# ECONOMIC ANALYSIS OF 400 KV TRANSMISSION TOWERS WITH CROSS ARMS INSULATORS

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## ABSTRACT

For economic and technical reasons, future power transmission line will have to be built with new design concepts using new materials, reduction of construction costs and optimizing power delivery with restricted right of way. Pin type insulators made of glass and porcelain and Long Rod insulators made of silicon and composite materials are widely used in high voltage transmission line towers. The uses of composite cross arms insulators have become widespread due to the increase in the use of composite materials depending on technological developments. This paper discusses experimental studies carried out on new type of insulators made from composite and Fiber Reinforced Polymer (FRP) materials, and also this paper describes the duty of insulators, the different types of insulators, their design characteristics and their application. Economic analyzes were carried out for different types of insulators, taking into consideration the span between towers, interest rate, easement area and unit price $\$/m^2$.

**Keywords:** Composite towers, Composite insulators, FRP materials.

## INTRODUCTION

An overhead line may be used to transmit or distribute electrical energy. The transmission of electrical energy is carried out over long distances, whereas distribution is carried out over short distances. While transmission and distribution distances increased, the system voltage increases respectively. As a result, the pin-type insulators were increased in size to provide longer leakage paths to earth, also conductor sizes were increased to allow higher current carrying capacities. The successful operation of an overhead line depends to a great extent upon the mechanical design of the line. To design of the overhead line need to consider the main components of an overhead line. The important components are line supports, conductors, insulators, cross arms, miscellaneous items. [1], [2]

Line supports are various types of poles and towers and keep the conductors at an appropriate level above the earth. The supports used for transmission and distribution of electrical energy are made of different types of wooden poles, steel poles, reinforced concrete cement (R.C.C.) poles and lattice steel towers. The choice of supporting structure depends upon the line voltage, the line span, the cost and local conditions. Conductors carry electrical energy from the sending to the receiving end station. The conductor is one of the main items. In generally as conductor materials for overhead lines used are copper, aluminum, steel-cored aluminum, galvanized steel and cadmium copper. The choice of a material depends upon the required electrical and mechanical properties, the cost and local conditions. Cross arms provide support to the insulators. [3]

To ensure the electric power transmission to urban areas, it is necessary to technically develop compact transmission line structures to minimize the Right of Way (ROW). In addition, there is a concern with worldwide for deterioration and corrosion of steel power transmission line structures. Further deterioration and corrosion may be prevented by using pultruded Fiber Reinforced Polymer (FRP) composite materials for overhead power line structures. The advantages FRP composites over traditional materials motivate their use in load bearing structures. Pultruded profiles are often the structural members of choice where significant corrosion and chemical resistance is required. [4]

In reference [5] have been studied different types of insulators, as well as lightning and pollution performance of the most used glass insulator. The precise gap factors have been determined theoretically and practically in full scale. Tools for the determination of the exact air clearances have been taken into use. A tool for determination of the total line performance with accurate gap factors and insulator performance has been developed.

In this study, easement areas were calculated for different types of insulators. Economic analyzes were carried out for the cases where the span between towers is 300 and 500 m, the easement area unit price is 1$ and 3$, and the annual interest rate is 5% considering the calculated easement area and insulator prices. As a result of the study, it is seen that the use of composite cross arms insulators are more economical due to the increase of span between towers.

## INSULATORS

The transmission and distribution line cannot be suspended from a supports directly. Not every piece of insulating material, which is mechanically strong enough to carry the lines. Imagine that we would use a cylindrical piece of insulating material to isolate the line from the tower; falling raindrops would immediately cause a short circuit, as the water film creates a conducting path between the tower and the line. Consequently, insulators are designed such that the leakage path is much longer. [3]

The conductors should be supported on the line towers in such a way that currents from conductors do not flow to earth through towers. The conductors must be correctly insulated from towers. The insulators provide need insulation between the conductors and towers and they should have the following desirable properties:
- High mechanical strength in order to withstand conductor load, wind load, ice load etc.
- High electrical resistance of insulator material in order to avoid leakage currents to earth.
- High relative permittivity of insulator material in order that dielectric strength is high.
- High ratio of puncture strength to flashover.
- The insulator material should be non-porous, free from impurities and cracks otherwise the permittivity will be lowered. [1]

Insulator design varies according to tower function. For suspension towers (line of conductors is straight), the insulator assembly is called a suspension string. For angle towers (the conductors change direction), the insulator assembly is called a strain string. For 500-kV lines, the insulator strings are built up from individual porcelain disks typically 5.75 inches thick and 10 inches in diameter. The full string is composed of 18 to 28 discs, providing a long path for stray currents to negotiate to reach ground. At this voltage, two to four insulator strings are commonly used at each conductor connection point, often in a V pattern to limit lateral sway. [6]

For distribution voltages up to 40 kV is a used 'pin-type' insulator. To the highest transmission system voltages is a used 'cap and pin' insulator. In Germany and parts of the world influenced by German design practice, the 'long rod' insulator is used. Nowadays, other designs of insulator have been developed, notably rigid insulators utilizing a central load-bearing core formed from glass fibre bonded to form a rod, and having plastic sheds. New type is often named as 'composite' insulator.

## Insulator Materials

There are basic materials such as glass, porcelain and polymeric composite. Porcelain material has high impact and self-cleaning support, good service history, good compressive strengh. Porcelain is produced by firing at a high temperature a mixture of kaolin, feldspar and quartz. Glass material has obvious failure may be spotted with glass shattering, good service history. Porcelain is stronger mechanically than glass, gives less trouble from leakage and is less effected by changes of temperature. Polymeric material has advantage for special applications, some composite polymer insulators have excellent pollution withstand performance and early problems now overcome with this material. [6], [7]

## Glass and Porcelain

Both glass and porcelain are used materials for insulators and have given good service history by years. There is little difference in the cost or performance between glass and porcelain. Toughened glass has the advantage, such that broken insulators more easily find during maintenance inspections. On the other hand, glass insulators are rarely used in substation practice since on shattering they leave only some 15 mm between the top metal cap and the pin. Porcelain insulators, which may be chipped or cracked but not shattered, are therefore preferred for substation use since access for replacement may require a busbar outage. [8]

## Silicon and Resin Materials

The overhead line polymeric insulators, often called 'silicone' insulators, are a development dating from the 1960s. The polymeric insulators have the advantage of reduced weight, high leakage offset and resistance to the effects of vandalism since the sheds do not shatter on impact. Epoxy resin cast insulators are used in indoor substation equipment and metal enclosed switchgear. Epoxy resins have been used to a limited extent on medium voltage current transformers installed outdoors and in particular on neutral connections. [8]

## Insulator Types

The successful operation of an overhead line depends to a considerable extent upon the proper selection of insulators. There are several types of insulators, such as pin type insulators, post insulators, cap and pin insulators, strain insulators, shackle insulators, long rod insulators, composite insulators.

## Cap and Pin Insulators

The name cap and pin insulator is given because the insulators are fitted with a bell shaped galvanized, malleable cast iron or forged steel cap and galvanized forged steel pin. The dielectric material can be of toughened glass or porcelain. Cap and pin insulators of porcelain or glass predominate as overhead line suspension or tension sets above 33 kV and they are also used for substation busbar high level strained connections. Such substation short span applications do not require high strength cap and pin units and the insulators are often specified with 80 kN minimum failing electromechanical failing test load to meet a 33 safety factor requirement. Overhead line cap and pin insulators are specified with correspondingly higher failing loads of 125 and 190 kN.

**Long Rod Insulators**

Long rod insulators are generally manufactured from high alumina porcelain and have a similarity to porcelain solid core cylindrical post insulators except that the top and bottom fittings are of the cap and pin type. Long rods are an alternative to the traditional cap and pin insulators with the possibility of providing longer leakage paths per unit length. [9]

Figure 1 Long rod insulators.

The composite insulators are based on a load bearing resin bonded glass fiber core fitted into cylindrical metal, aluminum alloy or galvanized steel end fittings. Composite insulators have been under development, notably in the USA at transmission lines and in the UK also at transmission lines but the majority of composite insulators have fitted to distribution lines. Typically, a 50 mm diameter core will have a minimum failing load of about 500 kN. To protect the core from attack by leakage currents the core is surrounded by weather sheds. It is under the research and the development effort has been concentrated at different types of polymer materials. Considerable progresses have been made by the use of silicone rubber compounds. These compounds were formed into weather sheds and they are hydrophobic. It means, the level of discharge activity under heavy rain and pollution conditions is minimized. Composite insulators are lighter in weight than the insulators made from glass or porcelain. [9]

Figure 2 Polymeric material insulators. Composite insulators

The composite insulator contains a core material, end-fitting, and a rubber insulating housing. The core is of Fiber Reinforced Polymer (FRP) to disseminate the tensile load. The reinforcing fibers used in FRP are glass and epoxy resin is used for the matrix. The portions of the end-fitting that transmit tension to the cable and towers are of forged steel, malleable

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cast iron, aluminum, etc. The rubber housing provides electrical insulation and protects the FRP from the elements. Figure 3 shows the structure of a composite insulator. [10]

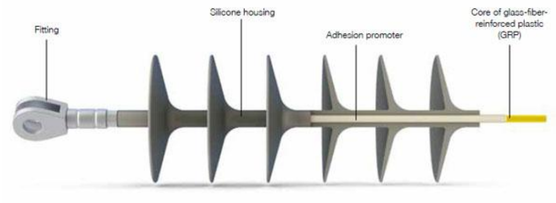


Figure 3 Structure of composite insulators

**Composite Cross-arms**

The composite cross arms have been invented to change conventional steel cross arms with porcelain insulators. This type of cross arms consists of four pultruded structural components. Each component contains of a solid core, metal end-fittings and silicone rubber housing with sheds. The core is a composite pultruded rod, it withstands mechanical loads. The reinforcing fiber used is E glass and the matrix is epoxy resin. The composite rod is made by pultrusion process. The silicone rubber housing provides electrical insulation and protects the composite rod. The sheds are provided to increase the insulator performance under wet and polluted conditions. The composite cross arm can be used for up-rating the existing transmission lines. By reason of the light weight, this type of towers can be used for earthquake prone zones as well as for Emergency Restoration System (ERS) towers. [11]

Figure 4 Composite cross arms on tower body

The composite insulators or polymeric insulators, which consist of the silicone rubber and the FRP cylinder, have more and more used for outdoor terminations by reason of their ease of handling. In reference [12], they have developed a new type of outdoor termination for a XLPE cable that further decreases weight and permits for horizontal use by using a composite insulator.

To apply the new type outdoor termination to the ultra-high voltage power lines is difficult due to the weight of cable and its termination. However, at ultra-high voltage level, the composite insulator has the great advantage of material cost than ceramic insulator. [13]

**CASE STUDY**

In power transmission line the easement area varies according to span between two towers. Figure 5 shows calculation scheme for safety clearance distance of transmission line in Turkey for 400 kV double circuit transmission line. [14], [15]

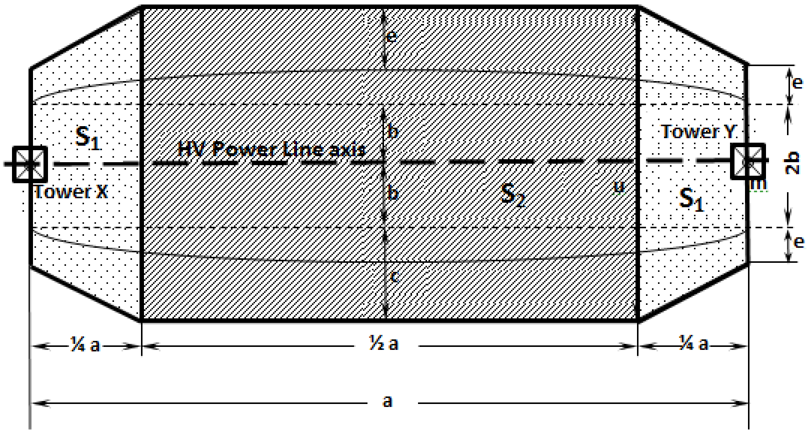


Figure 5 Safety clearance distance of transmission line

Where,
a = span between towers (m)
b = length of half of cross arms (m)
e = safety distance (m)
u = the total width of the right and left borders (m)
c = maximum sag and safety distance function (m)
m = expropriation area of towers by the administration ($m^2$)
S= Total easement area ($m^2$)

Power transmission line is divided into different zones according to the ice load and there are Zones II, III, IV according to the Turkey's ice load Map. The maximum sag function 'c' varies depending on 'a' span between towers and zones. The maximum sag function 'c' changes in II, III, IV zones for 3B 954 MCM conductors and it has showed in equation 1:

$$\begin{aligned} &\text{Zone II} \rightarrow c = 5.00 + 3.482\cdot 10^{-5}\cdot a^2 \\ &\text{Zone III} \rightarrow c = 5.00 + 4.061\cdot 10^{-5}\cdot a^2 \\ &\text{Zone IV} \rightarrow c = 5.00 + 5.225\cdot 10^{-5}\cdot a^2 \end{aligned} \quad (1)$$

Where 'a' and 'c' are in meters.

The formulas to calculate the total easement area have showed in equation (2):

$$\begin{aligned} &u=2(b+c) \\ &S_1=\frac{u+2(b+e)}{2}\cdot\frac{1}{4}a-\frac{m}{2} \\ &S_2=\frac{1}{2}a\cdot u \\ &S=2S_1+S_2 \end{aligned} \quad (2)$$

There is no change in the easement area when a pin type insulator or a long rod insulator is used. There will be change in the easement area when a new type composite cross arms insulator is used. Total easement area is given in Table 1, which calculated with Equation 1 and 2 when span between towers was 300 m and 500 m.

Table 1 Total easement area ($m^2$)

| Type of insulators | 300 m | | | 500 m | | |
|---|---|---|---|---|---|---|
| | Zone II | Zone III | Zone IV | Zone II | Zone III | Zone IV |
| Pin type / Long rod insulator | 10214.21 | 10448.71 | 10920.13 | 21332.75 | 22418.38 | 24600.88 |
| Composite cross arms insulator | 7454.21 | 7688.705 | 8160.125 | 16732.75 | 17818.38 | 20000.88 |

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In case of using for 380 kV transmission line in towers pin type insulator then cost for one phase is cross arms + insulator = 1618 $. In case of using silicon insulator (long rod) cost is cross arms + insulator = 950 $. In case of using new type composite cross arms insulator cost is cross arms + insulator = 1700 $.

Economic analysis methods were used for different insulator types and different span between towers by using the "annual value method" equation. In this paper was carried out two cases:

Case I: New type composite cross arms insulators are used instead of pin type insulators.
Case II: New type composite cross arms insulators are used instead of long rod insulators.
The annual interest rate is assumed to be 5% and the economic life of the insulator is assumed to be 30 years, and the annual uniform income is given in Table 2 and Table 3 for cases where the unit cost of the fair easement area is 1$ and 3$, respectively. [14], [15]

Table 2 The fair easement area is 1 $

| | 300 m | 500 m |
|---|---|---|
| Case I | 102.8 | 222.5 |
| Case II | -419.2 | -299.5 |

Table 3 The fair easement area is 3 $

| | 300 m | 500 m |
|---|---|---|
| Case I | 436.4 | 795.4 |
| Case II | -85.6 | 273.5 |

As you can see in table 1, in case the unit price per square meter is 1$, using composite cross arms insulators instead of pin type insulators, save 102.8$ per 300 meters of span between towers and 222.5$ per 500 meters for 30 years of economic life every year. In case of unit price per square meter is 3$, the annual income is obtained by using composite cross arms insulators instead of both pin type insulators and long rod insulators for 500 meters of span between towers.

Use of composite materials for power line and its components is decreasing the ROW and costs. ROW is reduced by using composite cross arms insulator instead of pin type and long rod insulator in 400 kV energy transmission line towers. In addition, insulator life is extended by using composite material instead of glass and porcelain material. Insulator costs are reduced by using composite cross arms insulator instead of glass and porcelain pin type insulators. The use of composite cross arms insulators instead of long rod insulators is more economical and saves money as the span between towers increases.

## CONCLUSIONS

In recent times, public opposition to the construction of new power lines has increased due to awareness of environmental implications which is limiting the space for transmission lines. In addition, conventional metallic tower with heavy ceramic insulators tend to corrode fast and become damaged. New types of support structures for a transmission line are to be developed to reduce the dimension of the line, in both horizontal and vertical directions. Thus technology of compact transmission lines is being increasingly adopted by the power industry to effectively make use of the ROW. The result of the study encourages the possibility of using composite cross arms either with steel tower body or FRP (Fiber Reinforced Polymer) composite tower body to reduce the horizontal phase distance to build compact transmission lines.

Use of composite materials for power transmission line and its components is increased due to their light weight, durability and long life. Composite material is also widely used in high voltage insulators. In this study, economical analyzes were carried out for pin type, long rod and composite cross arms insulators used in high voltage power transmission line.

As a result of this study, it is clearly seen that ROW decreases in 400 kV power transmission line towers using composite cross arms insulators instead of pin type and long rod insulators. Also, insulator costs are reduced by using composite cross arms insulator instead of glass and porcelain pin type insulators. In addition, as the span between towers increases, the use of composite cross arms insulators instead of long rod insulators is more economical and saves during the time they are used.

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