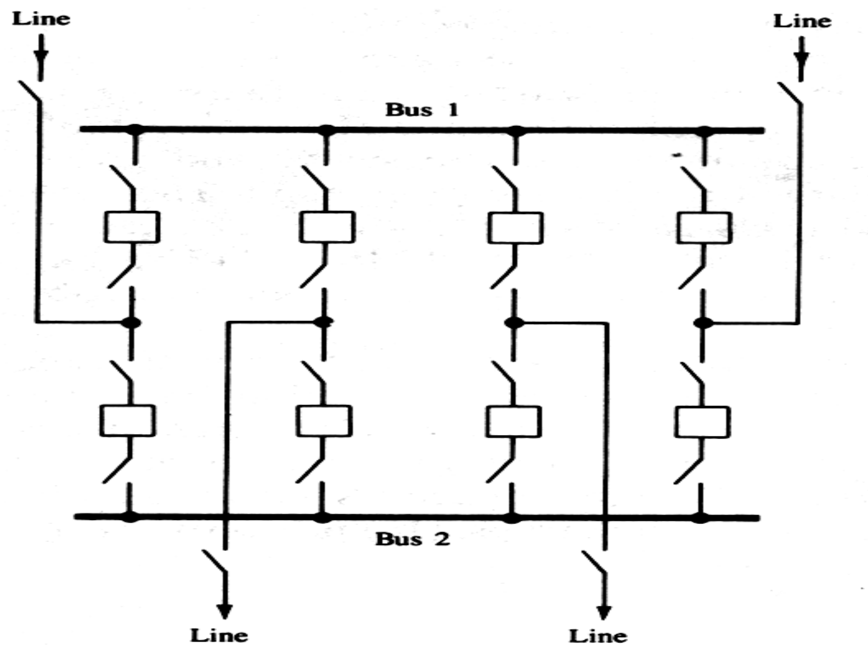


Figure 4.1

| Advantages: | Disadvantages: |
|---|---|
| 1. Flexible operation | 1. This configuration carries a high cost. |
| 2. Very high reliability | 2. Two circuit breakers are required for each circuit |
| 3. Isolation of either main bus for maintenance without disrupting service | |
| 4. Isolation of any circuit breaker for maintenance without disrupting service | |
| 5. Double feed to each circuit | |
| 6. No interruption of service to any circuits from bus fault | |
| 7. Loss of only one circuit for breaker failure | |
| 8. All switching with circuit breakers | |

Table 4.1 advantage and disadvantage for double breaker double bus

And according to a high cost this configuration costs 190% with respect to the cheapest one single breaker single bus (100%) .

## 4.2 Power transformer:

We use Siemens power transformers with medium range with a power range from 12 to 250 MVA and a voltage 161/33 KV .

- Transformer design according to national and international standards (IEC/ANSI) with or without voltage regulation
- 3-phase or 1-phase .
- Tank-attached radiators or separate radiator bank .

### 4.2.1 Cooling system:

The necessity of not exceeding the generally permissible maximum heating and of avoiding hot spots in the transformer require the cooling system to be dimensioned accordingly. Various methods of cooling can be used depending on the individual service conditions to guarantee reliable and problem-free operation over many years. The most noteworthy are the ONAN, ONAF, OFAF oil-air cooling and OFWF oil-water cooling systems. The radiator banks and oil-air and oil water coolers can be attached to the transformer or installed separately.

The transformers larger than 10,000 kVA can include up to two stages of cooling. Each stage of cooling increases the capacity of the transformer by a fixed percentage of the base rating for transformers above 10,000 kVA, additional stages of cooling may be used to increase the continuous kVA rating of the transformer by 33 percent per stage.

### 4.2.2 Temperatures:

transformer design is based on ambient temperatures of 40°C maximum, 30°C average over 24 hours, and –20°C minimum. And this is suitable

with our environment which want to design .

### 4.2.3 Capacity:

Depending on the load growth (2010-2040) the capacity of step down power transformers (161 / 33) KV.

Nablus capacity is 112 MVA so , according to standard capacity rating available we choose two transformers with capacity 50 MVA and one transformer with capacity 12 MVA and.

Tulkarm capacity is 70 MVA so , according to standard capacity rating available we choose two transformers with capacity 25MVA and one transformer 20MVA.

Jenin capacity is 60 MVA so , according to standard capacity rating available we choose three transformers with capacity 20 MVA.

### 4.2.4 Taps:

Because of a drop in voltage we should change in regulator taps to save the voltage in desirable range of supply .

### 4.2.5 Impedance :

Transformer impedance affects transformer voltage regulation, efficiency, and magnitude of through short-circuit currents. Both regulation and efficiency are generally improved with lower impedance.

| Transformer rating MVA | Impedance % |
|---|---|
| 50 | 9.5 |
| 25 | 9.5 |
| 20 | 9.5 |
| 12 | 9.5 |

Table: 4.2 the impedances% of the transformers

### 4.2.6 Protection

we use ABB differential relay to protect power transformer at the substation.

$$I = \frac{S}{\sqrt{3} \cdot V}$$

$$I_1 - I_2 = m \frac{I1 + I2}{2}$$

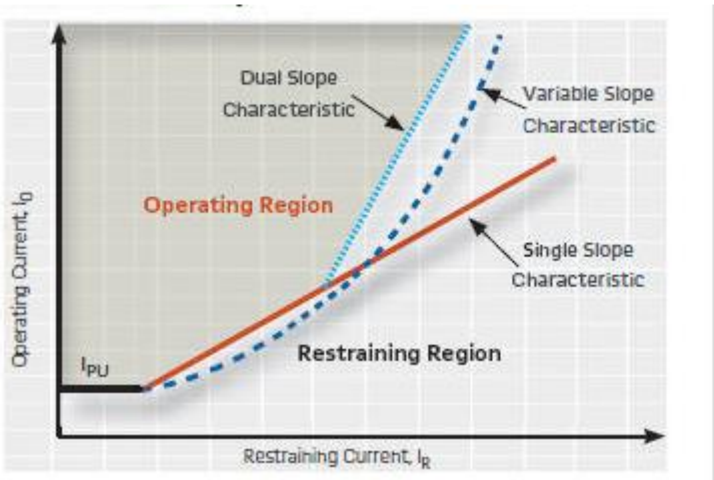


Figure 4.2

## 4.3 Substation insulator :

We use Porcelain in our project that is made of ceramic material and it was widely used in all Over Head Transmission Line with different voltages because of its efficiency and price comparing to the other one. The main disadvantage of this type is that it needs frequently cleaning from the accumulated dust on it because this dust reduces the insulation efficiency.

To achieve the necessary electrical characteristics, a number of suspension insulators are strung together in series. It is important to coordinate the insulation characteristics of suspension insulator strings with the insulation systems of other substation equipment and the characteristics of various insulation protective devices. The quantity of suspension insulators chosen for a particular application should be large enough to prevent unnecessary flashovers. Over insulation, however, can result in flashovers occurring from phase to phase rather than from phase to ground. Consequently, the quantity of insulators should be small enough that all flashovers occur to ground. The table 4.3 and table 4.4 show the properties of this insulator.

| **Typical Voltage, Kv** | **161** |
|---|---|
| Length (mm) | 1458 |
| No. of Sheds | 18 |
| Dry Arc Distance (mm) | 1245 |
| Leakage Distance (mm) | 3150 |
| 60 Flashover ANSI /WET | 430 |
| Critical Flashover ANSI /NEGATIVE | 865 |
| Net Weight (Kg) | 20.4 |

Table 4.3 insulator properties for 161 kV

| **Working voltage kV** | **33** |
|---|---|
| Highest voltage system kV | 36 |
| Creepage distance mm | 580 |
| Power frequency kV /WET | 90 |
| Impulse kV /NEGATIVE | 195 |
| One minute power frequency kV /WET | 75 |
| Visible discharge test kV | 27 |
| Power frequency punture kV | 180 |
| Net weight approx. Kg | 5.5 |
| Content of each package NOS. | 2 |

Table 4.4 insulator properties for 33 kV

## 4.4 Power circuit breaker :

circuit breaker is a device that closes and interrupts (opens) an electric circuit between separable contacts under both load and fault conditions, the power circuit breaker is limited to circuit breakers rated 1000 volts and above.

In our project we will use $SF_6$ circuit breaker

### 4.4.1 Ratings:

1. Line to line primary voltage (rms) = 161 kV

Line to line secondary voltage (rms) = 33 kV

2. Rated Maximum Voltage: is the maximum voltage for which the circuit breaker is designed and is also the upper limit for operation on an electric system.

Rated Max. voltage (rms)= 170 kV, 38 kV (According to available standard) .

3. Current:

   Main circuit breaker for transmission line :

$I_t = \frac{0.5\ GW}{\sqrt{3} * 161 KV * 1} = 1975A$

The safety factor for circuit breaker is 1.25 the current equal :

$I_{tCB}$=$1.25\times1975 = 2243.75\ A$

We use over current relay to protect the transmission line system .

In the substations :

According to the transformers in Nablus 50 MVA and 12 MVA:

In the primary system :

$I_{1P}=\frac{50MVA}{\sqrt{3}*161KV} = 180A$

And according to safety factor for circuit breaker 1.25 the current equal :

$I_{1PCB}=1.25\times180 = 225A$

$I_{2p}=\frac{12MVA}{\sqrt{3}*161KV} = 43\ A$

$I_{2PCB}=1.25\times43 = 53.75\ A$

In the secondary system :

$I_{1s}=\frac{50MVA}{\sqrt{3}*33KV} = 438A$

$I_{1sCB}=1.25\times438 = 547.5\ A$

$I_{2s} = \frac{12MVA}{\sqrt{3}*33KV} = 210\ A$

$I_{2sCB}=1.25\times210 = 262.5\ A$

the load circuit breaker :

depending on the scheme double breaker double bus we have four feeders , each feeder with 28 MVA . So the current of the load equal :

$I_{L1}=\frac{28\ MVA}{\sqrt{3}*33KV} = 490A$

$I_{L1CB}=1.25\times 490 = 612.5\ A$

The transformers in Tulkurm 25MVA and 20MVA:

In the primary system :

$I_{3\ P}=\frac{25MVA}{\sqrt{3}*161KV} = 90\ A$

$I_{3PCB}=1.25\times 90 = 112.5A$

$I_{4p}=\frac{20MVA}{\sqrt{3}*161KV} = 72\ A$

$I_{4PCB}=1.25\times 170 = 90\ A$

In the secondary system :

$I_{3\ S}=\frac{25MVA}{\sqrt{3}*33KV}$ =438A

$I_{3SCB}=1.25\times 438 = 547.5A$

$I_{4S}=\frac{20MVA}{\sqrt{3}*33KV} = 350\ A$

$I_{4SCB}=1.25\times 350 = 437.5A$

the load circuit breaker :

depending on the scheme double breaker double bus we have four feeders , each feeder with 17.5 MVA . So the current of the load equal :

$I_{L2}=\frac{17.5MVA}{\sqrt{3}*33KV} = 306.5A$

$I_{L2CB}=1.25\times 306.5 = 383.1A$

The transformer in jenin 20 MVA :

In the primary system :

$I_{5P}=\frac{20MVA}{\sqrt{3}*161KV}=72A$

$I_{5PCB}=1.25\times72=90A$

In the secondary system :

$I_{5S}=\frac{20MVA}{\sqrt{3}*33KV}=350A$

$I_{5SCB}=1.25\times350=437.5\ A$

the load circuit breaker :

depending on the scheme double breaker double bus we have four feeders , each feeder with 15 MVA . So the current of the load equal :

$I_{L3}=\frac{15MVA}{\sqrt{3}*33KV}=262.7A$

$I_{L3CB}=1.25\times262.7=328.37A$

### 4.4.2 Working of $SF_6$ Circuit Breaker :

$SF_6$ gas was compressed and stored in a high pressure reservoir. During operation of $SF_6$ circuit breaker this highly compressed gas is released through the arc in breaker and collected to relatively low pressure reservoir and then it is pumped back to the high pressure reservoir for re utilizer. In buffer type design, the arc energy is utilized to develop pressure in the arcing chamber for arc quenching.

### 4.4.3 Arc quenching in $SF_6$ circuit breaker :

The breaker is filled with $SF_6$ gas at rated pressure. There are two fixed contact fitted with a specific contact gap. A sliding cylinder bridges these to fixed contacts. The cylinder can axially slide upward and downward along the contacts. There is one stationary piston inside the cylinder which is fixed with other stationary parts of the $SF_6$ circuit breaker, in such a way that it cannot change its position during the movement of the cylinder. As the piston is fixed and cylinder is movable or sliding, the internal volume of the cylinder changes when the cylinder slides. During opening of the breaker the cylinder moves downwards against position of the fixed piston hence the volume inside the cylinder is reduced which produces compressed $SF_6$ gas inside the cylinder. The cylinder has numbers of side vents which were blocked by upper fixed contact body during closed position. As the cylinder move further downwards, these vent openings cross the upper fixed contact, and become unblocked and then compressed $SF_6$ gas inside the cylinder will come out through this vents in high speed towards the arc and passes through the axial hole of the both fixed contacts. The arc is quenched during this flow of $SF_6$ gas. During closing of the circuit breaker, the sliding cylinder moves upwards and as the position of piston remains at fixed height, the volume of the cylinder increases which introduces low pressure inside the cylinder compared to the surrounding. Due to this pressure difference $SF_6$ gas from surrounding will try to enter in the cylinder. The higher pressure gas will come through the axial hole of both fixed contact and enters into cylinder via vent and during this flow; the gas will quench the arc.

## 4.5 Earthing switch:

Earthing switch connect the live parts/ line conductors and earth. This switch is normally open.

Earthing switch is used to earth the live parts during maintenance and during testing. During maintenance although circuit is open still there are some voltages on line, due to which capacitance between line and earth is charged.

Before proceeding to maintenance work the voltage s discharged to earth, by closing the earth switch.

1. **Maintenance Earthing Switch**: These are two or three pole units with a manual operating mechanism.

2. **High Speed Earthing Switch:** These are operated by spring energy. Spring is charged by motor-mechanism.

**Earthing switch parts:**

1- Moving contact.
2- Operating lever.
3- Position indicator.

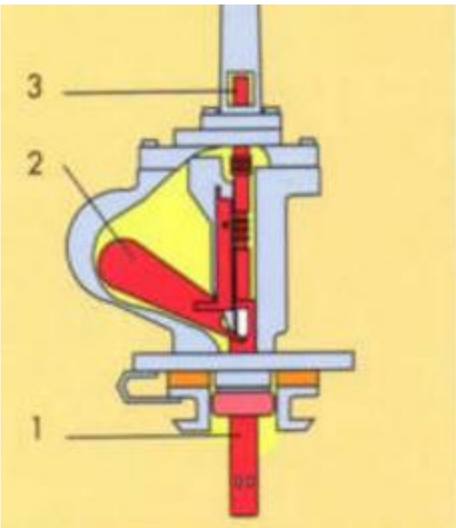


Fig4.3: Closed position

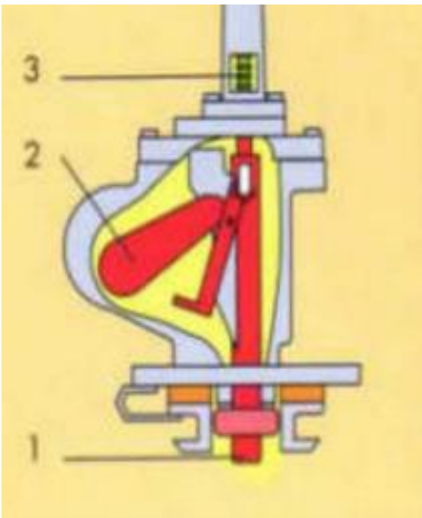


Fig4.4: open position

In systems where the object is fed from double-breaker, it is more practical to use a freestanding earthing switch at the common connection point to the object (Figures 4.5). This is because the purpose of the earthing switch is to earth the connected object (line/transformer, etc.) and not the circuit breaker or other high voltage equipment.

Remote operation of the earthing switches is recommended and a motorized earthing switch should thus be used.

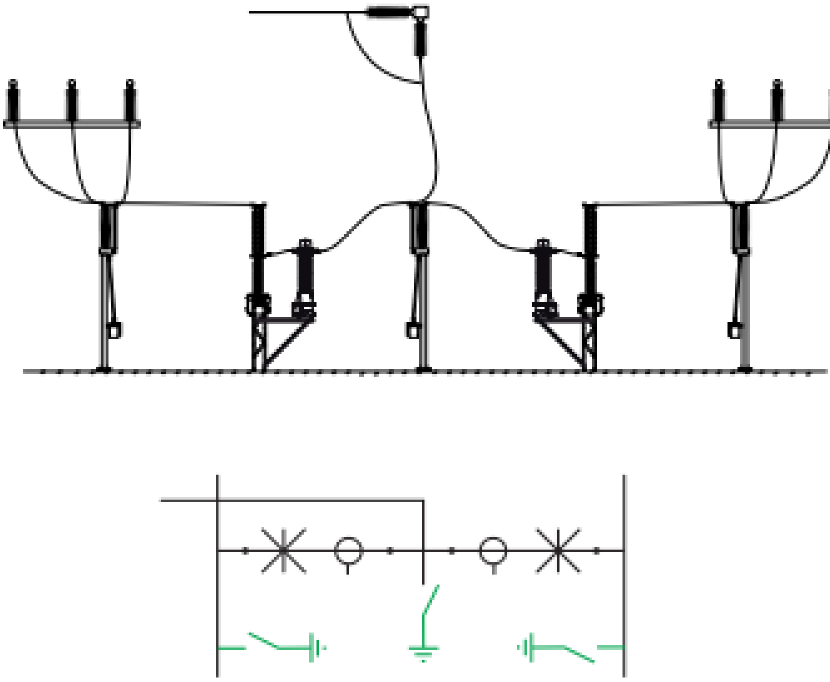

Fig. 4.5: Double Breaker

## 4.6 Substation Earthing System (Grounding System) [15]

Substation grounding is a critical part of the overall electric power system. It is designed to not only provide a path to dissipate electric currents into the earth without exceeding the operating limits of the equipment, but also provide a safe environment for any people that are in the vicinity.

The grounding system in substation is very important to:

1) To ensure safety to personnel in substations against electrical shocks.
2) To provide the ground connection for connecting the neutrals of stat connected transformer winding to earth (neutral earthing).
3) To discharge the over voltages from overhead ground wires or the lightning masts to earth. To provide ground path for surge arresters.
4) To provide a path for discharging the charge between phase and ground by means of earthing switches.
5) To provide earth connections to structures and other non-current carrying metallic objects in the sub-station (equipment earthing).

The IEEE standard 80-2000 describes conditions that accidental shock may develop as follows:

1) Relatively high fault current to ground in relation to the area of ground system and its resistance to remote earth.
2) Soil resistivity and distribution of ground currents such that high potential gradients may occur at points at the earth's surface.
3) Presence of an individual at such a point, time, and position that the body is bridging two points of high potential difference.
4) Absence of sufficient contact resistance or other series resistance to limit current through the body to a safe value under circumstances a) through c).
5) Duration of the fault and body contact, and hence, of the flow of current through a human body for a sufficient time to cause harm at the given current intensity.

**Input Data for the Grounding design:**

| | | | |
|---|---|---|---|
| Average Soil resistivity | 57.4 Ω.m | Fault current split Factor | 0.6 |
| Current | 1794A | Crushed rock layer inside sub | 0.1016m |
| Resistivity of crushed Rock layer | 2500 Ω.m | Grid buried 18” | 0.4572m |
| Switch Yard operator | >50kg | Current Division Factor $S_f$ | 0.6 |
| Soil location Type | Uniform | Length in X direction | 40 m |
| Projection Factor | 20% | Length in Y direction | 30 m |
| Shock Duration | 0.5s | Ambient Temperature | 40°C |
| Fault duration | 0.5s | Grid Shape | Rectangular |

Table 4.5 input data for grounding design

### 4.6.1 Field Data

The Area for the substation is (40 x 30) m, with assumption of average soil resistivity of 57.4 Ω.m .[15]

### 4.6.2 Obtaining the Conductor Size

Calculation of ground fault

$I_f$ = 3I =3×8970 =26910 A (4.1)

where X/R is assumed to be 10.

Adding the current protection factor with growth factor of 20%, the ground fault current is computer as follows:

$$I_f = 3I = 32292 \text{ A.}$$

| Fault duration($t_f$) | | Decrement factor($D_F$) | | | |
|---|---|---|---|---|---|
| Seconds | Cycles at 60 Hz | X/R=10 | X/R=20 | X/R=30 | X/R=40 |
| 0.008 | 0.5 | 1.576 | 1.648 | 1.675 | 1.688 |
| 0.05 | 3 | 1.232 | 1.378 | 1.462 | 1.515 |
| 0.10 | 6 | 1.125 | 1.232 | 1.316 | 1.378 |
| 0.20 | 12 | 1.064 | 1.125 | 1.181 | 1.232 |
| 0.30 | 18 | 1.043 | 1.085 | 1.125 | 1.163 |
| 0.40 | 24 | 1.033 | 1.064 | 1.095 | 1.125 |
| 0.50 | 30 | 1.026 | 1.052 | 1.077 | 1.101 |
| 0.75 | 45 | 1.018 | 1.035 | 1.052 | 1.068 |
| 1.00 | 60 | 1.013 | 1.026 | 1.039 | 1.052 |

Table 4.6: *Df Values (Typical)*

(From IEEE Std 80-2000 Table 10. )

Decrement factor ($D_f$) : is the tim e delay due to the thermal mass is known as a time lag.

Using Table 4.5 for the X/R ratio and fault duration given in Table 1, it is found that the decrement, $D_{f,}$ = 1.026.

Now finding the rms. symmetrical fault current is calculated as follows:

$$I_F = I_f \times D_f \tag{4.2}$$

$$= 32991 \text{ A}$$

Assuming the use of copper-clad steel wire at ambient temperature (Ta) of $30^0$ C with melting temperature of $1084^0$ C, $K_f = 10.45$ using Table 4.6.

| Material | Conductivity (%) | $T_m{}^a$(°C) | $K_f$ |
|---|---|---|---|
| Copper annealed soft drawn | 100.0 | 1083 | 7.00 |
| Copper commercial hard drawn | 97.0 | 1084 | 7.06 |
| Copper commercial hard drawn | 97.0 | 250 | 11.78 |
| Copper clad steel wire | 40.0 | 1084 | 10.45 |
| Copper clad steel wire | 30.0 | 1084 | 12.06 |
| Copper clad steel rod | 20.0 | 1084 | 14.64 |
| Aluminum EC Grade | 61.0 | 657 | 12.12 |
| Aluminum 5005 Alloy | 53.5 | 652 | 12.41 |
| Aluminum 6201 Alloy | 52.5 | 654 | 12.47 |
| Aluminum clad steel wire | 20.3 | 657 | 17.20 |
| Steel 1020 | 10.8 | 1510 | 15.95 |
| Stainless clad steel rod | 9.8 | 1400 | 14.72 |
| Zinc coated steel rod | 8.6 | 419 | 28.96 |
| Stainless steel 304 | 2.4 | 1400 | 30.05 |

Table 4.7: Material Constants

The required cross-sectional area in circular mils is computed as follows:

$$A_{Kcmil} = I \times K_f \times \sqrt{tc} \quad (4.3)$$

$$= 32991\text{x } 10.45 \text{ x}\sqrt{0.5}$$

$$=209.4 \ K_{kcmil}$$

Converting to $A_{kcmil}$ to $mm^2$is computed below as follows:

$$A_{mm^2} = \frac{\text{AKcmil} .1000}{1973.52} = 106.2\text{mm}^2 \quad (4.4)$$

Thus, the conductor diameter is equivalent to

$$d = \sqrt{\frac{4 \times Amm^2}{\pi}} \quad (4.5)$$

$= 12$ mm or 1.2Cm or 5\8" .

### 4.6.3 Touch and Step Criteria

The tolerable touch as step voltages need to be met in order ensure that a safe design is in place. The lower the maximum touch voltages are, the more challenges are presented in creating a design that fulfills the necessary requirements

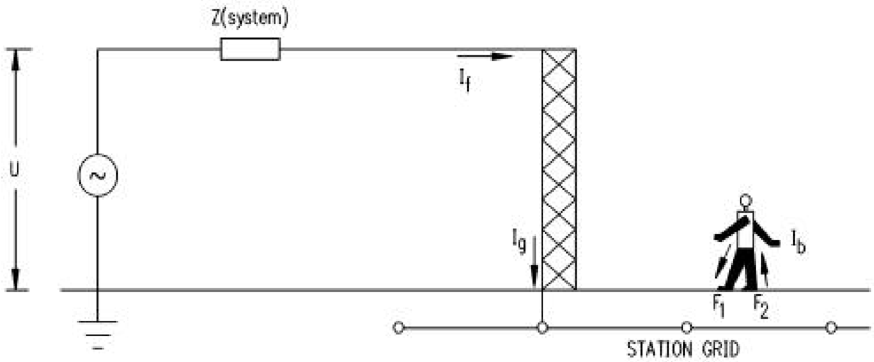


Fig.4.6: Exposure to Step Voltage

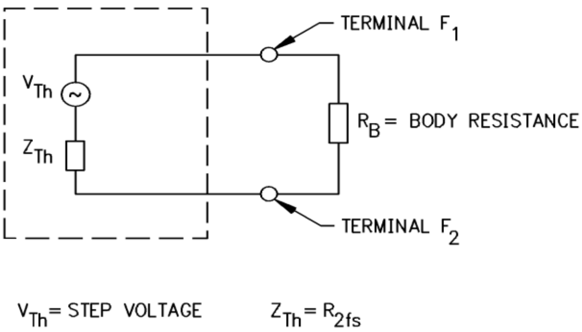


Fig.4.7: Step Voltage Circuit

Per IEEE Std, the resistance of a human body is $R_B = 1000\ \Omega$.

For step voltage, the limit is:

$E_{step} = ( R_B + 2R_f ) \times I_B$

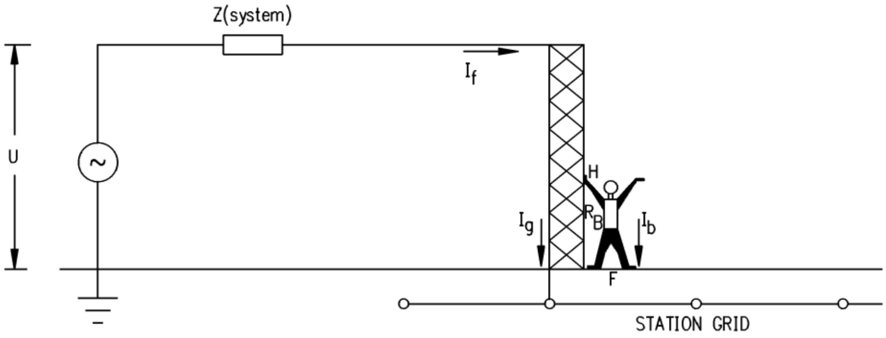


Fig. 4.8: Exposure to Touch Voltage

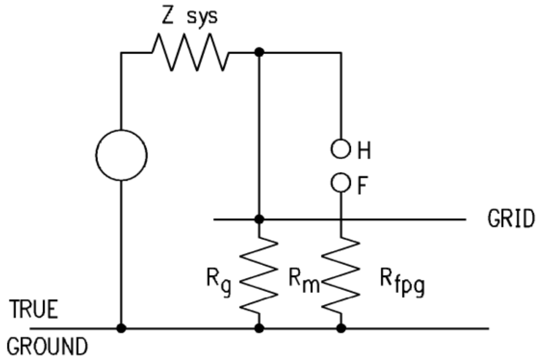


Fig. 4.9: Impedances in Touch Voltage Circuit.

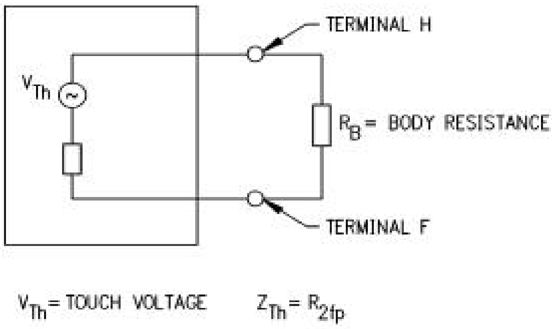


Fig. 4.10: Touch Voltage Circuit.

For touch voltage, the limit is

$E_{touch} = ( R_B + \frac{Rf}{2} ).I_B$

If no protective surface layer is used in the substation, $C_s$ = 1 and $\rho_s$=$\rho$.

If there is metal-to-metal contact, both hand-to-hand and hand-to-feet contact, $\rho_s$=0 since the ground is not included in this situation.

For a crushed rock-surfacing layer of 0.01268m, having resistivity of 2500Ω. m and with the computed soil resistivity of 57.4Ω. m, the reflection factor K is computed as:

$$K = \frac{\rho - \rho s}{\rho + \rho s} = \frac{57.4-2500}{57.4+2500} = -0.9511 \quad (4.6)$$

For the K= -0.93548. The crushed rock is to be de-rated by a factor of approximately, $C_s$, which is computed as:

$$C_s = 1 - \frac{0.09\,(1-\frac{\rho}{\rho s})}{2 \times hs + 0.09} \quad (4.7)$$

$$C_s = 1 - \frac{0.09\,(1-\frac{57.4}{2500})}{2 \times 0.1016+0.09} = 0.07$$

In the design criteria, the switch operator or the maintenance would be approximate 50kg or heavier.

The step and touch voltages are calculated as follows:

$$E_{step} = (\,1000 + 6 \times Cs \times \rho s\,)\frac{0.116}{\sqrt{ts}} \quad (4.8)$$

$$E_{step} = (\,1000 + 6 \times 0.7 \times 2500\,)\frac{0.116}{\sqrt{ts}}$$

$$= 1866.56 \text{ V .}$$

$$E_{touch} = (\,1000 + 1.5 \times Cs \times \rho s\,) \quad (4.9)$$

$$E_{touch} = (\,1000 + 1.5 \times 0.7 \times 2500\,)$$

$$=594.67 \text{ V}$$

### 4.6.4 Design

The design is based on the minimum amount of conductor needed that fulfills the requirements.

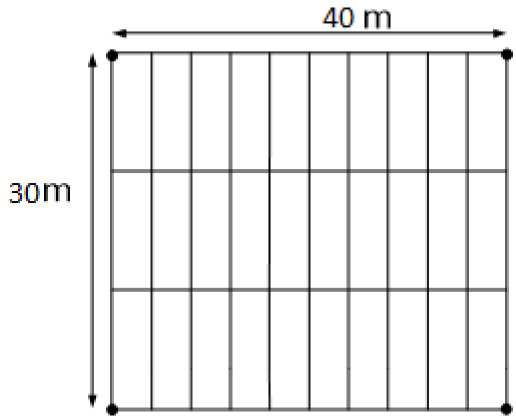


Fig. 4.11: 4 ground rods

Horizontal Mesh conductor spacing (4x10) m.

Vertical Electrode Configuration 4.

Assuming any given area for 40m x 30m the grid burial depth h=3m.

Thus, the grid conductor combined length is

$$L_c = L_1 .L_X + L_2 .L_y \tag{4.10}$$

$$= 4\times40 + 11\times30$$

$$= 490 \text{ m}$$

Assuming 4 ground rods of 3 meters long are used:

Buried conductor length $=L_R= 4 \times 3 = 12$ m. (4.11)

The total length of buried conductor would be computed as

$$L_T = L_C + L_R \tag{4.12}$$

$$= 490\text{m} + 12\text{m}$$

= 502m.

### 4.6.5 Determination of Grid Resistance

For uniform soil, the minimum value of the grounding resistance is approximated using the following formula:

$$R_g = \rho \ \left( \frac{1}{Lt} + \frac{1}{\sqrt{20.A}} \left( 1 + \frac{1}{1+h\sqrt{\frac{20}{A}}} \right) \right) \qquad (4.13)$$

From the previous computations, the length of buried conductor is known to be 1,402 m, having an area A=9000$m^2$.

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

$$= 57.4 \ \left( \frac{1}{502} + \frac{1}{\sqrt{20 \times 1200}} \left( 1 + \frac{1}{1+0.4572\sqrt{\frac{20}{1200}}} \right) \right)$$

$$=0.4849 \ \Omega$$

h : depth of the grid in meters

### 4.6.6 Maximum Grid Current $I_G$

Some part of the fault current will flow to the earth through the grounding grid. This current is called the grid current.

Calculating, $I_G$, using IEEE Std.80-2000 is done as follows:

$$I_g = I_f \text{ x } S_f \qquad (4.14)$$

$$= 32292 \text{ x } 0.6 \text{ A}$$

where

$I_g$ : rms symmetrical grid current in Amps.

$I_f$ : rms symmetrical grid fault current in Amps.

$S_{f}$ : fault current division factor.

and

$$I_G = D_f \,.\, I_g \qquad (4.15)$$

$$= D_f \,.3\,.\, I_0 \,.\, S_f$$

where

$I_G$ : is the maximum grid current in Amps

$D_g$ : decrement factor for the duration of the fault .

$I_g$ : rms symmetrical grid current in Amps

$I_G$ = 1.026 . 3 . 8970 . 0.6 = 16565.7A.

### 4.6.7 Ground Potential Rise (GPR)

GPR - Ground potential rise is "the maximum electrical potential that a substation grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth." GPR is equal to the maximum grid current times the grid resistance as defined in the equation below:

$$GPR = I_G \,.\, R_g \qquad (4.16)$$

$$=16565.7 \cdot 0.4849 = 8032.7 \text{ V}$$

where

$R_g$ : substation ground resistance in ohms

$I_G$ : maximum grid current in Amps

Comparing with the touch voltage computed in step 3 which was 594.67 V. The GPR is far exceeds the safe touch voltage. But to optimize cost, rods can be reduced to ensure no overspending occurs.

### 4.6.8 Mesh Voltage ( $E_m$ )

The mesh voltage is the highest possible touch voltage within a substations grounding grid. The basis of a safe grounding grid system is the mesh voltage. This includes the grounding grid inside the substation and outside of the substation fence. For a safe grounding grid system, the mesh voltage needs to be less than the touch volta**ge.**

The geometric factor , n :

$n = n_a \cdot n_b \cdot n_c \cdot n_d$ (4.17)

$n_a = \frac{2 \times Lc}{Lp}$ (4.18)

$= \frac{2 \times 490}{2 \times 40 + 2 \times 30}$

$= 7.32$

$n_b = \sqrt{\frac{Lp}{4 \times \sqrt{A}}}$ (4.19)

$= \sqrt{\frac{140}{4 \times \sqrt{1200}}}$

$= 1.00693$

$n_c = 1$ for square and rectangular grids.

$n_d = 1$ for square, rectangular, and L-shaped grids.

$n = n_a \cdot n_b \cdot n_c \cdot n_d$

$= 7.32 \times 1.006 \times 1 \times 1$

$= 7.363$

The irregularity factor , $K_i$ , can be calculated as follows:

$K_i = 0.644 + 0.148 \cdot n$ (4.20)

$= 0.644 + 0.148 \times 7.363$

=1.733

The effective buried length, $L_M$

$$L_M = L_C + \left( 1.55 + 1.22 \left( \frac{Lr}{\sqrt{Lx^2 + Ly^2}} \right) \right) L_R \tag{4.21}$$

where

$L_r$ : total length of each ground rods in meters.

$L_c$ : total length of conductor in the horizontal grid in meters

$L_R$ : total length of all ground rods in meters

$$L_M = L_C + \left( 1.55 + 1.22 \left( \frac{Lr}{\sqrt{Lx^2 + Ly^2}} \right) \right) L_R$$

$$= 490 + \left( 1.55 + 1.22 \left( \frac{3}{\sqrt{4.40^2 + 11.30^2}} \right) \right) 12$$

$$= 508.64 \text{ m}$$

The corrective weighting factor, $K_h$ is defined as follows:

$$K_h = \sqrt{1 + \frac{h}{h0}} \tag{4.22}$$

where

$h_0$ : is the grid reference at depth equivalent to 1

$$K_h = \sqrt{1 + \frac{h}{h0}}$$

$$K_h = \sqrt{1 + \frac{0.4572}{1}}$$

$$= 1.2329$$

$K_m$, is the geometrical spacing factor for the mesh voltage and is defined as:

$$K_m = \frac{1}{2.\pi} \left( \ln\left( \frac{D^2}{16.h.d} + \frac{(D+2.h)}{8.D.d} - \frac{h}{4.d} \right) + \frac{Kii}{Kh} . \ln \frac{8}{\pi(2.n-1)} \right) \tag{4.23}$$

where

D : spacing between parallel conductors in meters

d : diameter of grid conductors in meters h : depth of ground grid conductors in meters

Kii : corrective weighting that adjusts effects of inner conductors on the corner mesh

$K_h$ : corrective weighting factor emphasizing the grid depth effects

$$K_m = \frac{1}{2.\pi} \cdot \left(\ln\left(\frac{D^2}{16.h.d} + \frac{(D+2\times h)}{8\times D\times d} - \frac{h}{4\times d}\right) + \frac{Kii}{Kh} \cdot \ln\left(\frac{8}{\pi(2.h-1)}\right)\right)$$

$$= \frac{1}{2.\pi} \cdot \left(\begin{array}{c}\ln\left(\frac{5^2}{16\times 0.4572\times 0.01168} + \frac{(5+2\times 0.4572)}{8\times 5\times 0.01168} - \frac{0.4570}{4\times 0.011672}\right) \\ + \frac{1}{2.\pi\times 1.225} \cdot \ln\left(\frac{8}{\pi(2\times 7.363-1)}\right)\end{array}\right)$$

**= 0.736**

The mesh voltage, $E_m$:

$$E_m = \frac{\rho .IG .Kh .Ki}{LM} \tag{4.24}$$

where

ρ : resistivity of earth in ohm meters

$L_M$ : effective burial length in meters

$K_M$ : geometrical spacing factor

$K_i$ : irregularity factor

$$= \frac{57.4\times 16565.7\times 0.736\times 1.733}{508.64}$$

= 529 Volt.

The effective buried conductor length $L_S$:

$$L_S = 0.75\times L_C + 0.85\times L_R \tag{4.25}$$

$$= 0.75\times 502 + 0.85\times 12$$

=386.7 m

The step factor , $K_s$ , is defined as follows

$$K_S = \frac{1}{\pi}\left(\frac{1}{2.h} + \frac{1}{D+h} + \frac{1}{D}(1-0.5^{n-2})\right) \tag{4.26}$$

where

D : spacing between parallel conductors in meters

h : depth of ground grid conductors in meters

n : geometric factor composed of factors $n_a$ , $n_b$ ,$n_c$ and $n_d$

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

$$= \frac{1}{\pi}\left(\frac{1}{2\times 0.4571} + \frac{1}{5+0.4571} + \frac{1}{5}(1 - 0.5^{7.363-2})\right)$$

= 0.46856

The step voltage, $E_S$:

$$E_S = \frac{\rho\,.K_S\,.K_i\,.I_G}{L_S} \tag{4.27}$$

$$= \frac{57.4\times 0.46856\times 16565.7\times 1.733}{386.7}$$

= 450.87 Volt.

**Parts of the Substation :**

| Apparatus | Parts to be Earthed | Method of Connection |
|---|---|---|
| Power Transformer | Transformer tank | Connect the earthing bolt on transformer tank to station earth. Connect the neutral to earthing system |
| High Voltage Circuit Breakers | Operating mechanism, frame | Connect the earthing bolt on the frame and the operating mechanism of Circuit Breaker to earthing system |
| Surge Arrester | Lower Earth Point | To be directly connected to the earth mat |
| Potential Transformer | Potential transformer tank, LV neutral. | Connect the transformer earthing bolt to earthing system Connect LV neutral of phase lead to case with flexible copper conductor |
| Isolator | Isolator frame, operating mechanism, bedplate | Weld the isolator base frame, connects it to the bolt on operating mechanism base plate and station earth. |
| Current Transformer | Secondary winding and metal case | Connect secondary winding to earthing bolt on transformer case with a flexible copper conductor. |

Table 4.8 : the earthing method for the parts of the substation

## 4.7 Isolators

Isolator is a device which is used to isolate the circuit after opening the breaker. In order to maintenance purpose of breaker we will use isolator. In isolator, we don't have any arc quenching medium so we cannot eliminate the arc in isolator. So, after opening the breaker only we should open the isolator, so we should design some interlocks:

a. Breaker close condition: isolator should not open.
b. Breaker open condition: isolator can close or open

**Types of isolator:**

1. Double break type.
2. Knee type.
3. Single break type.

Depending upon the position in power system, the isolators can be categorized as

1. Bus side isolator – the isolator is directly connected with main bus
2. Line side isolator – the isolator is situated at line side of any feeder
3. Transfer bus side isolator – the isolator is directly connected with transfer bus.

## 4.8 Surge arrester

Ur0 = 0.72xUm (according to table 4.6) = 0.72x161 = 115.92 Kv rms.

(Ur): Arrester rated voltage

Um: Maximum system voltage

Select the next higher standard Ur from "Guaranteed protective data" = 132 kVrms

| System earthing | Fault duration | System voltage $U_m$ (kV) | Min. rated voltage $U_r$ (kV) |
|---|---|---|---|
| Effective | $\leq 1s$ | $\leq 100$ | $U_m \geq 0.8 \times$ |
| Effective | $\leq 1s$ | $\geq 123$ | $U_m \geq 0.72 \times$ |
| Non-effective | $\leq 10s$ | $\leq 170$ | $U_m \geq 0.91 \times$<br>$U_m \geq 0.93 \times$<br>(EXLIM T) |

| | | | |
|---|---|---|---|
| Non-effective | $\leq 2\,h$ | $\leq 170$ | $U_m \geq 1.11 \times$ |
| Non-effective | >2 h | $\leq 170$ | $U_m \geq 1.25 \times$ |

Table 4.9: minimum value of the arrester rated voltage (Ur).

According to table 4.7, a common choice selection for 161 kVrms would be a line discharge class 2 arrester, PEXLIM R.

This arrester has a Upl /Ur of 2.59. Upl of 342 kVpeak at 10 kA(according to table 4.11).

With a Uwl of 674 kVpeak this would give a protective margin of (674/342-1) x100 = 97 %.

| Arrester type | Line discharge class | Energy capability (2 impulses) KJ/kV ($U_r$) | Normal application range ($U_m$) |
|---|---|---|---|
| EXLIM R | 2 | 5.0 | $\leq 170kV$ |
| PEXLIM R | 2 | 5.1 | $\leq 170kV$ |
| EXLIM Q | 3 | 7.8 | 170 - 420 kV |
| PEXLIM Q | 3 | 7.8 | 170 - 420 kV |
| EXLIM P | 4 | 10.8 | 362 - 550 kV |
| PEXLIM P | 4 | 12 | 362 - 550 kV |
| HS PEXLIM P | 4 | 15.4 | 362 - 550 kV |
| EXLIM T | 5 | 15.4 | 420 - 800 kV |
| HS PEXLIM T | 5 | 15.4 | 420 - 800 kV |

Table 4.10. Energy capability of ABB arresters.

| Arrester type | Nom. Dis-charge current ($I_n$) | $U_p/U_r$ at 10 $kA_P$ | $U_p/U_r$ at 20 $kA_P$ | $U_{ps}/U_r$ |
|---|---|---|---|---|
| EXLIM R | 10 | 2.59 | | 2.060 at 0.5 $kA_P$ |
| PEXLIM R | 10 | 2.59 | | 2.060 at 0.5 $kA_P$ |
| EXLIM Q | 10 | 2.35 | | 1.981 at 1.0 $kA_P$ |
| PEXLIM Q | 10 | 2.35 | | 1.981 at 1.0 $kA_P$ |
| EXLIM P | 20 | 2.275 | 2.5 | 2.020 at 2.0 $kA_P$ |
| PEXLIM P | 20 | 2.275 | 2.5 | 2.020 at 2.0 $kA_P$ |
| HS PEXLIM P | 20 | 2.275 | 2.5 | 2.020 at 2.0 $kA_P$ |

| | | | | |
|---|---|---|---|---|
| EXLIM T | 20 | 2.2 | 2.4 | 1.976 at 2.0 kAp |

Table 4.11. Upl and Ups ratios for ABB arresters

| Arrester type | Cantilever strength (Nm) | | |
|---|---|---|---|
| | MPDSL | PSSL | DPSSL |
| EXLIM R-C | 7500 | 3000 | n.a. |
| EXLIM Q-D | 18000 | 7200 | n.a. |
| EXLIM Q-E | 7500 | 3000 | n.a. |
| EXLIM P-G | 18000 | 7200 | n.a. |
| EXLIM T-P | 18000 | 7200 | n.a. |
| PEXLIM R-Y | 1600 | n.a. | 1000 |
| PEXLIM Q-X | 4000 | n.a. | 2500 |
| PEXLIM P-X | 4000 | n.a. | 2500 |
| HS EXLIM P | 28000 | n.a. | 19000 |
| HS EXLIM T | 28000 | n.a. | 19000 |

Table 4.12. Permissible strength loading for ABB arresters

With a required creepage distance of 3000 mm. 18.7 mm/kV, (YH161 for PEXLIM R) housing should be selected.

The type designation of the selected arrester will then be: PEXLIM R132-YH161.

## 4.9 Instrument transformer

### 4.9.1 Voltage Transformers

Voltage transformers are used in conjunction with the circuit and equipment protection, synchronization, and metering schemes. They are normally mounted on individual or three-position stands. Depending on the bus configuration and the relaying schemes, the voltage transformers may be positioned near the circuit entrance positions or adjacent to the buses.

### 4.9.2 Current Transformers

Current transformers used in both relaying and metering schemes can usually be located inside major equipment such as power circuit breakers and power transformers. These current transformers are normally multi-ratio bushing type and therefore do not require special mounting provisions. In some cases, separately mounted current transformers may be required, such as for revenue metering purposes. They are usually installed on individual stands and located as required.

In this project, we will use (ABB Instrument Transformers)

| Type | Name | Description |
|---|---|---|
| High accuracy extended range current/voltage transformers | KXM | • Substation Class oil-filled (CLASS 0.15S) high accuracy wide measurement range current/voltage combined metering transformer for space savings.<br>• Special design capable of metering accurately over wide current swing.<br>• Special series-parallel multi-ratio high accuracy wide range design available for short lead times/stock availability (subject to prior sale). |

Current for 150 MVA:

In primary :

$I_{P1} = \frac{S}{\sqrt{3}\times 161\ KV} = \frac{150MVA}{\sqrt{3}\times 161K} = 592\ A$

In secondary :

$I_{S1} = \frac{S}{\sqrt{3}\times 33KV} = \frac{150MVA}{\sqrt{3}\times 33K} = 2890\ A$

Current for 150 MVA:

In primary :

$I_{P2} = \frac{S}{\sqrt{3}\times 161\ KV} = \frac{50MVA}{\sqrt{3}\times 161K} = 180\ A$

In secondary :

$I_{S2} = \frac{S}{\sqrt{3}\times 33KV} = \frac{50MVA}{\sqrt{3}\times 33K} = 877\ A$

Current for 25 MVA :

In primary :

$I_{P3} = \frac{S}{\sqrt{3}\times 161\ KV} = \frac{25MVA}{\sqrt{3}\times 161K} = 90\ A$

In secondary :

$I_{S3}=\frac{S}{\sqrt{3}\times 33KV}=\frac{25MVA}{\sqrt{3}\times 33K}=900\ A$

Current for 20 MVA:

In primary :

$I_{P4}=\frac{S}{\sqrt{3}\times 161\ KV}=\frac{20MVA}{\sqrt{3}\times 161K}=75\ A$

In secondary :

$I_{S4}=\frac{S}{\sqrt{3}\times 33KV}=\frac{20MVA}{\sqrt{3}\times 33K}=350\ A$

Current for 12 MVA

In primary :

$I_{P5}=\frac{S}{\sqrt{3}\times 161\ KV}=\frac{12MVA}{\sqrt{3}\times 161K}=200\ A$

In secondary :

$I_{S5}=\frac{S}{\sqrt{3}\times 33KV}=\frac{12MVA}{\sqrt{3}\times 33K}=900\ A$

## 4.10 Shunt capacitor :

According to the Etap report, the power factor was 0.91 so we make an improvement to increase the power factor by adding a capacitor bank to reach a desirable value to be equal a 0.94 .

Depending to the data (2010-2030):

Rated max. MVA = 112 + 70 + 60 = 242 .

Pf = cos $\theta$ (28)

$\theta$=cos$^{-1}$ 0.94=19.2 °.

Tan $\theta=\frac{Q}{P}$ (29)

Q=87.5 Mvar

Q at the system depending on the pdf report = 95.5 Mvar .

$Q_C$ =95.5 – 87.5 = 8 Mvar .

We make a percentage to distribute the Mvar value according to rated for each city.

$Q_C$ for Nablus = 4 Mvar .

$Q_C$ for Tulkarm = 2 Mvar .

$Q_C$ for Jenin = 2 Mvar .

## 4.11 Spare capacity system:

We design a spare capacity system for future demand (2015 – 2040) .

Design Requirements:

The spare for Nablus:

Demand Load: MVA :138

Transformers : 150 MVA

Number of Primary Feeds: One transformer.

Overhead or Underground Entry: Overhead with length 1 km to the first joint point.

Secondary Voltage Level: 33KV

The auxiliary for Tulkarm:

Demand Load: MVA :42

Transformer: 50MVA

Number of Primary Feeds: One transformer.

Overhead or Underground Entry: Overhead with length25 km to the first joint point.

Secondary Voltage Level: 33KV

The auxiliary for Jenin :

Demand Load: MVA :165

Transformer:150 MVA

Number of Primary Feeds: One transformer.

Overhead or Underground Entry: Overhead with length 30 km to the first joint point.

Secondary Voltage Level: 33KV

### 4.12 Auxiliary system:

Substation ac auxiliary systems are typically used to supply loads such as:

1. Transformer cooling, oil pumps, and load tap changers
2. Circuit breaker air compressors and charging motors
3. Outdoor device heaters
4. Outdoor lighting and receptacles
5. Control house
   a. Lighting and receptacles
   b. Heating, ventilating, and air conditioning
   c. Battery charger input
   d. Water well pump
6. Motor-operated disconnecting switches

Design Requirements:

Demand Load: 7-10 KVA

Transformers: 160 KVA (min. capacity standard rating for transformers)

Number of Primary Feeds: One transformer.

Overhead or Underground Entry: Overhead.

Secondary Voltage Level: 0.4 kV

Critical Loads: Some low-voltage loads have to be maintained at all times:

1. Battery chargers which, through the batteries, supply breaker trip and close circuits as well as communication circuits.

2. Transformer cooling.

3. Power circuit breaker compressors and motors.

4. Trouble light receptacles in the station yard.

5. Security lighting.

6. Breaker control circuits.

7. Fire alarm circuit.

8. Electric heating.

9. Substation automation circuitry.

# Chapter 5: ETAP

## 5.1 Introduction

The Windows NT, 4.0 and 2000 platforms provide the highest performance level for demanding applications, such as large network analysis requiring intensive computation and online monitoring and control applications.

Windows NT. 4.0. And 2000 also provide the highest levels of reliability, protection. And security of critical applications. Large PowerStation projects (approximately 500 buses and larger) should be built and maintained via Windows NT. 4.0. Or 2000. The Windows 98 and me platforms provide excellent performance for analysis of small and medium size systems (a few hundred buses) and support a variety of other popular applications.

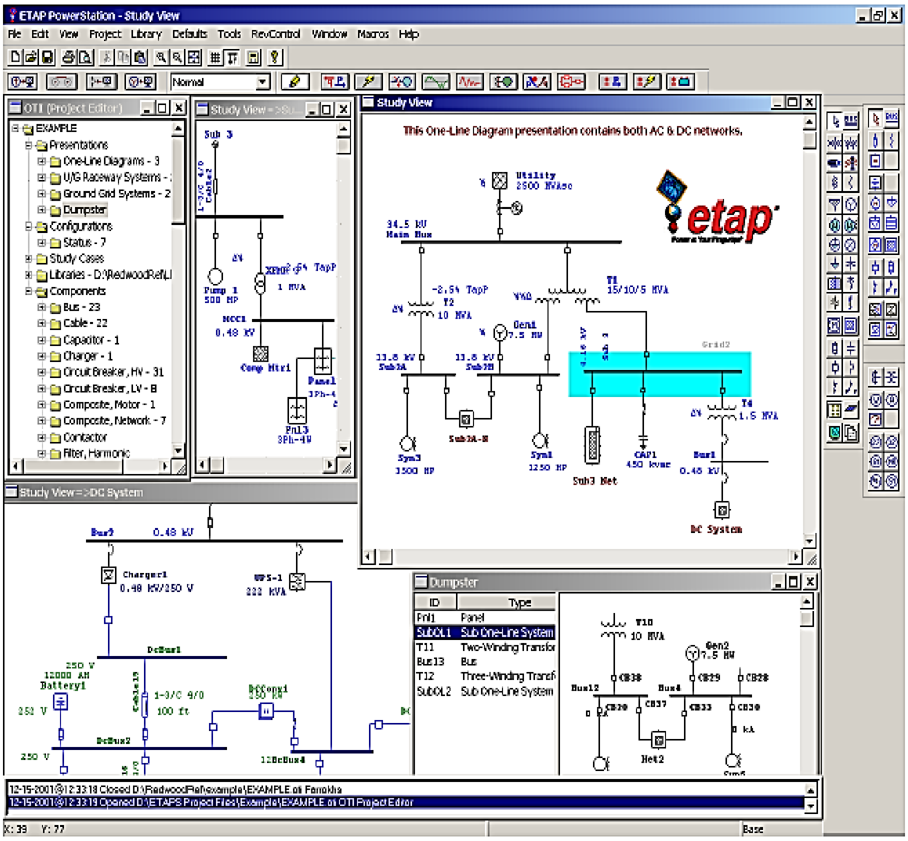


Figure 5.1:E-TAP configuration

## 5.2 ETAP Description

### 5.2.1 Modeling:

1- Virtual reality operation.
2- Total integration of data (electrical, logical, mechanical, and physical attributes).
3- Ring and radial systems.
4- Unlimited isolated subsystems.
5- No system connection limitations.
6- Multiple loading conditions.
7- User access control and data validation.
8- Asynchronous calculations, allow multiple modules to calculate simultaneously.
9- 3-phase and single-phase modeling including panels and subpanels.

### 5.2.2 Filling data

To run the program we must to enter the data from chapter 2 and chapter 3 in filling spaces for feeder, transmission line, cable, circuit breaker , transformer, and load.

### 5.2.3 Feeder

Choose 3 phase connection feeder from info Icon.1-

2 - Choose "in" service feeder from info Icon.

3- Choose swing mode feeder from info Icon.

4- Choose 8 MVA delta connection feeder from short circuit icon.

This steps is clear in fig 4.

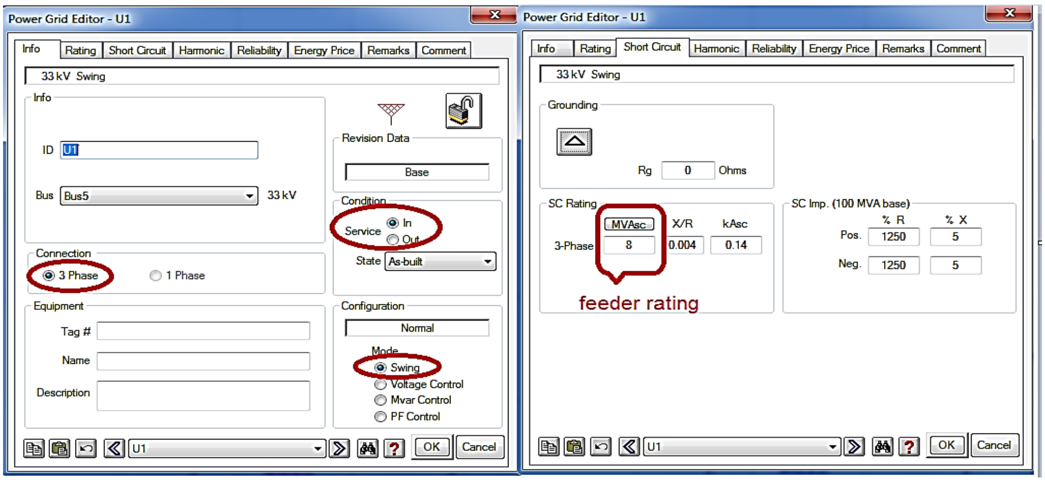


Figure 5.2:feeder data in E-TAP

### 5.2.4 Transmission line

Transmission lines for network using 262mm underground cable and transmission line in domestic region that implemented by the following parameter:

Impedance per conductor**

After filing the needed data from data sheet in to the library of the program, the program choose atypical value for impedance per conductor per length unit

** Reliability parameter

Shows the reliability of the cable per year per length unit

** Power parameter

Gives the rated current and voltage for the cable

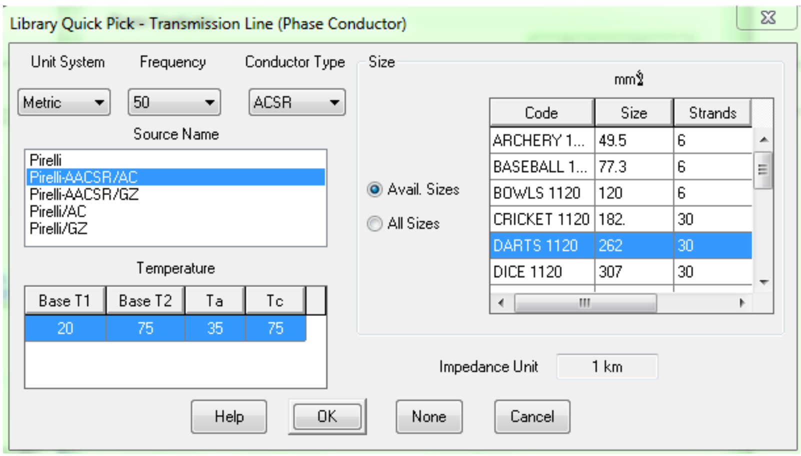


Figure 5.3: Cable data in E-TAP

In this part we can put transmission line parameters and how to put the information of impedance and how to fill the parameter to calculate the sizing of correct conductor And we see Conductor resistance vs. temperature and Physical parameter and filling distances between parameters.(clearances between conductors and length line ).

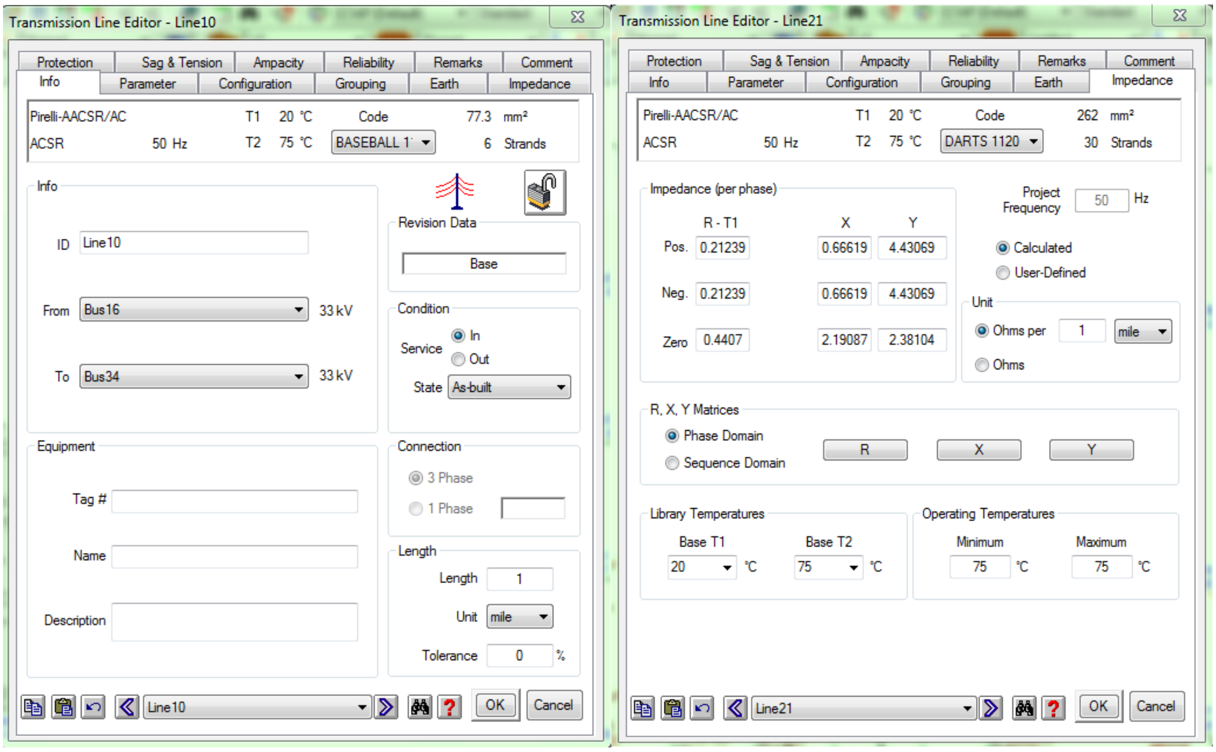


Figure 5.4: Transmission line data in E-TAP

### 5.2.5 Transformers

From the data in chapter two and the load growth (2010-2040) for transformer Specifications and data in chapter three for transformer loading we can fill this parameter

** rating

In the E-TAP window below shows voltage rating and power rating that needed for power flow calculation and short circuit analysis.

The rating of the transformer in cities in south west bank. depending at the load growth (2010-2040)

The max power rating at Nablus = 112MVA.

The max power rating at Tulkarm = 70MVA.

The max power rating at Jenin = 60MVA.

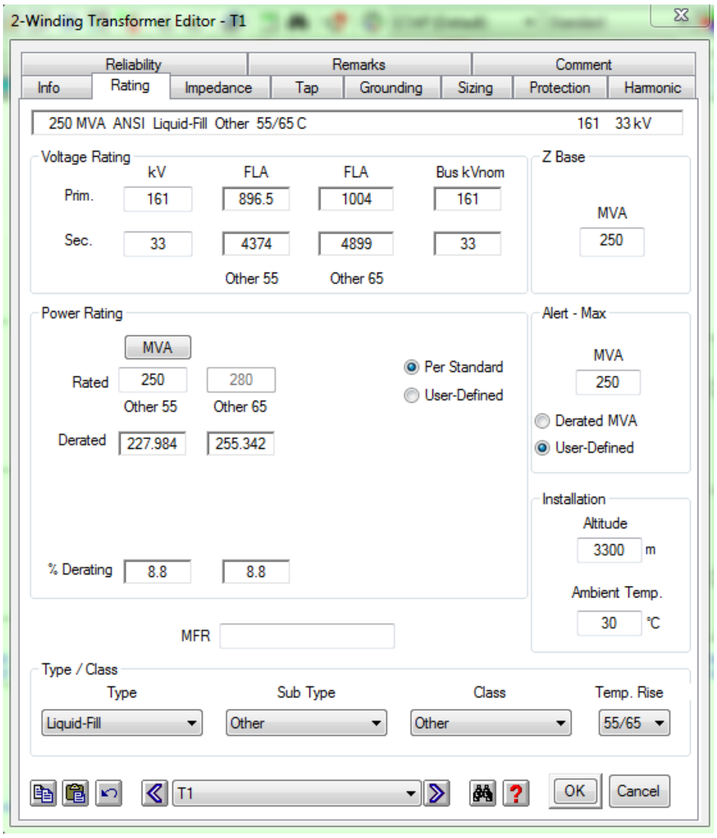


Figure 5.5: Transformers data in E-TAP

** Impedance

The program select the zero and positive impedance parameter for X,R, Z.

Reliability parameter **

Shows the reliability of the cable as failure and repair per year.

In this part we can put transmission line parameters and how to put the information of impedance and how to fill the parameter to calculate the sizing of correct conductor And we see Conductor resistance vs. temperature and Physical parameter and filling distances between parameters.(clearances between conductors and length line ).

### 5.2.6 Load

In the following parameter that concerning load we put the power in MVA for lumped load rating and choose a value of resistive load between 15% and 20% in domestic transformer and smaller or larger value of " R " percentage in the industrial region because of induction and synchronous motors, the E-TAP window show the parameter that filled for a Sponge factory

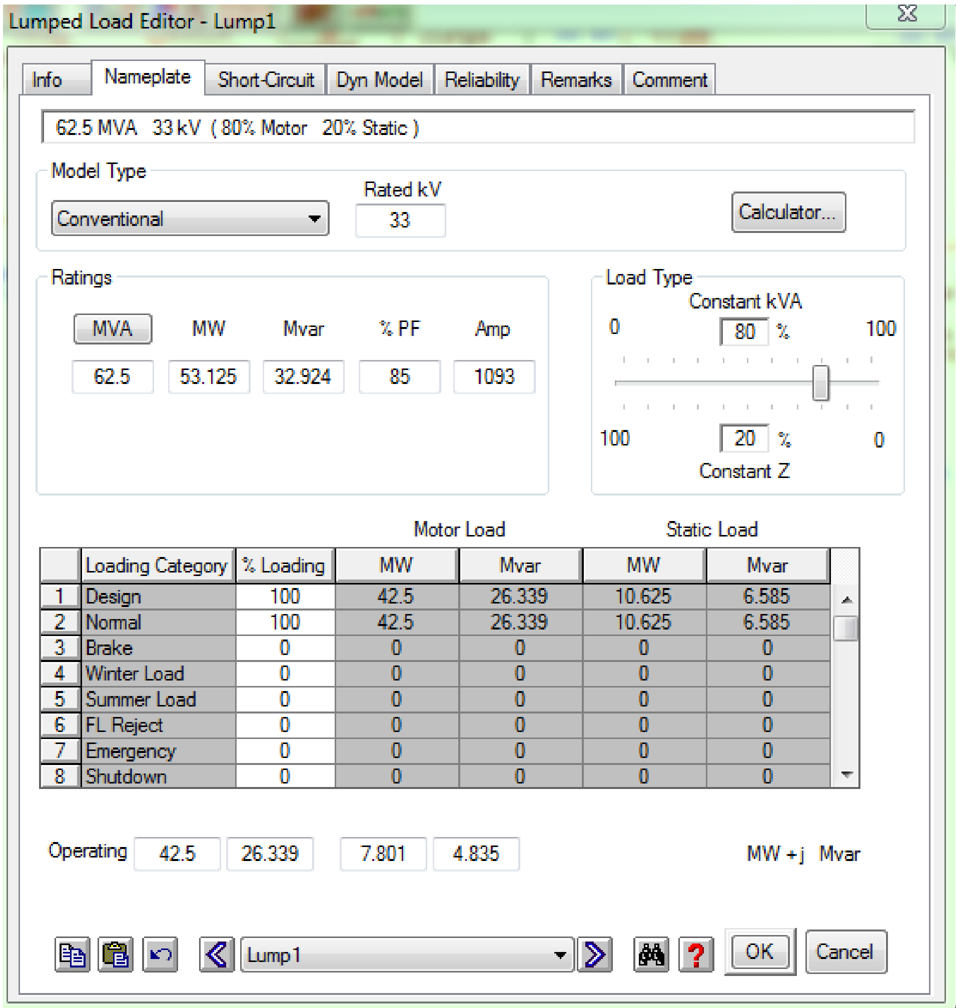


Figure5.6 :Load data in E-tab

### 5.2.7 Load flow analysis:

**Case study 1:**

In this case, the power factor was 0.92 less than 0.94 , so we add capacitor bank to improve the power factor by provide the reactive power in the net work .

**Case study 2:**

In this case, we improve the voltage drop by change the taps of the transformer

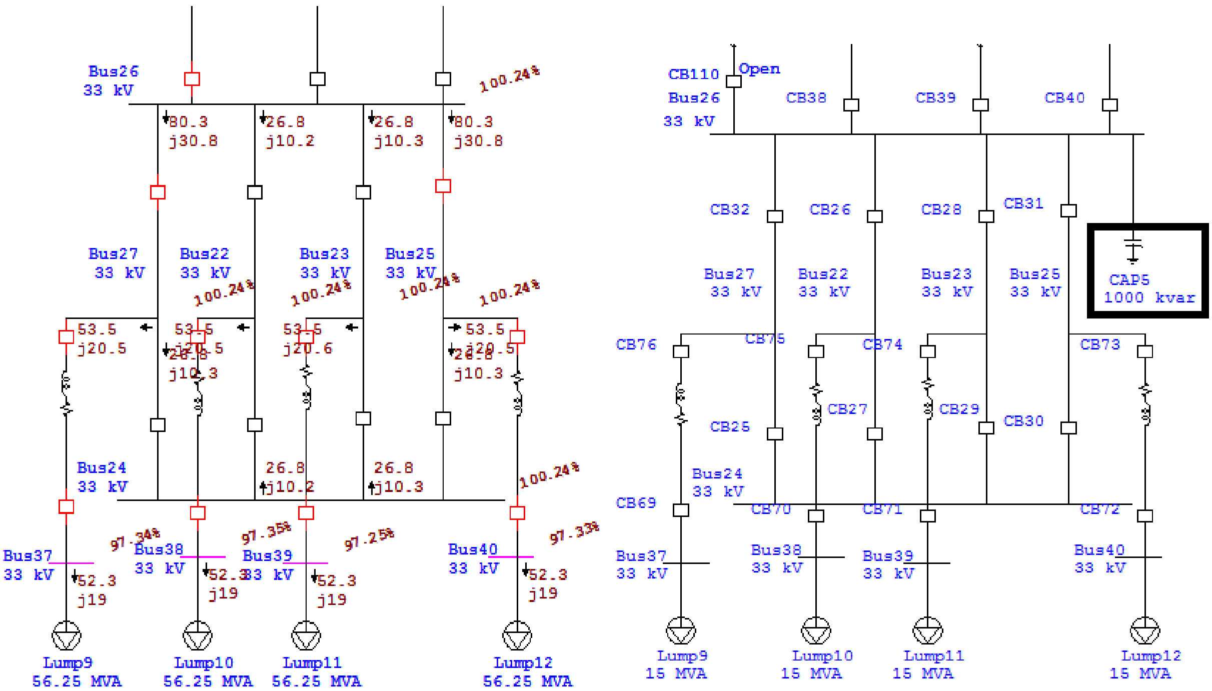


Fig.5.7: case study 1&2.

**SUMMARY OF TOTAL GENERATION , LOADING & DEMAND**

| | MW | Mvar | MVA | % PF |
|---|---|---|---|---|
| Source (Swing Buses): | 231.762 | 94.308 | 250.215 | 92.63 Lagging |
| Source (Non-Swing Buses): | 0.000 | 0.000 | 0.000 | |
| Total Demand: | 231.762 | 94.308 | 250.215 | 92.63 Lagging |
| Total Motor Load: | 181.984 | 66.051 | 193.600 | 94.00 Lagging |
| Total Static Load: | 45.980 | 13.555 | 47.936 | 95.92 Lagging |
| Total Constant I Load: | 0.000 | 0.000 | 0.000 | |
| Total Generic Load: | 0.000 | 0.000 | 0.000 | |
| Apparent Losses: | 3.798 | 14.702 | | |
| System Mismatch: | 0.000 | 0.000 | | |

Number of Iterations: 3

Fig: 5.8 summary of ETAP pdf.

**Result and comments on Etap Simulation:**

1. We improve the power factor by adding capacitor bank to the circuit
2. Increase the voltage drop after built the circuit by change the taps of transformer
3. We protect the transmission line by using overcurrent relay and differential relay to protect the transformer.

## Conclusion:

In this project, we designed a transmission line system from Huwara to Jenin. The appropriate design for towers, conductors, insulators has been done as well as for protection system, considering future loads for the area of the project in the period of (2015-2040).

we designed substation for each city that the transmission line cross it, and we make calculations for spare system (2015– 2040), and after getting the specific information of the network a project synchronization built using E-TAP program, we noticed during design the substation on ETAP that the power factor needs to improved so, we add capacitor bank to improve it and to reach the desirable value.

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# Appendix A

## Types of transmission line

### Short transmission line

- Length is about 50 km.
- Voltage level is up to 20 kV.
- Capacitance effect is negligible.
- Only resistance and inductance are taken in calculation, capacitance is neglected.

### Medium transmission line

- Length is about 50km to 150km.
- Operational voltage level is from 20 kV to 100 kV.
- Capacitance effect is present.
- Distributed capacitance form is used for calculation purpose.

### Long transmission line

- Length is more than 150 km.
- Voltage level is above 100 kV.
- Line constants are considered as distributed over the length of the line.
- In this project, the distance between Huawara to Jenin about 50 km, it is the short transmission line.

## Component of transmission line

1- Towers.
2- Conductors.
3- Insulators.
4- Protection.

# Appendix B

## Towers

### Introduction

The main supporting unit of overhead transmission line is transmission tower. 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.

The design of Power Transmission line tower depends on, type of conductor and Earth-wire, wind zone, deviation angle and material specification. These towers are galvanized to protect the steel from corrosion. The galvanizing coating thickness depends on the weather conditions at the location of tower.[1]

### Electrical tower parts

A power transmission tower consists of the following parts:

1) Peak of transmission tower
2) Cross arm of transmission tower
3) Boom of transmission tower
4) Cage of transmission tower
5) Transmission Tower Body
6) Leg of transmission tower

7) Stub/Anchor Bolt and Base plate assembly of transmission tower.

The main parts among these are shown in the fig. 1.

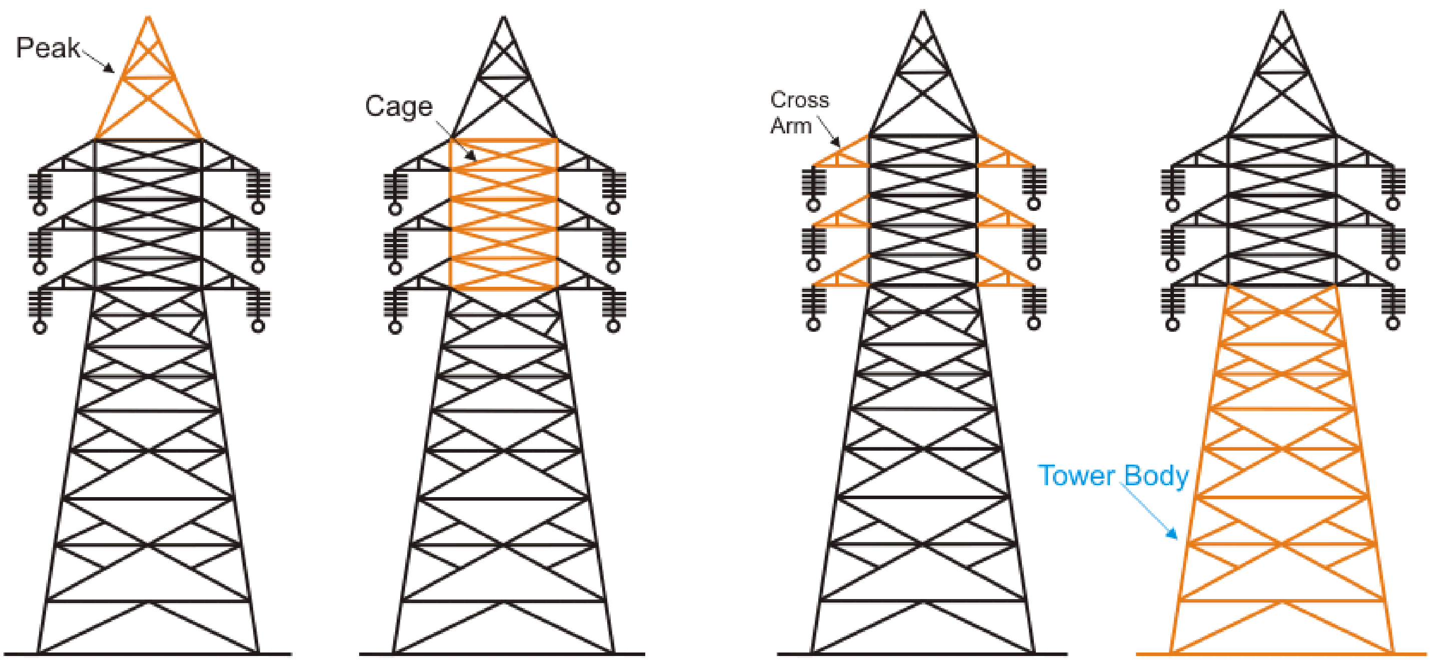



Fig. 1 Tower parts

**Peak of Transmission Tower**

The portion above the top cross arm is called peak of transmission tower. Generally, earth shield wire connected to the tip of this peak.

**Cross Arm of Transmission Tower**

Cross arms of transmission tower hold the transmission conductor. The dimension of cross arm depends on the level of transmission voltage, configuration and minimum forming angle for stress distribution.

**Cage of Transmission Tower**

The portion between tower body and peak is known as cage of transmission tower. This portion of the tower holds the cross arms

**Types of transmission towers.**

According to different considerations, there are different types of transmission towers.

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-

1. A – Type tower – angle of deviation 0° to 2°.
2. B – Type tower – angle of deviation 2° to 15°.
3. C – Type tower – angle of deviation 15° to 30°.
4. D – Type tower – angle of deviation 30° to 60°.

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

1. Tangent suspension tower and it is generally A – type tower.
2. Angle tower or tension tower or sometime it is called section tower. All B, C and D types of transmission towers come under this category.

Apart from the above customized type of tower, the tower is designed to meet special usages listed below; these are called special type towers:

1. Tension Towers:

   The benefits in tensile thread.

2. Suspension Towers.

The towers constitute about 80% of the total number of towers in the font used in the load conductor.

3. Transposition Towers:

They are exchanged phases on equal distances along the line to occur equal to or equal to the power capacitance and inductance of the three-line length phases.

4. Angle Towers.

Benefits and change the font path.

5. Crossing Towers:

Used when crossing rivers or at least lines low voltage lines effortlessly.

6. Terminal Towers:

Used at the beginning and end of the transmission line or inlet and outlet transport stations, a tightening of electrical towers and utility withstand tensile from one side.

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

1. Single circuit tower.
2. Double circuit tower.
3. Multi circuit tower.

## Poles

Poles used to support the overhead power lines and other public utility like cables and fiber optic cables.

Poles used for two types of power lines:

a. Transmission lines which carry higher voltage power between substations.

b. Distribution lines which distribute lower voltage power to customers.

## Types of poles

1. Wood poles.

2. Concrete poles.

3. Metal poles.

## Wood poles

It's the cheapest type of poles and its made from cedar and pine trees because of its length and straightness, this type of poles has tall from (25-130) ft. or more as the customer need.

This type is characterized by its flexibility which make it good to hold the conductor, it has high resistance to pass the current the current and, it easy to structure it, wooden poles handling by coal tar until it totally saturated and this make the wood age between (40-50) years and protect it from rot.

## Concrete poles

It made in circular clips or square or polygonal (6 or 8) ribs, and it be hollow to decrease its weight which represents a negative effect when transfer and install the pole, and this hole used to pass the cable in it, and using iron skewer 8- skewer to increase the strength of the pole.

Concrete poles cost is higher than wood poles and has higher weight so this decrease of use this type of poles.

This type is characterized that it doesn't affected in mold, rust, fire and it's the most strength type of poles and don't need maintenance.

## Metal poles

It made in different lengths and thicknesses, as the durability required, it has many shapes square or polygonal or circular.

This type of poles flexible as wood poles, and it age between (25-30) years, this age depends on thickness of Electroplating layer, the cost of this poles is higher than wood poles, the main reason to use this type of poles because most of people see it more beautiful than other poles, and it used on highways, streets, courts in lighting.

This type is characterized that it is easy to transfer it, because this poles made as part we can transfer it easily then assemble it.

### Framing

It is the component that installs on poles to carry the conductors, and to keep the needed space between the conductors.

There are two forms for the framing:

**1**. **Cross arm**:

Its hold two conductors on either side, and sometimes its hold three conductors and one of them on the middle of cross arm.

**2**. **Bracket**:

Its hold one conductors and fix it to the side of the pole.

## Design span lengths

In transmission line calculations, the following terms are commonly used

1. Basic or normal span

2. Ruling oe equivalent span

3. Average span

4. Wind span

5. Weight span

**Basic or normal span**

The normal span is the most economic span for which the line is designed over level ground, so that the requisite ground clearance is obtained at the maximum specified temperature.

**Ruling span**

The ruling span is the assumed design span that will produce, between dead ends, the best average tension throughout a line of varying span lengths with changes in temperature and loading. It is the weighted average of the varying span lengths, calculated by the formula:

Ruling span = $\sqrt{\frac{I1^3 + I2^3 + .. In^3}{I1 + I2 + .. In}}$

Where (l1, l2 ... ln) are the first, second and last span lengths in sections. The erection tension for any line section is calculated for this hypothetical span.

Tower spotting on the profile is done by means of a sag template, which is based on the ruling span. Therefore, this span must be determined before the template can be made.

**Average span**

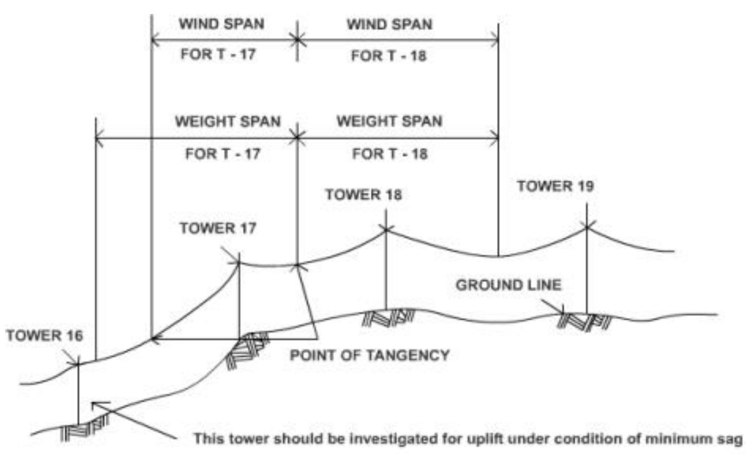
The average span is the mean span length between dead ends. It is assumed that the conductor is freely suspended such that each individual span reacts to changes in tension as a single average span. All sag and tension calculations are carried out for the average span, on this assumption. Wind span the wind span is that on which the wind is assumed to act transversely on the conductors and is taken as half the sum of the two spans, adjacent to the support (fig. wind span and weight span) In order to take full advantage of towers located on elevated ground, it is usual to allow a wind span of 10 to 15 percent in excess of the normal span. This additional strength can be used in taking a small angle of deviation on an intermediate tower, where the actual wind span is less than the design wind span. The angle of deviation to be taken in such cases is approximately given by:

$$\theta = \frac{wl}{\pi T} \times 180$$

Where w = total and load per unit run of span length of all conductor carried by the tower, l = difference between the wind span used for design and the actual wind span, and T = the total maximum working tension of all conductors carried by the tower.

**Weight span**

The weight span is the horizontal distance between the lowest point of the conductors, on the two spans adjacent to the tower (fig. wind span and weight span) The lowest point is defined as the point at which the tangent to the sag curve, or to the sag curve produced, is horizontal. The weight span is used in the design of cross-arms.



## Tower configurations

Depending upon the requirements of the transmission system, various line configurations have to be considered - ranging from single circuit horizontal to double circuit vertical structures and with single or V strings in all phases, as well as any combination of these.

The configuration of a transmission line tower depends on:

1. the length of the insulator assembly
2. the minimum clearances to be maintained between conductors, and between conductors and tower
3. the location of ground wire or wires with respect to the outermost conductor
4. the mid-span clearance required from considerations of the dynamic behavior of conductors and lightning protection of the line
5. the minimum clearance of the lowest conductor above ground level.

The tower outline is determined essentially by three factors: tower height, base width, and top hamper width.

## Minimum permissible ground clearance

For safety considerations, power conductors along the route of the transmission line should maintain requite clearance to ground in open country, national highways, rivers, railways tracks, telecommunication lines, other power lines, etc.., as laid down in the Indian Electricity Rules, or Standards or codes of practice in vogue.

Rule 77(4) of the Indian Electricity Rules, 1956, stipulates the following clearances above ground of the lowest point of the conductor:

For extra- high voltage lines, the clearance above ground shall not be less than 5.182 meters plus 0.305 meters for every 33,000 volts or part there of by which the voltage of the line exceeds 33,000 volts.

Accordingly, the values for the various voltages, 66kV to 400 kV, are:

66kV - 5.49m

132kV - 6.10m

220kV - 7.01m

400kV - 8.84m

The above clearances are applicable to transmission lines running in open country.

**Power line crossings**

In crossings over rivers, telecommunication lines, railway tracks, etc.., the following clearances are maintained:

1. Crossing over rivers

a. Over rivers which are not navigable. The minimum clearance of conductor is specified as 3.05 over maximum flood level.

b. Over navigable rivers: Clearances are fixed in relation to the tallest mast, in consultation with the concerned navigation authorities.

2. Crossing over telecommunication lines. The minimum clearances between the conductors of a power line and telecommunication wires are

66 kV - 2,440mm

132 kV - 2,740mm

220 kV - 3,050mm

400 kV - 4,880mm

3. Crossing over railway tracks: The minimum height over the rail level, of the lowest portion of any conductor under conditions of maximum sag, as stipulated in the regulations for Electrical Crossings of Railway Tracks, 1963, is given in Table 4.1.

4. Between power lines

a. Between power lines L.T up to 66 kV - and 66 kV line 2.44m

b. Between power lines L.T up to 132 kV - and 132kV line 2.75m

c. Between power lines L.T up to 220kV - and 220kV line 4.55m

d. Between power lines L.T up to 400kV - and 400kV line 6.00m(Tentative)

**Spacing of conductors**

Considerable differences are found in the conductor spacing's adopted in different countries and on different transmission systems in the same country.

The spacing of conductors is determined by considerations which are partly mechanical. The material and diameter of the conductors should also be considered when deciding the spacing, because a smaller conductor, especially if made of aluminum, having a small weight in relation to the area presented to a crosswind, will swing out of the vertical plane father than a conductor of large cross-section. Usually conductors will swing synchronously (in phase) with the wind, but with long spans and small wires, there is always a possibility of the conductors swinging non-synchronously, and the size of the conductor and the maximum sag at the center of the span are factors which should be taken in to account in determining the distance apart at which they should be strung.

There are a number of empirical formulae in use, deduced from spacing's which have successfully operated in practice while research continues on the minimum spacing's which could be employed.

The following formulae are in general use:

1. Mecomb's formula

Spacing in cm = 0.3048V + 4.010 $\frac{D}{w}\sqrt{S}$

Where V = Voltage in kV,

D = Conductor diameter in cm,

S = sag in cm, and

W = Weight of conductor in kg/m.

2. NESC, USA formula

Horizontal spacing in cm

$$= A + 3.681\sqrt{S} + \frac{L}{\sqrt{2}}$$

Where A=0.762 cm per kV line voltage

S = Sag in cm, and

L = Length of insulator string in cm

Offset of conductors (under ice-loading conditions)

The jump of the conductor, resulting from ice dropping off one span of an ice-covered line, has been the cause of many serious outages on long-span lines where conductors are arranged in the same vertical plane. The 'sleet jump' has been practically cleared up by horizontally offsetting the conductors. Apparently, the conductor jumps in practically a vertical plane, and this is true if no wind is blowing, in which cases all forces and reactions are in a vertical plane. In double circuit, vertical configuration, the middle conductors are generally offset in accordance with the following formula:

Offset in cm = 60 + Span in cm / 400

**Vertical clearance between ground wire and top conductor**

This is governed by the angle of shielding, the angle which the line joining the ground wire and the outermost conductor makes with the vertical, required for the interruption of direct lightning strokes at the ground and the minimum midspan clearance between the ground wire and the top power conductor. The shield angle varies from about 25$^{o}$ to 30$^{o}$, depending on the configuration of conductors and the number of ground wires (one or two) provided.

**Determination of base width**

The base width at the concrete level is the distance between the center of gravity at one corner leg and the center of gravity of the adjacent corner leg. There is a particular base width which gives the minimum total cost of the tower and foundations.

Ryle has given the following formula for a preliminary determination of the economic base width:

B=$0.42\sqrt{M}\ or\ 0.013\sqrt{m}$

Where B = Base width in meters,

M = Overturning moment about the ground level in tone-meters,

and M= Overturning moment about the ground level in kg. meters.

The ratio of base width to total tower height for most towers is generally about one-fifth to one-tenth from large-angle towers to tangent towers.

The following equations have been suggested9, based on the best fit straight line relationship between the base width B and $\sqrt{M}$

B=$0.0782\sqrt{M}$ +1.0

$B=0.0691\sqrt{M} + 0.7$

Equations are for suspension and angle towers respectively.

It should be noted that Ryle's formula is intended for use with actual external loads acting on the tower whereas the formulae in Equations take into account a factor of safety of 2.0.

Narrow-base towers are commonly used in Western Europe, especially Germany, mainly from way-leave considerations. British and American practices generally favor the wide base type of design, for which the total cost, of tower and foundations is a minimum. In the USA, a continuous wide strip of land called the 'right of way' has usually to be acquired along the line route. In Great Britain, the payments made for individual tower way-leaves are generally reasonably small and not greatly affected by tower base dimensions. Therefore, it has been possible to adopt a truly economic base width in both the United States and Great Britain.

A wider taper in the tower base reduces the foundation loading and costs but increases the cost of the tower and site. A minimum cost which occurs with a tower width, is greater with bad soil than with good soil. A considerable saving in foundation costs results from the use of towers with only three legs, the tower being of triangular section throughout its height. This form of construction entails tubular legs or special angle sections. The three-footing anchorage has further advantages, e.g., greater accessibility of the soil underneath the tower when the land is cultivated.

**Determination of top hamper width**

The width at top hamper is the width of the tower at the level of the lower cross-arm in the case of barrel type of towers (in double circuit towers it may be at the middle level) and waist line in the case of towers with horizontal configuration of conductors.

The following parameters are considered while determining the width of the tower at the top bend line:

1. Horizontal spacing between conductors based on the midspan flashover between the power conductor under the severest wind and galloping conditions and the electrical clearance of the line conductor to tower steel work.

2. The sloe of the legs should be such that the corner members intersect as near the center of gravity (CG) of the loads as possible. Then the braces will be least loaded. Three cases are possible depending upon the relative position of the CG of the loads and intersection of the tower legs.

In Case (1) the entire shear is taken up by the legs and the bracings do not carry any stress.

Case (2) shows a condition in which the resultant of all loads O' is below the inter-section of tower legs O. The shear here is shared between legs and bracings which is a desirable requirement for an economical tower design.

In Case (3), the legs have to withstand greater forces than in cases (1) and (2) because the legs intersect below the center of gravity of the loads acting on the tower. This outline is uneconomical. The top hamper width is generally found to be about one-third of the base width for tangent and light angle towers and about 1.35 of the base width for medium and heavy angle towers. For horizontal configurations, the width at the waistline is, however, found to vary from 1/1.5 to ½.5 of the base width.

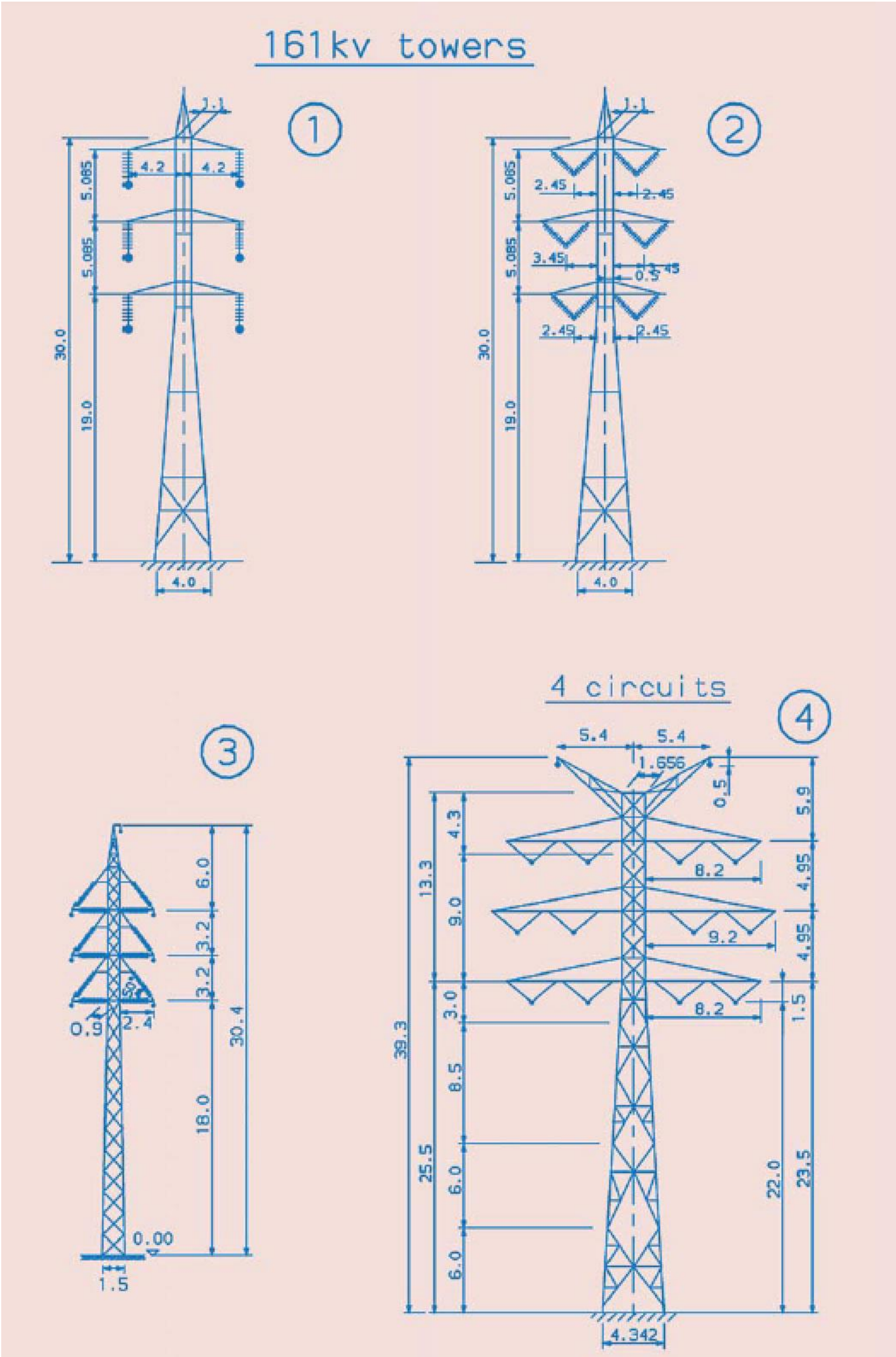
**Minimum height above ground for overhead line in UK (electricity regulation 1988, amended 1990)**

| Nominal system voltage Vn (kV) | Clearance (m) |
|---|---|
| **33<Vn<66** | 6.0 |
| **66<Vn<132** | 6.7 |
| **132<Vn<275** | 7.0 |
| **275<Vn<400** | 7.3 |

**Typical overhead line clearances (based om maximum conductor temperature the load – EN 50341)**

| | Clearance (m) from line with highest system voltage of: |
|---|---|
| Clearance consideration | 161kV |
| To ground in unobstructed countryside | 6.2 |
| To rockface or steep slope | 3.2 |
| To trees which cannot be climbed | 1.2 |
| To trees which can be climbed | 2.7 |
| To buildings with fire-resistance roofs and roofs with slope < 15$^{o}$ to horizontal | 5.2 |
| To buildings with fire-resistance roofs and roofs with slope > 15$^{o}$ to horizontal | 3.2 |
| Horizontal clearance to buildings | 3.2 |
| To fire sensitive installations | 11.2 |
| To antennae, lamp posts, etc. which cannot stoop upon | 3.2 |
| Line crossing of minor roads, railways and waterways | 3.2-7.2 depending on nature of roads, railways (e.g. electrified or not) and waterway (e.g. with structures or not) |

## 161 kV Towers [5]



## Appendix C

## Conductors

## Introduction

Conductor is a physical high to carry electrical energy form one place to other. It is an important component of transmission and distribution systems. The choice of conductor depends on the cost and efficiency. An ideal conductor has following features:

1.  It has maximum electrical conductivity.

2. It has high tensile strength so that it can withstand mechanical stresses.

3. It has least specific gravity i.e. weight / unit volume.

4. It has least cost without sacrificing other factors.

In early days' copper ‘Cu’ conductors were 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:

1. It has lesser cost than copper.

2. It offers larger diameter for same amount of current which reduces corona.

**Aluminum also has some disadvantages over copper**

1. It has less conductivity.

2. It has larger diameter which increase surface area to air pressure thus it swings more in air than copper so larger cross arms required which increases the cost.

3. It has lesser tensile strength ultimately larger sag.

4. It has lesser specific gravity (2.71gm/cc) than copper (8.9 gm/cc) cc = cubic centimeter.

The temperature of the conductor increases with increasing heat produced by the current through it, it is sometimes possible to increase the power handling capacity (uprate) by changing the conductors for a type with a lower coefficient of thermal expansion or a higher allowable operating temperature.

$$\mathbf{P} = \boldsymbol{I}^{\mathbf{2}} \times \boldsymbol{R}$$

## Aluminum conductors

**1. All Aluminums Conductors (A.A.C.)**

1. 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.

2. It has slightly better conductivity at lower voltages than ACSR i.e. at distribution level.

3. Cost of ACSR is equal to AAC.

**2. All Aluminum Alloy Conductors (A.A.A.C.):**

A.A.A.C. is mainly used for overhead lines, in transmission and distribution electrical networks, having relatively long span. They are also used a messenger to support overhead electrical cables.

**3. Aluminum Conductor Steel Reinforced (A.C.S.R.):**

A.C.S.R conductors are widely used for electrical power transmission- over long distances, since they are ideal for long overhead lines spans. They are- also used as a messenger for supporting overhead electrical cables.


Figure ACSR Conductor, Aluminum Conductors Steel

**4. International Annealed Copper Stand (I.A.C.S)**

It is 100 % pure conductor and it is standard for reference.

**Structure of Conductor:**

An ACSR conductor consists of a couple of wires of steel core which is zinc Coated. External skin consists of one or more layer of aluminum wires.

**Voltage Ratings**

Voltage is the electrical potential difference between two points. Voltage is divided into three different voltage areas which are low voltage, medium voltage and high voltage (extra high voltage and ultra-high voltage).

.

| | |
|---|---|
| Low voltage | From 0kv to 1kv |
| Medium voltage | From 1kv to 45kv |
| High voltage | From 45kv to 300 kv |
| Extra high voltage | From 300kv to 750 kv |
| Up high voltage | Up to 800 kv |

# Data sheet for used conductors

## ASTM CONDUCTOR SIZES - METRIC UNITS

| Code Word | Nominal Size (AWG or KCM) | Nominal Size ($mm^2$) | Stranding (Al/Stl) | Diameter (mm) Individual Wires Al | Diameter (mm) Individual Wires Stl | Steel Core | Complete Cable | Weight[1] (kg/krn) At | Weight[1] (kg/krn) Stl | Weight[1] (kg/krn) Total | Content % Al | Content % Stl | Rated Strength[2] kg | Resistance[3] ohms/km DC@ 20 °C | Resistance[3] ohms/km AC @ 75 °C | Current Rating[4] (Amps) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Turkey | 6 | 13.30 | 6/1 | 1.679 | 1.679 | 1.68 | 5.04 | 36.4 | 17.2 | 53.7 | 67.90 | 32.10 | 540 | 2.10 | 2.64 | 105 |
| Swan | 4 | 21.15 | 6/1 | 2.118 | 2.118 | 2.12 | 6.36 | 58.0 | 27.4 | 85.4 | 67.90 | 32.10 | 844 | 1.32 | 1.69 | 140 |
| Swanate | 4 | 21.15 | 7/1 | 1.961 | 2.614 | 2.61 | 6.54 | 58.0 | 41.7 | 99.7 | 58.13 | 41.87 | 1070 | 1.31 | 1.70 | 140 |
| Sparrow | 2 | 33.63 | 6/1 | 2.672 | 2.672 | 2.67 | 8.02 | 92.3 | 43.6 | 135.9 | 67.90 | 32.10 | 1293 | .832 | 1.09 | 184 |
| Sparate | 2 | 33.63 | 7/1 | 2.474 | 3.299 | 3.30 | 8.25 | 92.3 | 66.5 | 158.8 | 58.13 | 41.87 | 1651 | .823 | 1.11 | 184 |
| Robin | 1 | 42.41 | 6/1 | 3.000 | 3.000 | 3.00 | 9.00 | 116.3 | 55.0 | 171.4 | 67.90 | 32.10 | 1615 | .660 | .878 | 212 |
| Raven | 1/0 | 53.51 | 6/1 | 3.371 | 3.371 | 3.37 | 10.11 | 146.9 | 69.4 | 216.2 | 67.90 | 32.10 | 1987 | .523 | .711 | 242 |
| Quail | 2/0 | 67.44 | 6/1 | 3.782 | 3.782 | 3.78 | 11.35 | 184.9 | 87.4 | 272.3 | 67.90 | 32.10 | 2404 | .415 | .579 | 276 |
| Pigeon | 3/0 | 85.03 | 6/1 | 4.247 | 4.247 | 4.25 | 12.47 | 233.1 | 110.2 | 343.3 | 67.90 | 32.10 | 3003 | .329 | .474 | 315 |
| Penguin | 4/0 | 107.22 | 6/1 | 4.770 | 4.770 | 4.77 | 14.31 | 294.1 | 139.0 | 433.1 | 67.90 | 32.10 | 3787 | .261 | .390 | 357 |
| Waxwing | 266.8 | 135.19 | 18/1 | 3.091 | 3.091 | 3.09 | 15.46 | 372.4 | 58.4 | 430.7 | 86.45 | 13.55 | 3121 | .211 | .259 | 449 |
| Partridge | 266.8 | 135.19 | 26/7 | 2.573 | 2.002 | 6.00 | 16.30 | 374.5 | 172.0 | 546.5 | 68.53 | 31.47 | 5126 | .209 | .255 | 457 |
| Ostrich | 300.0 | 152.01 | 2617 | 2.728 | 2.121 | 6.36 | 17.27 | 421.0 | 193.1 | 614.0 | 68.53 | 31.47 | 5761 | .186 | .227 | 492 |
| Merlin | 336.4 | 170.46 | 18/1 | 3.472 | 3.472 | 3.47 | 17.36 | 469.8 | 73.6 | 543.5 | 86.45 | 13.55 | 3937 | .167 | .205 | 519 |
| Linnet | 336.4 | 170.46 | 26/7 | 2.891 | 2.248 | 6.74 | 18.29 | 471.8 | 216.4 | 688.2 | 68.53 | 31.47 | 6396 | .166 | .203 | 529 |
| Oriole | 336.4 | 170.46 | 30/7 | 2,690 | 2.690 | 8.07 | 18.83 | 473.4 | 310.9 | 784.3 | 60.35 | 39.65 | 7847 | .165 | .201 | 535 |
| Chickadee | 297.5 | 201.42 | 18/1 | 3.774 | 3.774 | 3.77 | 18.87 | 555.2 | 87.0 | 642.2 | 86.45 | 13.55 | 4509 | .142 | .174 | 576 |
| Brant | 397.5 | 201.42 | 24/7 | 3.269 | 2.179 | 6.54 | 19.61 | 558.0 | 203.9 | 761.9 | 73.23 | 26.77 | 6622 | .141 | .172 | 584 |
| Ibis | 397.5 | 201.42 | 26/7 | 3.139 | 2.441 | 7.32 | 19.88 | 557.5 | 255.7 | 813.3 | 68.53 | 31.47 | 7394 | .140 | .172 | 587 |
| Lark | 397.5 | 201.42 | 30/7 | 2.924 | 2.924 | 8.77 | 20.46 | 559.2 | 367.2 | 926.5 | 60.35 | 39.65 | 9208 | .139 | .170 | 594 |
| Pelican | 477.0 | 241.70 | 18/1 | 4.135 | 4.135 | 4.14 | 20.68 | 666.4 | 104.4 | 770.8 | 86.45 | 13.55 | 5352 | .118 | .144 | 646 |


| Code Word | Nominal Size (AWG or KCM) | Nominal Size ($mm^2$) | Stranding (Al/Stl) | Diameter (mm) Individual Wires Al | Diameter (mm) Individual Wires Stl | Steel Core | Complete Cable | Weight[1] (kg/km) At | Weight[1] (kg/km) Stl | Weight[1] (kg/km) Total | Content % Al | Content % Stl | Rated Strength[2] kg | Resistance[3] ohms/km DC@ 20 °C | Resistance[3] ohms/km AC @ 75 °C | Current Rating[4] (Amps) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Turkey | 6 | 13.30 | 6/1 | 1.679 | 1.679 | 1.68 | 5.04 | 36.4 | 17.2 | 53.7 | 67.90 | 32.10 | 540 | 2.10 | 2.64 | 105 |
| Swan | 4 | 21.15 | 6/1 | 2.118 | 2.118 | 2.12 | 6.36 | 58.0 | 27.4 | 85.4 | 67.90 | 32.10 | 844 | 1.32 | 1.69 | 140 |
| Swanate | 4 | 21.15 | 7/1 | 1.961 | 2.614 | 2.61 | 6.54 | 58.0 | 41.7 | 99.7 | 58.13 | 41.87 | 1070 | 1.31 | 1.70 | 140 |
| Sparrow | 2 | 33.63 | 6/1 | 2.672 | 2.672 | 2.67 | 8.02 | 92.3 | 43.6 | 135.9 | 67.90 | 32.10 | 1293 | .832 | 1.09 | 184 |
| Sparate | 2 | 33.63 | 7/1 | 2.474 | 3.299 | 3.30 | 8.25 | 92.3 | 66.5 | 158.8 | 58.13 | 41.87 | 1651 | .823 | 1.11 | 184 |
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| Quail | 2/0 | 67.44 | 6/1 | 3.782 | 3.782 | 3.78 | 11.35 | 184.9 | 87.4 | 272.3 | 67.90 | 32.10 | 2404 | .415 | .579 | 276 |
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| Penguin | 4/0 | 107.22 | 6/1 | 4.770 | 4.770 | 4.77 | 14.31 | 294.1 | 139.0 | 433.1 | 67.90 | 32.10 | 3787 | .261 | .390 | 357 |
| Waxwing | 266.8 | 135.19 | 18/1 | 3.091 | 3.091 | 3.09 | 15.46 | 372.4 | 58.4 | 430.7 | 86.45 | 13.55 | 3121 | .211 | .259 | 449 |
| Partridge | 266.8 | 135.19 | 26/7 | 2.573 | 2.002 | 6.00 | 16.30 | 374.5 | 172.0 | 546.5 | 68.53 | 31.47 | 5126 | .209 | .255 | 457 |

## Insulators

### Introduction

- The overhead line conductors are bare and not covered with any insulating coating or covering.
- The insulators are the means of insulating medium which keep the line conductor away from the supporting structure.
- It provides necessary clearance between conductor and metal works.
- Proper selection of overhead line insulator is essential for successful operation of overhead lines.

### types of insulator

1. Pin type insulator
2. Post insulator
3. Suspension type insulators
4. Strain insulators
5. Shackle insulators

### 1. pin type insulator:

It provides the most economic, simple and efficient method for voltages less than 33KV

It can have fitted on cross arm with the help of pins and conductor is placed in the groove at the top of insulator and it is tied with the help of copper or aluminum wires.

Pin should be able to with stand the mechanical stress, wind and ice loading

**advantages:**

- It is cheaper
- Pin insulator can do the work of two suspension insulators
- Since pin insulator rises the conductor above the cross arm so required height of towers is also less.

**disadvantages**

- For operating voltage, greater than 33kv, it in uneconomical and size is also bulky.
- Once a pin insulator is failed short circuit can occur.

### 2. Post insulator

- There are used for supporting the busbars and disconnecting switches in sub stations.
- It is similar to pin type insulator but has metal base and metal cap.

- In this insulator, the porcelain elements are in the form of cones fitting one side the other and are bonded by special cement.
- Used for voltage up to 33kv.

3. **suspension type insulators**

- It consists number of porcelain discs flexibly connected in series by metal links in form of a string.
- In hangs from cross arms and conductor is attached to lower end.
- As there is no pin. we can put any distance between the cross arms and the conductors by adding a disc
- Number of insulator in a string depends on operating voltages, weather condition, type of transmission structure and the size of insulator used
- Each unit of suspension insulator for 11kv.

**advantages**

- It is cheaper for operating voltage above 33kv.
- It one disc is damaged, whole string will need not to be replaced.
- Less mechanical stress.
- The operating voltage can be increased according to demand by adding disc of insulator to the string.

**disadvantages**

- Spacing between conductor should be large to allow swing of conductors.
- Height of line supports should be large as conductor is hanged below the cross arms.

**4. strain insulators**

- At the dead end and corner the line is subjected to great tension.
- To withstand this tension strain insulators are used.
- For voltage, less than 11kv, shackle insulators are used as strain insulators
- For voltage, greater than 11kv suspension (disc) insulators are used.
- The discs of strain are used in vertical plane.
- When the tension is higher as at river spans tower, more string are used in parallel.

5. **Shackle insulators**

- It is used for low voltage distribution
- Such insulators can be used either in vertical position or horizontal position.
- They are directly fixed to pole with the help bolts.
- The conductor in groove is fixed with soft binding wires.

**how to test the electrical insulators:**

**1-Testing lightning:**

a. **power frequency dry flash over**

The use of effort between the two poles of the separation and then increases the effort for 1 minute until the ionized air around Bazl and broken.

b. **power frequency wet flash over**

The use of effort between the two poles of the separation effort then sprayed with water resistance between 9000 increase to 11,000 ohm-on-insulator 45-degree angle provided that the water does not fall more than 5.0 mm per minute for a period of 30 seconds

**2-Hole-voltage tests:**

It is fed high voltage and then gradually increase the effort where the hole Bazl happen and is used by high voltage higher than 30% of the operating voltage

**3-Strong test mechanic**.

This test uses screw insulators to make sure that the separation is capable of carrying Mosul is done to add 250% of the load of the separation of conductor, one minute for the separation and be force in newton's.

**4-Strong electrical test**

This test is used in insulation comment where this is done to add 250% of the load of the separation of conductor, one minute for then is used 55% of lightning effort.

**5-Test softness of texture**

Sample is taken from the separation and then breaks it and put it in a ratio of 1% of the Fuxin solution under pressure as 150 grams per square centimeters for an hour and then takes out the sample and note there is no uh scratches or puncture

**6-High voltage test**

Insulation is placed in the water is then used high voltage for 5 minutes where it should not damage the insulation

**7-Corrosion Testing**

Insulating material is placed in the copper phosphate at a temperature of 15 ° C for a minute and then goes out and cleans the separation and placed the separation time second in the converter and repeat it 4 times.

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