



# Mechanical Design of Overhead Lines

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## Introduction

Electric power can be transmitted or distributed either by means of underground cables or by overhead lines. The underground\* cables are rarely used for power transmission due to two main reasons. Firstly, power is generally transmitted over long distances to load centres. Obviously, the installation costs for underground transmission will be very heavy. Secondly, electric power has to be transmitted at high voltages for economic reasons. It is very difficult to provide proper insulation† to the cables to withstand such higher pressures. Therefore, as a rule, power transmission over long distances is carried out by using overhead lines. With the growth in power demand and consequent rise in voltage levels, power transmission by overhead lines has assumed considerable importance.

\* The underground system is much more expensive than overhead system. Therefore, it has limited use for distribution in congested areas where safety and good appearances are the main considerations.

† In overhead lines, bare conductors are used and air acts as the insulation. The necessary insulation between the conductors can be provided by adjusting the spacing between them.





An overhead line is subjected to uncertain weather conditions and other external interferences. This calls for the use of proper mechanical factors of safety in order to ensure the continuity of operation in the line. In general, the strength of the line should be such so as to provide against the worst *probable* weather conditions. In this chapter, we shall focus our attention on the various aspects of mechanical design of overhead lines.

### 8.1 Main Components of Overhead Lines

An overhead line may be used to transmit or distribute electric power. The successful operation of an overhead line depends to a great extent upon the mechanical design of the line. While constructing an overhead line, it should be ensured that mechanical strength of the line is such so as to provide against the most *probable* weather conditions. In general, the main components of an overhead line are:

- (i) **Conductors** which carry electric power from the sending end station to the receiving end station.
- (ii) **Supports** which may be poles or towers and keep the conductors at a suitable level above the ground.
- (iii) **Insulators** which are attached to supports and insulate the conductors from the ground.
- (iv) **Cross arms** which provide support to the insulators.
- (v) **Miscellaneous items** such as phase plates, danger plates, lightning arrestors, anti-climbing wires etc.

The continuity of operation in the overhead line depends upon the judicious choice of above components. Therefore, it is profitable to have detailed discussion on them.

### 8.2 Conductor Materials

The conductor is one of the important items as most of the capital outlay is invested for it. Therefore, proper choice of material and size of the conductor is of considerable importance. The conductor material used for transmission and distribution of electric power should have the following properties :

- (i) high electrical conductivity.
- (ii) high tensile strength in order to withstand mechanical stresses.
- (iii) low cost so that it can be used for long distances.
- (iv) low specific gravity so that weight per unit volume is small.

All above requirements are not found in a single material. Therefore, while selecting a conductor material for a particular case, a compromise is made between the cost and the required electrical and mechanical properties.

**Commonly used conductor materials.** The most commonly used conductor materials for overhead lines are *copper, aluminium, steel-cored aluminium, galvanised steel* and *cadmium copper*. The choice of a particular material will depend upon the cost, the required electrical and mechanical properties and the local conditions.

All conductors used for overhead lines are preferably stranded\* in order to increase the flexibility. In stranded conductors, there is generally one central wire and round this, successive layers of wires containing 6, 12, 18, 24 ..... wires. Thus, if there are  $n$  layers, the total number of individual wires is  $3n(n + 1) + 1$ . In the manufacture of stranded conductors, the consecutive layers of wires are twisted or spiralled in opposite directions so that layers are bound together.

**1. Copper.** Copper is an ideal material for overhead lines owing to its high electrical conductivity and greater tensile strength. It is always used in the hard drawn form as stranded conductor.

\* Solid wires are only used when area of X-section is small. If solid wires are used for larger X-section and longer spans, continuous vibrations and swinging would produce mechanical fatigue and they would fracture at the points of support.





Although hard drawing decreases the electrical conductivity slightly yet it increases the tensile strength considerably.

Copper has high current density *i.e.*, the current carrying capacity of copper per unit of X-sectional area is quite large. This leads to two advantages. Firstly, smaller X-sectional area of conductor is required and secondly, the area offered by the conductor to wind loads is reduced. Moreover, this metal is quite homogeneous, durable and has high scrap value.

There is hardly any doubt that copper is an ideal material for transmission and distribution of electric power. However, due to its higher cost and non-availability, it is rarely used for these purposes. Now-a-days the trend is to use aluminium in place of copper.

**2 Aluminium.** Aluminium is cheap and light as compared to copper but it has much smaller conductivity and tensile strength. The relative comparison of the two materials is briefed below :

- (i) The conductivity of aluminium is 60% that of copper. The smaller conductivity of aluminium means that for any particular transmission efficiency, the X-sectional area of conductor must be larger in aluminium than in copper. For the same resistance, the diameter of aluminium conductor is about 1.26 times the diameter of copper conductor.

The increased X-section of aluminium exposes a greater surface to wind pressure and, therefore, supporting towers must be designed for greater transverse strength. This often requires the use of higher towers with consequence of greater sag.

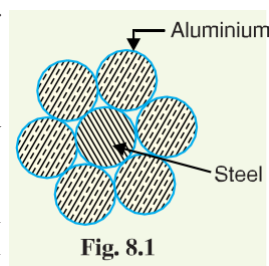
- (ii) The specific gravity of aluminium (2.71 gm/cc) is lower than that of copper (8.9 gm/cc). Therefore, an aluminium conductor has almost one-half the weight of equivalent copper conductor. For this reason, the supporting structures for aluminium need not be made so strong as that of copper conductor.
- (iii) Aluminium conductor being light, is liable to greater swings and hence larger cross-arms are required.
- (iv) Due to lower tensile strength and higher co-efficient of linear expansion of aluminium, the sag is greater in aluminium conductors.

Considering the combined properties of cost, conductivity, tensile strength, weight etc., aluminium has an edge over copper. Therefore, it is being widely used as a conductor material. It is particularly profitable to use aluminium for heavy-current transmission where the conductor size is large and its cost forms a major proportion of the total cost of complete installation.

**3. Steel cored aluminium.** Due to low tensile strength, aluminium conductors produce greater sag. This prohibits their use for larger spans and makes them unsuitable for long distance transmission. In order to increase the tensile strength, the aluminium conductor is reinforced with a core of galvanised steel wires. The \*composite conductor thus obtained is known as *steel cored aluminium* and is abbreviated as A.C.S.R. (aluminium conductor steel reinforced).

Steel-cored aluminium conductor consists of central core of †galvanised steel wires surrounded by a number of aluminium strands. Usually, diameter of both steel and aluminium wires is the same. The X-section of the two metals are generally in the ratio of 1 : 6 but can be modified to 1 : 4 in order to get more tensile strength for the conductor. Fig. 8.1 shows steel cored aluminium conductor having one steel wire surrounded by six wires of aluminium.

The result of this composite conductor is that steel core takes greater percentage of



\* The reader may think that reinforcement with steel increases the weight but actually the weight of composite conductor is 25% less as compared with equivalent copper conductor.

† The galvanised steel is used in order to prevent rusting and electrolytic corrosion.





mechanical strength while aluminium strands carry the bulk of current. The steel cored aluminium conductors have the following advantages :

- (i) The reinforcement with steel increases the tensile strength but at the same time keeps the composite conductor light. Therefore, steel cored aluminium conductors will produce smaller sag and hence longer spans can be used.
- (ii) Due to smaller sag with steel cored aluminium conductors, towers of smaller heights can be used.

**4. Galvanised steel.** Steel has very high tensile strength. Therefore, galvanised steel conductors can be used for extremely long spans or for short line sections exposed to abnormally high stresses due to climatic conditions. They have been found very suitable in rural areas where cheapness is the main consideration. Due to poor conductivity and high resistance of steel, such conductors are not suitable for transmitting large power over a long distance. However, they can be used to advantage for transmitting a small power over a small distance where the size of the copper conductor desirable from economic considerations would be too small and thus unsuitable for use because of poor mechanical strength.

**5. Cadmium copper.** The conductor material now being employed in certain cases is copper alloyed with cadmium. An addition of 1% or 2% cadmium to copper increases the tensile strength by about 50% and the conductivity is only reduced by 15% below that of pure copper. Therefore, cadmium copper conductor can be useful for exceptionally long spans. However, due to high cost of cadmium, such conductors will be economical only for lines of small X-section *i.e.*, where the cost of conductor material is comparatively small compared with the cost of supports.

### 8.3 Line Supports

The supporting structures for overhead line conductors are various types of poles and towers called *line supports*. In general, the line supports should have the following properties :

- (i) High mechanical strength to withstand the weight of conductors and wind loads etc.
- (ii) Light in weight without the loss of mechanical strength.
- (iii) Cheap in cost and economical to maintain.
- (iv) Longer life.
- (v) Easy accessibility of conductors for maintenance.

The line supports used for transmission and distribution of electric power are of various types including *wooden poles, steel poles, R.C.C. poles* and *lattice steel towers*. The choice of supporting structure for a particular case depends upon the line span, X-sectional area, line voltage, cost and local conditions.

**1. Wooden poles.** These are made of seasoned wood (sal or chir) and are suitable for lines of moderate X-sectional area and of relatively shorter spans, say upto 50 metres. Such supports are cheap, easily available, provide insulating properties and, therefore, are widely used for distribution purposes in rural areas as an economical proposition. The wooden poles generally tend to rot below the ground level, causing foundation failure. In order to prevent this, the portion of the pole below the ground level is impregnated with preservative compounds like *creosote oil*. Double pole structures of the 'A' or 'H' type are often used (See Fig. 8.2) to obtain a higher transverse strength than could be economically provided by means of single poles.

The main objections to wooden supports are : (i) tendency to rot below the ground level (ii) comparatively smaller life (20-25 years) (iii) cannot be used for voltages higher than 20 kV (iv) less mechanical strength and (v) require periodical inspection.



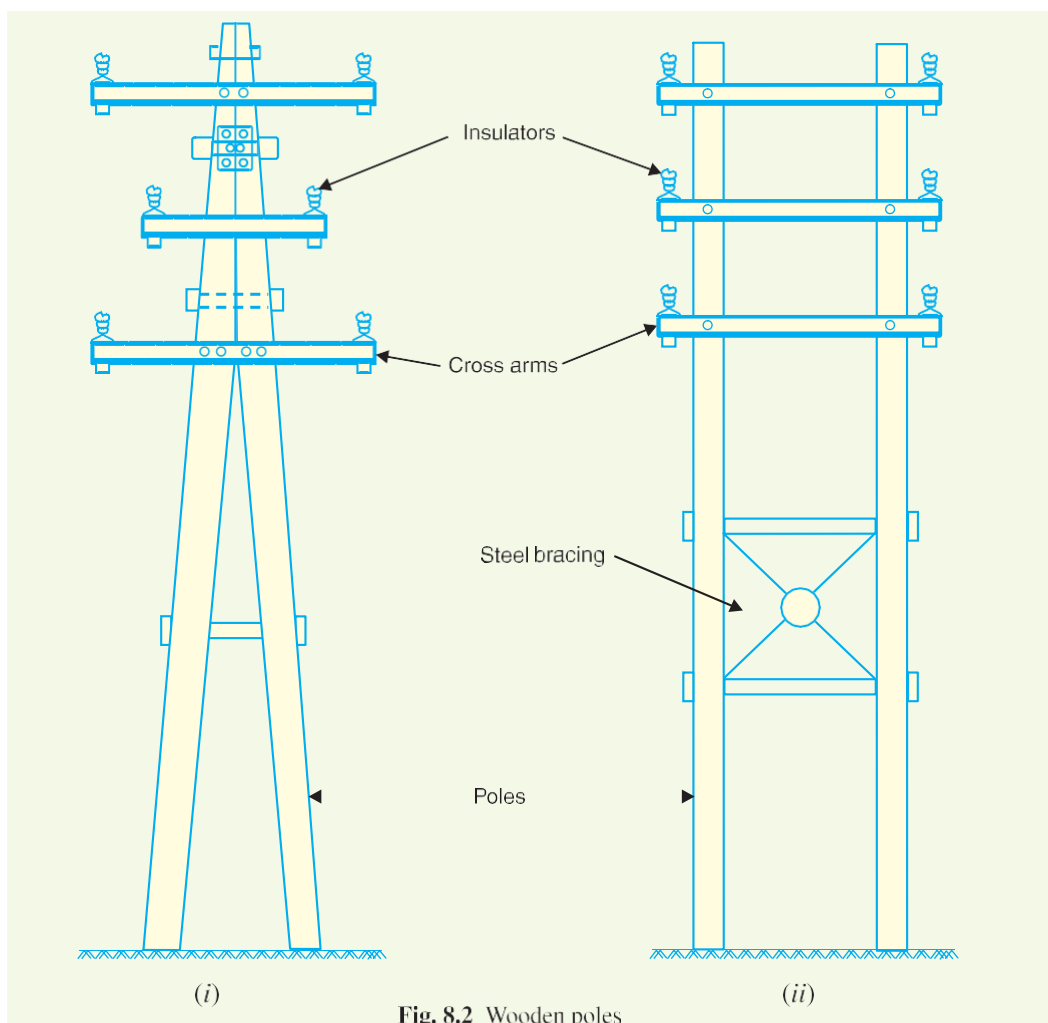


Fig. 8.2 Wooden poles

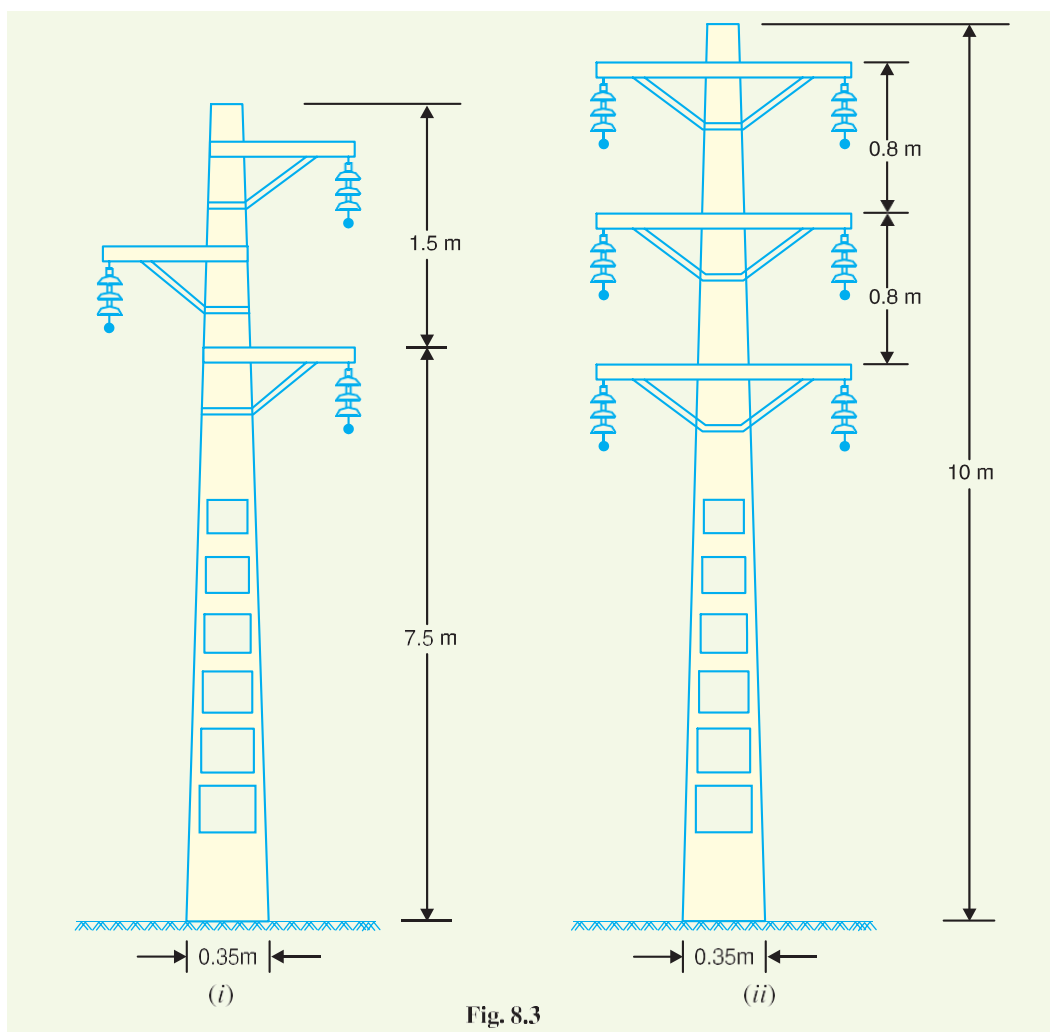
**2. Steel poles.** The steel poles are often used as a substitute for wooden poles. They possess greater mechanical strength, longer life and permit longer spans to be used. Such poles are generally used for distribution purposes in the cities. This type of supports need to be galvanised or painted in order to prolong its life. The steel poles are of three types *viz.*, (i) rail poles (ii) tubular poles and (iii) rolled steel joints.

**3. RCC poles.** The reinforced concrete poles have become very popular as line supports in recent years. They have greater mechanical strength, longer life and permit longer spans than steel poles. Moreover, they give good outlook, require little maintenance and have good insulating properties. Fig. 8.3 shows R.C.C. poles for single and double circuit. The holes in the poles facilitate the climbing of poles and at the same time reduce the weight of line supports.

The main difficulty with the use of these poles is the high cost of transport owing to their heavy weight. Therefore, such poles are often manufactured at the site in order to avoid heavy cost of transportation.

**4. Steel towers.** In practice, wooden, steel and reinforced concrete poles are used for distribution purposes at low voltages, say upto 11 kV. However, for long distance transmission at higher voltage, steel towers are invariably employed. Steel towers have greater mechanical strength, longer





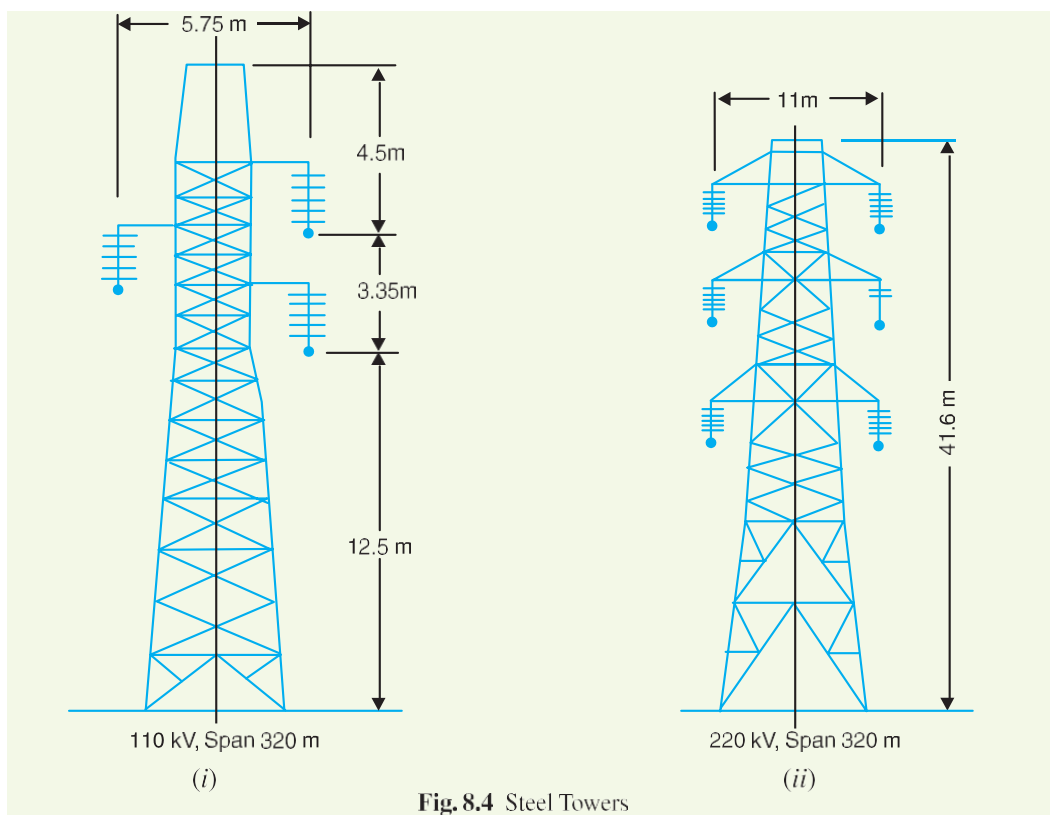
life, can withstand most severe climatic conditions and permit the use of longer spans. The risk of interrupted service due to broken or punctured insulation is considerably reduced owing to longer spans. Tower footings are usually grounded by driving rods into the earth. This minimises the lightning troubles as each tower acts as a lightning conductor.

Fig. 8.4 (i) shows a single circuit tower. However, at a moderate additional cost, double circuit tower can be provided as shown in Fig. 8.4 (ii). The double circuit has the advantage that it ensures continuity of supply. In case there is breakdown of one circuit, the continuity of supply can be maintained by the other circuit.

#### 8.4 Insulators

The overhead line conductors should be supported on the poles or towers in such a way that currents from conductors do not flow to earth through supports *i.e.*, line conductors must be properly insulated from supports. This is achieved by securing line conductors to supports with the help of *insulators*. The insulators provide necessary insulation between line conductors and supports and thus prevent any leakage current from conductors to earth. In general, the insulators should have the following desirable properties :





- (i) High mechanical strength in order to withstand conductor load, wind load etc.
- (ii) High electrical resistance of insulator material in order to avoid leakage currents to earth.
- (iii) High relative permittivity of insulator material in order that dielectric strength is high.
- (iv) The insulator material should be non-porous, free from impurities and cracks otherwise the permittivity will be lowered.
- (v) High ratio of puncture strength to flashover.

The most commonly used material for insulators of overhead line is *porcelain* but glass, steatite and special composition materials are also used to a limited extent. Porcelain is produced by firing at a high temperature a mixture of kaolin, feldspar and quartz. It is stronger mechanically than glass, gives less trouble from leakage and is less effected by changes of temperature.

### 8.5 Types of Insulators

The successful operation of an overhead line depends to a considerable extent upon the proper selection of insulators. There are several types of insulators but the most commonly used are pin type, suspension type, strain insulator and shackle insulator.

**1. Pin type insulators.** The part section of a pin type insulator is shown in Fig. 8.5 (i). As the name suggests, the pin type insulator is secured to the cross-arm on the

