NEAR EAST UNIVERSITY

NEAR EAST UNIVERSITY

FACULTY OF ENGINEERING
ELECTRIC & ELECTRONIC

ENERGY TRANSMISSION SYSTEMS

PROBLEMS AND THEIR SOLUTIONS IN ENERGY TRANSMISSIONS LINES

Prof. Dr. Haldun GÜRMAN

SEMİH KONUŞ (91129)

CONTENTS

SUMMARY

I told energy transmission lines and the problems on this lines and solutions of these problems.

In first section, I gave informations about transmission lines and types of power transmission lines. Then I told transmission-line reactance and capacitance for single and three phase lines. I told their calculations and told lines having considerable capacitance. I told solutions by complex quantities for these lines. Finally I told lines with distributed capacitance.

In second section, I told how we can construct an energy transmission line. Then, I told components of energy lines and construction of a line. Finally I told fundemental objectives of an energy transmission line.

In last section, I give informations about the problems and their solutions in energy transmission lines. Firstly I told corona effect, how it occur and how we can prevent from this effect. Then I told galloping lines. I told how a lightning occur and what its effects are. Then I gave informations about lightning arresters. Then I told the necessarity of grounding a tower. Finally I told effects of pollution to transmission lines.

1. ENERGY TRANSMISSION SYSTEMS

To transmit power economically over considerable distances, it is necessary that the voltage be high. High voltages are readily obtainable with alternating current. As high as 20,000 Volts may be generated directly. For voltages in excess of this it is desirable to use transformers, as it is difficult to insulate the generators for these higher voltages. The transmission voltage is usually too high for commercial uses, but for purposes of distribution it may be stepped down to the desired value by the use of transformers.

In the past it has been possible to raise and lower direct-current voltages for commercial power only by machines having rotating commutators. The efficiency of such apparatus is not high, and operating difficulties are encountered in connection with the commutators, even at comparatively low voltages. Thermionic tubes, the ignition of which is controlled by grids or other means, have been developed more or less experimentally to the point whereit is possible to transmit power with direct current at high voltage. However up to the the present time alternating current is nearly always used for transmission purposes. Where considerable power is involved, polyphase systems are used because of the many advantages of polyphase over single-phase systems. For example, polyphase motors are considerably cheaper and lighter than single-phase motors of equal rating and, as a rule, have better operating characteristics. The ratings of generators and converters when operating polyphase is much greater than when operating single-phase.

Of the polyphase systems, the 3-phase system is generally used for transmission, although the employment of 2-phase for distributionpurposes is not uncommon. The 3- phase systems has the advantage that it requires the least number of conductors of the polyphase systems; the voltage unbalancing even with unbalanced loads is not usually serious; and for a given voltage between conductors, with a given power transmitted a given distance with a given line loss, the 3-phase system requires only 75 percent as much copper as either the single-phase or the 2-phase system.

The single-phase system is used in railroad electrification, where single-phase power is supplied at the trolley. The most notable examples are the New York and Pennsylvania Railroad.

When the voltage is so high as to make transformers necessary, the power is usually generated at 6,600 or 13,200 volts. These voltages are not so high as to make difficult the proper insulation of the generators, while at the same time the armature conductors, the bus bars, and the leads running from the generator to the bus bars do not become too large.

The transmission voltage is determined largely by economic considerations. Although a high voltage reduces the conductor cross section, the saving in copper or aluminum may be offset by the increased cost of insulating the line, by the increased size of transmission-line structures , and by the increased size of generating stations and substations, due to the large clearances required by the high-voltage leads and bus bars. A rough basis for determining the transmission voltage is to use 1,000 volts per mile of line.

Because of the danger involved, it is not usually permissible to carry high-voltage transmission lines through thickly populated districts order to reach the distributing substations. The voltage is usually stepped down to about 13,200 or 26,400 volts at substations located at the outskirts of the city and is then carried into the city underground, or occasionally overhead, at 13200 or 26400 volts.

Figure 1 shows a typical system . no attempt is made to show switches, circuit breakers, etc. Power is generated at 13,200 volts and is delivered directly to the 13,200 volt bus bars. Then it is stepped up to 132,000 volts, the transmission voltage, by delta-Y transformer banks whose secondaries are connected to the 132,000 volt bus bars. The power then passes out over the duplicate transmission lines to a substation locatedin the outskirts of the district where the power is to be utilized. It is then stepped down to 26000 volts by Y-delta transformer banks and delivered to the 26,400 volt bus bars at this substation. The power then leaves the 26,400 volt bus bars for the various distributing substations in the district. One distributing substation is shown. Here the voltage is stepped down to a 3-phase 4-wire system. In this system there is 4,000 volts between conductors, or 2,310 volts to neutral, for distribution to the consumers.

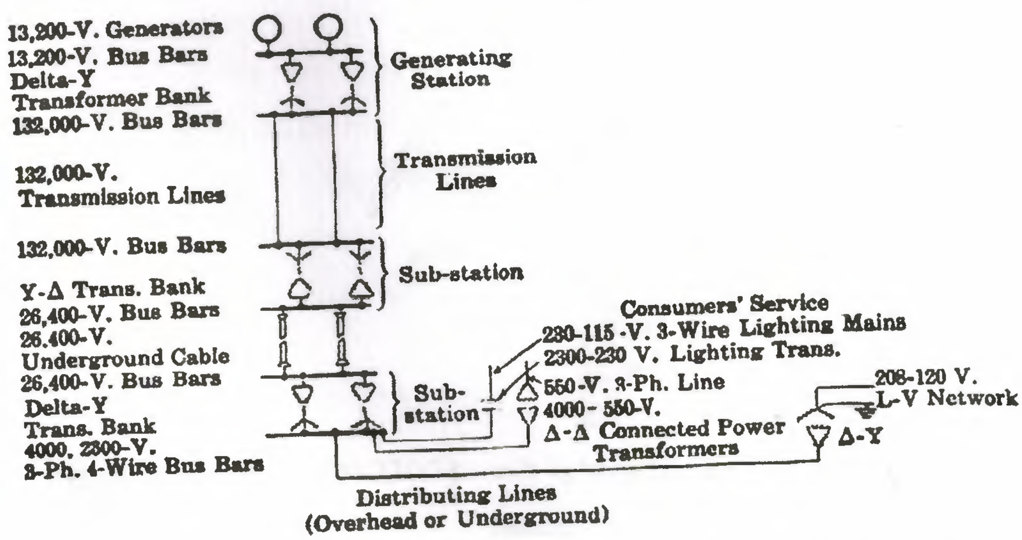


Figure 1 : Typical connections of power sytems

Usually, the lighting and the power loads are connected to seperate feeders, in order to avoid the annoying flickering of the lamps when motors are connected to or disconnected from the line. The lighting loads are usually supplied by 10/1 transformers, located on poles from whose secondaries 230-115 volt 3-wire systems are obtained (Fig.2). The two wires coming from the top crossarm to the crossarm next beneath and going through the fuse cutouts to the transformer are the 2,300 volt lines. In a 4-wire 3-phase 4,000 volt system, the primary of this transformer would be connected between one-line conductor and neutral. The 230-115 volt secondary wires leave the front side of the transformer and feed three vertically arranged conductors of the 3-wire secondary mains, which supply the local lighting loads. The powerconsumers are usually connected to the secondaries of V-connected or delta-connected transformers or are connected to the secondaries of 3-phase transformers located at the consumer's premises. In order that the secondary mains may not be too large, 440 and 550 volts are generally used for the power loads. Aline also runs from the substation to a delta-Y step-down transformer, which supplies a 208-120 volt network.

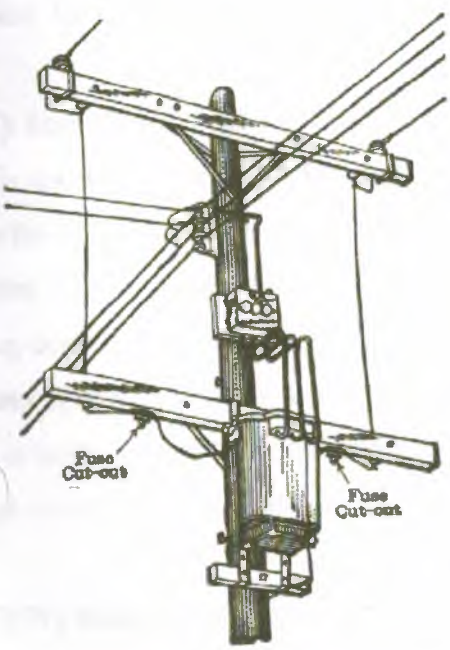


Figure 2 : Typical 2,300-230/115-volt lighting transformer and secondary three-wire mains.

In the substation other power –transforming apparatus may be installed, such as constant-current transformers, motor-generator sets, synchronous converters, or mercury-arc rectifiers for obtaining direct-current.

1.1 Types of Power Lines

The design of a power line dependsupon the following:

1) The amount of active power it has to transmit.
2) The distance over which the power must be carried
3) The cost of the power line.
4) Esthetic considerations, urban congestion, ease o finstallation, and excepted load growth

As mentioned previously, we distinguish four types power lines, according to their voltage class:

1. Low-voltage(LV) lines provide power to buildings, factories, and houses to drive motors, electric stoves, lanps, heaters, and air conditioners. The lines are insulated conductors, usually made of aluminum, often extending from a local pole-mounted distribution transformer to the service entrance of the consumer. The lines may be overhead or underground, and the transformer behaves like a miniature substation.

In some metropolitian areas, the distribution system feeding the factories, homes, and commercial buildings consists of a grid of underground cables operating at 600 V or less. Such a network provides dependable service, because even the outage of one or several cables will not interrupt costumer service.

2. Medium-voltage (MV) lines tie the load centers to one of the many substations of the utility company. The voltage is usually between 2.4 kV and 69 kV. Such medium-voltage radial distribution systems are preferred in the large cities. In radial systems the transmission lines spread out like fingers from one or more substations to feed power to various load centers, such as high-rise buildings, shopping centers, and colleges.

3. High-voltage (HV) lines connect the main substations to the generating stations.the lines are composed of aerial wire or underground cable operating at voltages below 230 kV,. In this category we also find lines that transmit energy between two power systems, to increase the stability of the network.

4. Extra-high-voltage (EHV) lines are used when generating stations are very far from the load centers. We put these lines in a seperste class becaues of their special electrical properties. Such lines operate at voltages up to 800 kV and may be as long as 1000 km.

1.2 Transmission–line Reactance, Single-phase

In making line calculations for the transmission o fdirect-current power, the resistance alone needs to be considered. In making similar calculations for alternating- current lines, it is necessary to take into consideration not only the line resistance but the line reactance as well. In cables and in overhead lines operating at high voltage, it is also necessary to consider the capacitance between conductors.

Figure 4 shows the cross section of a two-conductor single-phase line. As the current at any instant flows in oposite directions in the two conductors, the direction of the magnetic field set up about one conductor must always be opposite to that for the other conductor. That is, when one magnetic field has a clockwise direction. This causes the two fields to act in conjuction in the area between two conductors(Fig.3). Thus, two parallel wires form a rectangular loop of one turn through which flux is produced by the current in the two wires. This flux links the loop and the circuit, therefore, has inductance. It might appear that this inductance would be negligible; for the loop has only one turn, and the flux path is entirely in air. It must be remembered, however, that the cross-sectional area of the flux path is large, usuallly being from 1 to 20 ft wide and several miles long. Although the flux density is small, the total flux linking the loop is usually considerable.

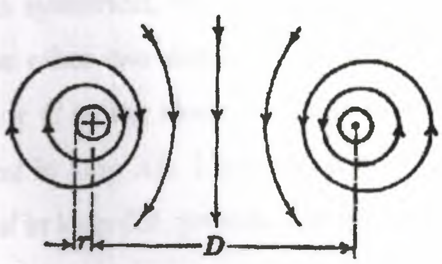


Figure 3 : Magnetic field between the two conductors of single-phase line

It can be shown that the inductance of such loop is

$$L = 2l\,(\,0.080 + 0.741\,\log(D/r)\,)\;10^{-3}\ \text{Henrys} \qquad (1)$$

where D is the distance between conductor centers and r the radius of each conductor, both expressed in the same units, l is the length of the line in miles. The reactance of the loop is

$$X = 2\pi fL \qquad \text{ohms} \qquad (2)$$

where f is the frequency in cycles per second.

It is usually more convinient to consider the inductance of a single conductor only. The inductance per single conductor is one-half the value given in Eq.1, which applies to the two conductors of the circuit.

The reactance per mile is

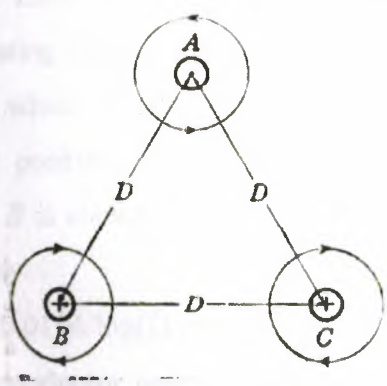
$$X = 2\pi f\,(\,80 + 741\,\log(D/r)\,)\;10^{-6}\ \text{ohms per mile} \qquad (3)$$

The reactance for stranded conductors is slightly less than the corresponding values given for solid conductors. The reactance at other frequencies may be found by direct proportion.

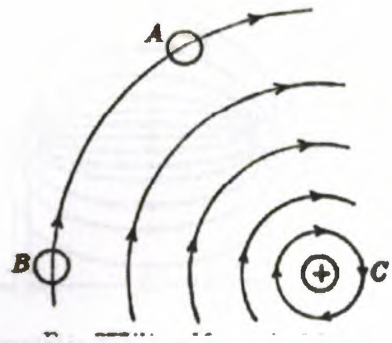
1.3 Transmission-line Reactance, Three-phase

It is more convenient to consider the reactance of the individual conductor, rather than the recatance of the looped line or of the entire circuit. The convience becomes more apparent when 3-phase lines are considered. In Fig.4a are shown the three conductors *A*, *B*, *C* of a 3-phase line, symetrically spaced. That is, each conductor is at an apex of the same equilateral triangle. The current at the instant shown is flowing outward in conductor *A* and inward in conductors *B* and *C*. The field produced by each conductor is indicated. These fields are continually changing, owing to the cyclic variation of the currents in the three phases , and this causes a rotating field in the region between the conductors. This rotating field is similar to the rotating field of the polyphase induction motor; and as it cuts all three conductors, it induces emfs in them.

In treating this problem it is simpler to consider the reactance of each conductor seperately. If the spacing is symetrical, the flux produced by each conductor induces no emf in the circuit composed of the other two conductors. For example, Fig.4b shows the circular field produced by each conductor *C* acting alone. As none of its magnetic lines links the circuit *AB*, conductor *C* induces no emf in loop *AB*. Likewise, conductor *A* induces no emf in loop *BC*, and conductor *B* induces no emf in loop *CA*, provide that the conductors are symetrically spaced.



(a)



(b)

Figure 4: a) Three symetrically spaced conductors of 3-phase line.

b) Magnetic field produced by conductor C does not link loop AB.

In 3-phase case for symetrical spacing, therefore, the reactance per conductor is found by Eq.3. The distance between centers of conductors is used for D.

1.4 Transmission-line Capacitance, Single-phase

If a direct current voltage be applied to a transmission line under no-load conditions, no current flows after the first few moments, except the almost negligible leakage current. If an alternating voltage be applied to a transmission line, considerable currnet may flow , even if there be no appreciable leakage and no connected load. This current is the charging current of the line and leads the voltage by almost 90^0. The line acts as a capacitor the conductors being the elsctrodes and the air the dielectric. Each conductor becomes charged, first positively and then negatively, which results in an alternating charging current.

This is illustrated by Fig.5, which shows conductors A and B of a single-phase line. At the instant shown, conductor A is positive and conductor B is negative. The dielectric flux existing in th efield between A and B is shown. The capacitance between conductors of such a line can be shown to be approximately

$$C = 0.0194/\log(D/r) \quad \mu\text{f per mile} \qquad (4)$$

Where D is the distance between conductor centers and r the radius of each conductor, both expressed in the same units.

The simplest method of treating transmission-line problems is to work with voltages to neutral and with capacitances to neutral.

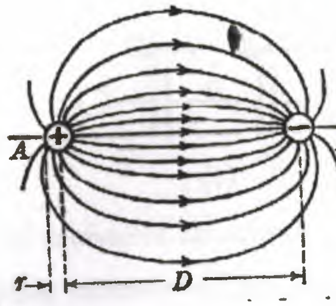
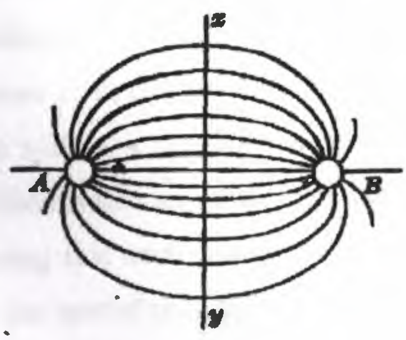


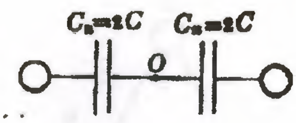
Figure 5: Electrostatic flux between line conductors.

In Fig. 6a an imaginary plane surface xy is shown midway between conductors *A* and *B* and perpendicular to the plane of the conductors. The electrostatic field between this surface and each conductor is the same. As the plane bisects every electrostatic flux line, the potential difference between conductor *A* and any point in the plane is equal to the potential difference between conductor *B* and this same point. That is, the potential of every point on the plane *xy* is midway between the potential of conductor *A* and that of conductor *B*. Hence, every point in this surface is at the same potential and *xy* is an equipotential surface. The plane *xy* may be replaced by a thin conducting plate of infinite breadth without disturbing the electrostatic field. Each conductor has the same capacitance to this plate. This capacitance must be twice the capacitance between the conductors themselves. That is , the capacitance *C* between conductors, Fig.6b , may be replaced by two equalcapacitances C_n, C_n connected in series , Fig.6c, where $C_n = 2C$. The joint capacitance of the two capacitances C_n, C_n in series is just equal to the single capacitance *C*. The point *O* is the neutral of the system, its potential being the same as that of the plate *xy*.



(a)

(b)



(c)

Figure 6 : Substitution of equivalent capacitors for transmission-line capacitance.

a) Neutral plane between two line conductors

b) Line capacitance replaced by a single capacitor

c) Line capacitance replaced by two series connected capacitors

If the capacitance to neutral is used in calculating the charging current, the voltage to neutral also must be used. With half the voltage and twice the capacitance, the charging current per conductor is the same as if the total voltage and the capacitance between conductors had been used.

The capacitance to neutral may be found by multiplying Eq.4 by 2

$$C_n = 0.0388/\log(D/r) \quad \mu f \text{ per mile to neutral} \quad (5)$$

The line charging current is

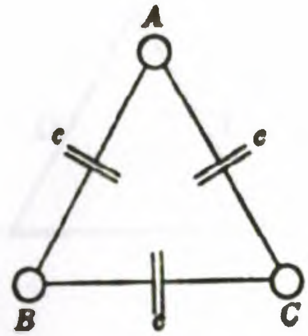
$$I_c = 2\pi f C_n E\, 10^{-6} \quad \text{amp per mile of line} \quad (6)$$

where f is the frequency in cycles per second, E the voltage to neutral, and C_n the capacitance to neutral, in microfarads per mile of line.

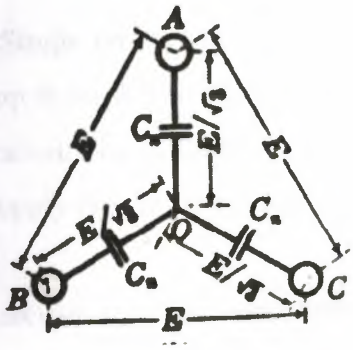
1.5 Transmission-line Capacitance, Three-phase

Fig. 7 shows the three conductors A, B, C, of a three-phase line, these conductors being symetrically spaced. There is capacitance between each pair of conductors, which can be represented by three equal capacitances c, c, c, Fig.7a, connected in delta. In determining the capacitive relations in this type of the system, it simplifies the problem to substitute an eqivalent Y-system for the delta system. It is obvious that any delta load may be replaced by an equivalent Y-load. This is the same as considering that each conductor has capacitance C_n to a fictitious neutral O, Fig.7b. In the actual line the neutral may be the ground. The voltage across each of these capacitiors C_n is $E / 3^{1/2}$, where E is the line voltage.

Eq. 5 then may be aplied to finding the capacitance to neutral C_n, D being taken as the distance between conductor centers. The voltage-to neutral $E/ 3^{1/2}$ is used for determining the charging current per conductor.



(a)



(b)

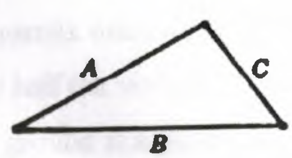
Figure 7 : Delta capacitanec of 3-phase system replaced by equivalent y-capaciyance.

1.6 Three-phase System; conductors Spaced Unsymmetrically

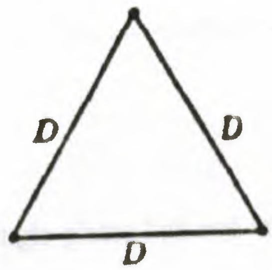
If the conductors in a 3-phase system are not symmetrically spaced,being located at the corners of a triangle whose sides may be of any length, as *A*, *B*, *C*, Fig.8a, the side *D* of the equivalent equilateral triangle, Fig.8b, may be found as follows:

$$D= (ABC)^{1/3} \qquad (7)$$

This value of *D* should be used as the distance between the conductor centers of the equivalent system in transmission-line calculations.



(a)



(b)

Figure 8 : Unsymmetrical spacing and equivalent symmetrical spacing.

1.6 Single-phase Line Calculations

In determining the voltage drop in an alternating-current line, both the resistance and the reactance must be taken into consşderation. The voltage to supply the resistance drop is in phase with the current, and the voltage to supply the resistance drop is in quadrature with the current, and leading.

In making transmission-line calculations, it is convenient to work to neutral in all cases. Fig. 9 shows a single-phase line that has a resistance per wire of R ohms and a reactance per wire of X ohms. The load takes a current I amp at a power factor cosθ, and thetotal voltage at the load or receiver is $2E_R$ The voltage to neutral at the receiver is , therefore, E_R. The total voltage at teh sending or generating end is $2E_S$.

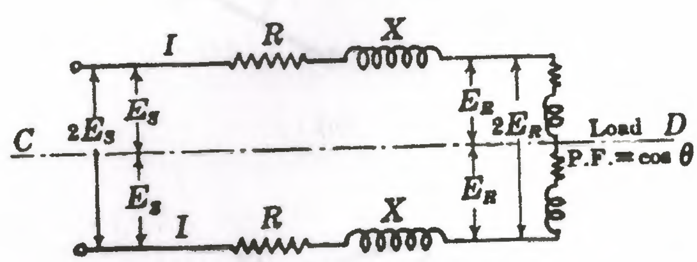


Figure 9 : Single-pahse line having resistance and reactance.

If this system be split along the line CD, two systes result, one of which is shown in Fig.10. Each of these two systems transmits one-half the total power, and the sending-end and receiving-end voltage of each system is half the voltage between conductors. The voltage at each end is now the voltage to neutral. The ground is assumed to be the return conductor. The return conductor need be merely hypothetical, however, for, under balanced conditions, Fig. 10, no current flows back through the ground, as each half of the systemacts as a return for the other half. The voltage drop through the ground, therefore, is zero. That is, Fig.10, for purposes of calculation, the ground may be considered as having zero resistance and zero reactance.

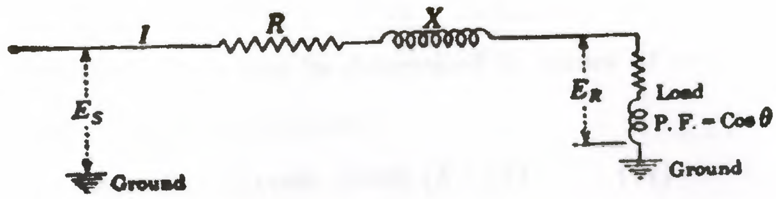


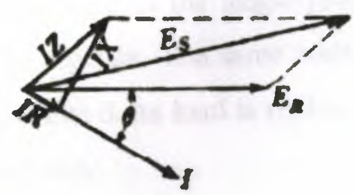
Figure 10 : Single-phase line and voltages to neutral.

Let it be required, Fig.11, to determine the sending-end voltage E_R, the current I, and power factor cosθ are given. The vector diagram is shown in Fig.11a. The component of voltage to supply the IR drop is laid off in phase with the current I; the component to supply the IX drop is laid off leading the current I by 90^0. The resultant of these two components is the component to supply the IZ drop or to supply the actual voltage drop or to supply the actual voltage drop per conductor. The voltage at the sending end E_S is the vector sum of E_R and IZ. In Fig.11b, the IR and IX components are added to E_R vectorially.

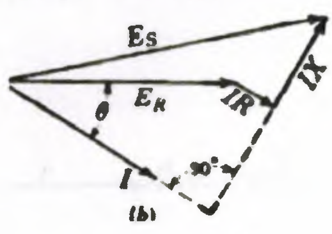
$$E_S = ((E_R \cos\theta + IR)^2 + (E_R \sin\theta + IX)^2)^{1/2} \qquad (8)$$

If the current leads E_S,

$$E_S = ((E_R \cos\theta + IR)^2 + (E_R \sin\theta - IX)^2)^{1/2} \qquad (9)$$



(a)



(b)

Figure 11 : Vector diagrams for single-phase transmission line.

Computation is frequently facilitated, particularly with reference to the decimal point, if E_R is factored and placed outside the radical.

$$E_S = E_R((\cos\theta + IR/E_R)^2 + (\sin\theta + IX/E_R)^2)^{1/2} \qquad (10)$$

These voltage relationships also may be determined by means of complex notation. E_R is taken along the axis of reals. With lagging current,

$$E_S = E_R + I(\cos\theta - j\sin\theta)(R + jX) \qquad (11)$$

With leading current,

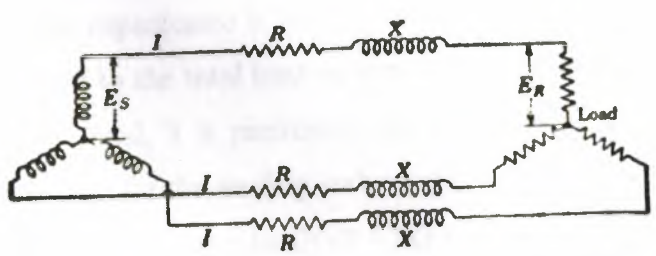
$$E_S = E_R + I(\cos\theta + j\sin\theta)(R + jX) \qquad (12)$$

1.7 Three-phase Line Calculations

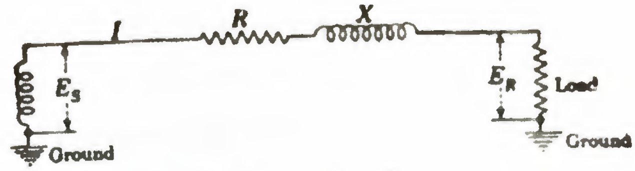
The advantage of working transmission line problems to neutral is more apparent in 3-phase lines than in single-phase lines. Fig.12a shows a 3-phase system, each conductor of which has a resistance of R ohms and a reactance of X ohms.the voltage to neutral at the load is E_R, and the voltage to neutral at the sending –end is E_S. In order to determine the line chracteristics determined. Under the condition of balanced load, which is assumed, the relations in all three phases are the same, so that the results are obtainedwith one phase may be applied to the other two. As each pair of wires is the common return of the third wire, no current returns through the ground under the balanced conditions assumed. As the voltage drop between the load neutral and the generator neutral is zero, the ground may be considered as a return conductor of zero resistance and of zero reactance, as was done in the single-phase case. The load nedd not be necessarily Y-connected, as indicated in Fig.12a. The same method is used even if the load be delta-connected and there be no neutral. The delta load is replaced by an equivalent Y-load, and the computations are made for one phase only.

1.8 Lines Having Considerable Capacitance

Heretofore, the line capacitance has been considered negligible in its effect on the regulation.



(a)



(b)

Figure 12 : Three-phase line having resistance and reactance.

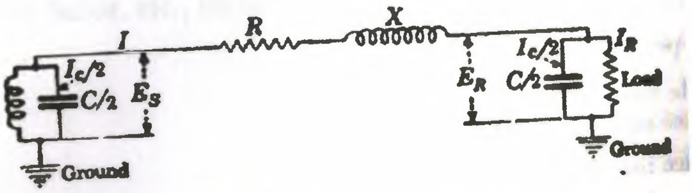


Figure 13 : Transmission line having resistance, reactance and capacitance.

In long lines of high voltage the charging current du eto the line capacitance, may have a considerable effect on the regulation. Its tendency is to cause the voltage to rise from the sending end to the receiving end. The capacitance of th eusual line is distributed uniformly along the line. The calculations are considerably simplified, however, if the total capacitance C to neutral be divided, one-half being concentrated at the sending end and one half at the receiving end in parallel with the load, Fig.13 . This assumption introduces little or no error, except in very long and very high voltage 60-cycle lines. The capacitor at the sending end has no effect on the regulation, but its charging current $I_c/2$ must be added vectorially to the line current I in order to obtain the total current supplied to the line at the sending end. The current $I_c/2$ must be taken by the capacitor at the load must be added vectorially to the load current I_R in order to obtain the total line current I.

1.9 Solution By Complex Quantities For Lines Having Considerable Capacitance

Transmission lines may be solved with complex quantities [Eq.11 and Eq.12]if the line capacitance is negligible. If the capacitance is not negligible, it is necessary to add one-half the total line-charging current $+jI_c/2$ to the total load current. Since this charging current is constant and nearly independent of the load, it is prefreable, for purposes of nalysis, to treat it as an independent current. The equation for the sending endvoltage then becomes

$$E_S = E_R + I(\cos\theta \pm j\sin\theta)\,(R + jX) + jI_c(R + jX)/2 \quad (13)$$

The minus sign is used for lagging current, and the plus sign for leading current.

The position of each vectors is shown in Fig.14 . Since $jI_c/2$ is assumed constant; triangel abc is constant; each side of triangle cde is proportional to the energy current of the load, I cosθ, and hence to the kilowatts taken by the load; each side of triangle efg is proportional to the quadrature current of the load, I sinθ, and henceto the reactive kva, or kilowars. For example, if the load power factor is unity, I sinθ is zero and triangle efg disappears. The foregoing relations make the diagram , Fig.14, very useful in analyzing the effects of varying load, power factor, etc., on such lines.

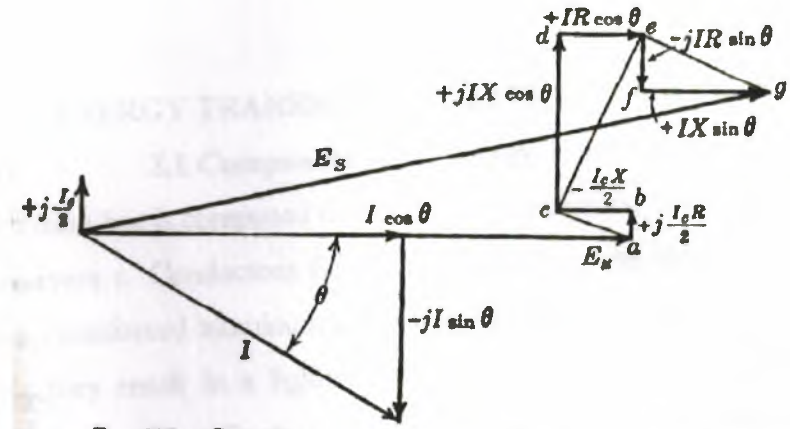


Figure 14 : Complete vector diagram for transmission line.

1.10 Lines with Distributed Capacitance

The method of splitting the total line capacitance and placing one-half at each end does not give the required accuracy with long high-voltage lines (220 kv and also the 287 kv Boulder Dam lines). In such lines it is found necessary to take into consideration ythe uniform distribution of capacitance along the entire line.

The exact equations for such lines are readily derived and are as follows:

$$E_S = E_R \cosh (ZY)^{1/2} + I_R (Z/Y)^{1/2} \sinh (Z/Y) \qquad (14)$$

$$I_S = I_R \cosh (ZY)^{1/2} + (E_R /(Z/Y)^{1/2})\sinh (Z/Y) \qquad (15)$$

where $Z = R + jX$ is the series reactance per conductor of the line and $Y = G + jB$ is the shunt admittance (capacitive) from conductor to neutral. In powe lines, the leakage G is almost always negligible, so that $Y = jB$, the shunt capacitive susceptance.

To faciliate computation, the cosh and sinh functions may be expanded into series and Eq.14 and Eq.15 become

$$\bar{E}_S = A\bar{E}_R + \bar{B}\bar{I}_R,$$

$$\bar{I}_S = A\bar{I}_R + \bar{C}\bar{E}_R$$

Where

$$A = (1 + ZY/1.2 + Z^2Y^2 / 1.2..3.4 + \dots);$$
$$B = Z(1 + ZY / 2.3 + Z^2Y^2 / 2.3.4.5 + \dots);$$
$$C = Y(1 + ZY /2.3 + Z^2Y^2 / 2.3.4.5 + \dots);$$

These values of A, B, C apply only to straightaway lines. If series or shunt impedances are inserted in the line, as ny transformers or reactors, these values must be modified.

The receiver voltages and currents may be determşned from the following equations :

$$E_R = AE_S - BI_S,$$
$$I_R = AI_S - CE_S$$

2 . ENERGY TRANSMISSION LINES CONSTRUCTION

2.1 Components of a Energy Transmission Line

A transmission line is composed of conductors, insulators, and supporting structures.

1. Conductors : Conductors for high–voltage lines are always bare. Stranded copper conductors or steel-reinforced aluminum cable (ACSR) are used. ACSR conductors are usually preferred because they result in a lighter and more economical line. Conductors have to be spliced when a line is very long. Special care must be taken so that the joints have low resistance and great mechanical strength.

2. Insulators : Insulators serve to support and anchor the conductors and to insulate them from ground.

The operating performance of a transmission line depends to a large extent on the insulators.The insulator not only must have sufficient mechanical strength to support the maximum loads of ice and the wind that reasonably may be expected but also must withstand severe mechanical abuse, lightning, and power arcs without dropping the line conductor. They also should be designed so that accumulated dirt and dustrare readily washed away by rain. Insulators are usually made of porcelain, but glass and other synthetic insulating materials are also used.

Form an electric standpoint, insulators must offer a high resistance to surface leakage currents and must be sufficiently thick to prevent breakdown under the high voltage stresses they have to withstand. To increase the leakage path (and hence the leakage resistance), the insulators are molded with wave-like folds. From a mechanical standpoint, they must be strong enough to withstand the dynamic pull and weight of the conductors.

There are two types of insulators ; pin-type insulators and suspension-type insulators..

Glass is suitable for lines of light construction, such astelephone lines, and for power lines of moderate voltage. Its advantages up to 10,000 or 15,000 volts are its cheapness and the fact that cracks and flaws are detected readily. On the other hand, it is hygroscopic and breaks readily. Only a high-quality heat-resistant glass such as Pyrex is suitable for high-voltage lines.

The pin-type insulator has several porcelain skirts (folds) and the conductor is fixed at the top. Porcelain has excellent mechanical and electrical characteristics but is more expensive than glass. Internal flaws are not detected readily, and cracks in the porcelain cause rapid deterioration of the insulator. Porcelainis the principal material used for insulators on high-voltage power lines.

Patented compounds have good mechanical characteristics and are readily molded to any desired form. However, they cannot withstand the severe mechanical stresses combined with the electrical stresses and weathering encontered in power lines. Hence they are limited to low-voltage and for indoor use. Pin-type insulators are used pratically always for such lines, since they are inexpensive, are easy to install, and act as rigid supports for the conductors.

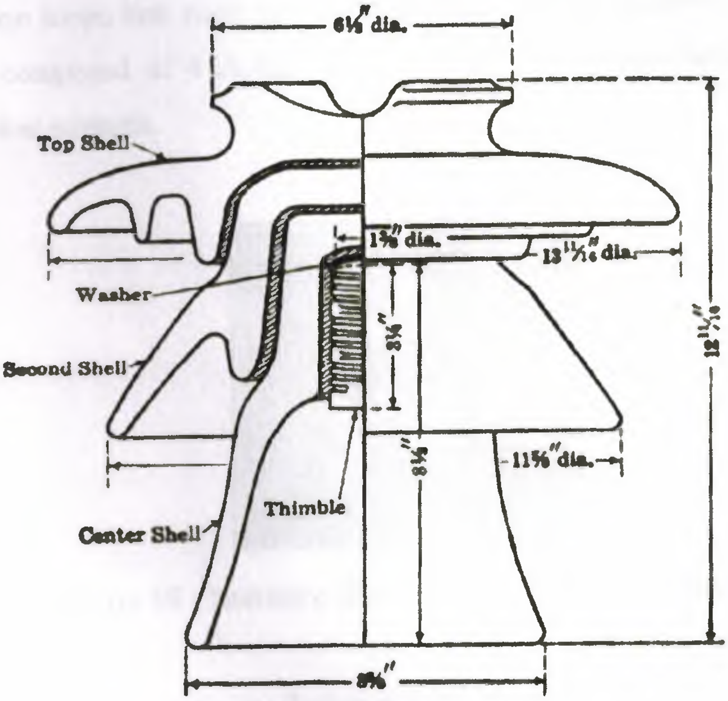


Figure 15 : High-voltage pin-type insulator.

In the larger sizes of pin-type insulator is made up in sections cemented together, Fig.15. Pin-type insulators can be usedsafely for voltages up to about 66,000 volts but for voltages near 66,000 volts and higher they are large, expensive and produce excessive torsion in the crossarms.

Suspension-type insulators; if it seemed at one time that the insulator would limit transmission voltages, as the pin-type insulator had practically reached its limit in size, weight and cost. The introduction of the suspended-type insulator, however, has raised the limit of transmission voltage sto more than four times the value possible with the pin-type insulator. With the suspension-type insulator, the conductor is suspended instead of being rigidly supported. A string of suspension insulators is made up of several units in series, the number of units depending on the voltage. A single unit can operate safely at 16,000 to 25,000 volts depending on local conditions. Under normal conditions, the insulator string act as a flexible support for the conductor and offers little or no resistance to horizontal forces. Hence the stresses in adjacent spans should be nearly balanced, or the string will be pulled out of the vertical. When a span breaks, the string is thrown temporarily into the adjacent unbroken span as a strain, or dead-end, insulator. Suspension-type insulators are used also as strain insulators at dead ends, railroad crossings, etc. Figure 15 shows a section of a link-type suspension insulator in whichthe suspension loops link each other. Figure 16 shows an insulator arrangement for a 735 kV line. I t is composed of 4 strings in parallel of 35 insulators each, to provide both mechanical andelectrical strength.

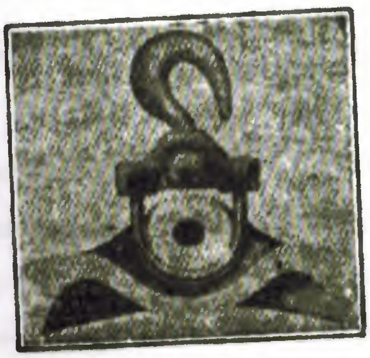


Figure 15 : Section o flink-type suspension-type insulator

It is good practice to require dry flashover of the assembled insulator unit at three to five times the operating voltage and wet flashover at twice the operating voltage. The leakage path should be approximately twice the shortest ait-gap distance.

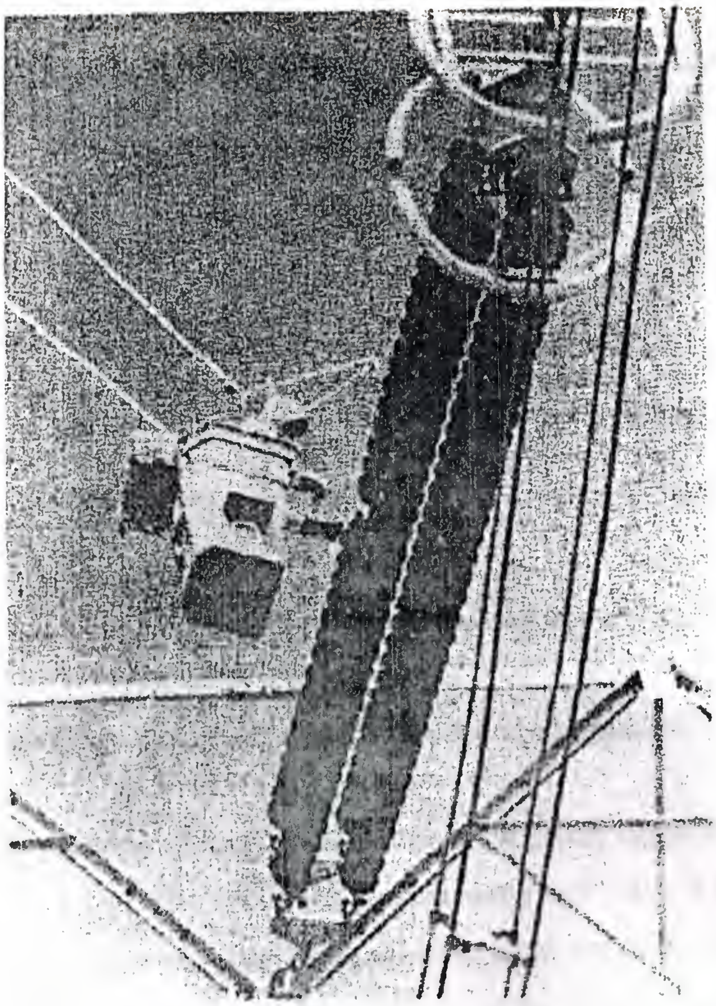


Figure 16 : 735 kV suspension-type insulator string.

3. Supporting structures : The supporting structure must keep the conductors at a safe height from the ground and at an adequate distance from each other. For voltages below 70 kV, we can use single wooden poles equipped with cross-arms, but for higher voltages, two poles are used to create an H-frame. The wood is treated with creosote or special metallicsalts to prevent it from rotting. For very high-voltage lines, we always use stell towers made of galvanized angle-iron pieces that are bolted together.

The spacing between conductors must be sufficient to prevent arc-over under gusty wind conditions. The spacing has to be increased as the distance between towers and as the line voltages become higher.

2.2 Construction Of a Line

Once we know the conductor size, the height of the poles, and the distance between the poles (span), we can direct our attention to stringing the conductors. A wire supported between two points (Fig.17) does not remain horizontal, but loops down at the middle. The vertical distance between the straight line joining the points of support and the lowest point of the conductor is called sag. The tighter the wire, the smaller the sag will be

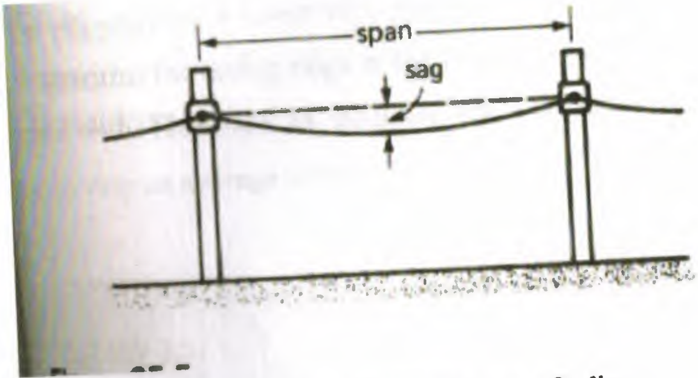


Figure 17 : Span and sag of a line.

There are three types of transmission structures are wooden poles, steel poles, and steel towers.

Wooden poles are used on the lighter lines, especially where the voltage is low. Wooden poles have the advantage of cheap, and this economical advantage is enhanced, in or near areas where suitable timber grows. They are light, easily fitted and easily erected. On the other hand, their life is less than that of steel or concrete structures. They are not strong enough for heavy lines operating at high voltage. Owing to the limited height of wooden poles, the span must be short.

Steel poles are made ordinarily of four main members supported and braced by latticework and usually are set in concrete. This type of pole is strong and, if painted occasionally, has a long life. It does not require a wide right of way and is particularly useful in mill yards and along railroad tracks, where space is limited. Except for moderate heights, however, towers are cheaper than steel poles, especially the labor costs are high.

Steel towers are a development of the windmill tower common in this country . They are composed ordinarily of four main members braced by light cross members. They are stronger an dmore rigid than either the wooden or the steel poles. As they are made of comparatively few standard members, riveted or bolted together, the labor costs are comparatively low. Owing to the spread of four main members, they are able to resist the high torsional stresses such as would result from , the breaking of the conductors on one side. Towers may be set in concrete bases. This is necessary if the ground is marshy. A less expensive method is to rivet plates, or feet, on the bottom and bury the lower supports directly in the ground. The towers are usually shipped "knocked down" and are assembledon the spot by the erecting crew.

Steel towers are the most satis factory type of the transmission-line support from the point of view of mechanical strenght, realibity, maintance, and life. They are used for practically all lines of 132 kv and higher.

In Fig.18 is shown a standard tower of a dam for 287,000 volt transmission line. Note the two overhead ground wires, the arcing rings at the tower end of the insulator strings, and the arcing rods at the upper end. Threr are 24 insulator units in each string, and the voltage to ground is 166,000 volts, giving an average voltage per unit of 6,900 volts.

Figure 17 : Standard tower and sharp-thorned on single-circuit section of a dam with 287,000 volts transmission line.

A less expensive form of transmission line structure is the flexible tower. This form of tower is based on the principle that, if the stresses in two adjacent spans are equal, the structure acts merely as a prop which supports the line but which need not resist longitudinal forces. Flexible towers, Fig.18, are merely A-frames designed to withstand the maximum transverse stress that may occur but are not intended to withstand stress in the direction of the line. When these towers are used , an anchor tower about every mile is needed, in order to take care of any unbalanced longitudinal forces, which occur when conductors break. When suspension-type insulators are used, a steel ground wire is necessary at the top of the structure to give longitudinal support to the tower. The advantage of flexible tower construction lies in the fact that the towers are usually assembled complete in the factory and are easily erected.

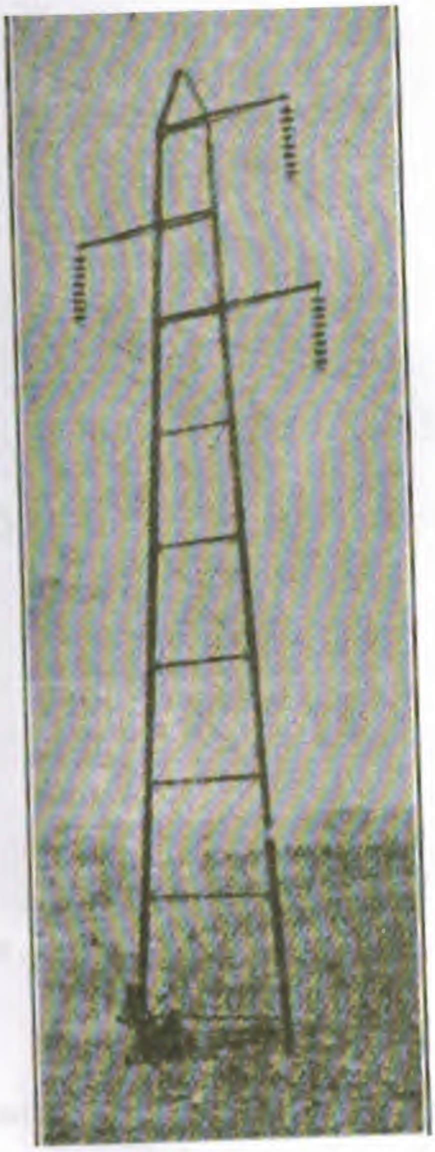


Figure 18 : 132,000 volt single-circuit A-frame flexible tower.

Before undertaking the actual construction of a line, it is important to calculate the permissible sag and the corresponding mechanical pull. Among other things, the summer to winter temperature range must be taken into account because teh length of the conductor varies with the temperature. Thus, if the line is strung in the winter, the sag must not be too great, otherwise the wire will stretch even more during the summer heat, with the result that the clearance to ground may no longer be safe. On the other hand, if the line is installed in the summer, the sag must not be too small otherwise the wire, contracting in winter, may become so dangerously tight as to snap. Wind and sleet add even more to the tractive force, which may also cause the wire to break(Fig.19).

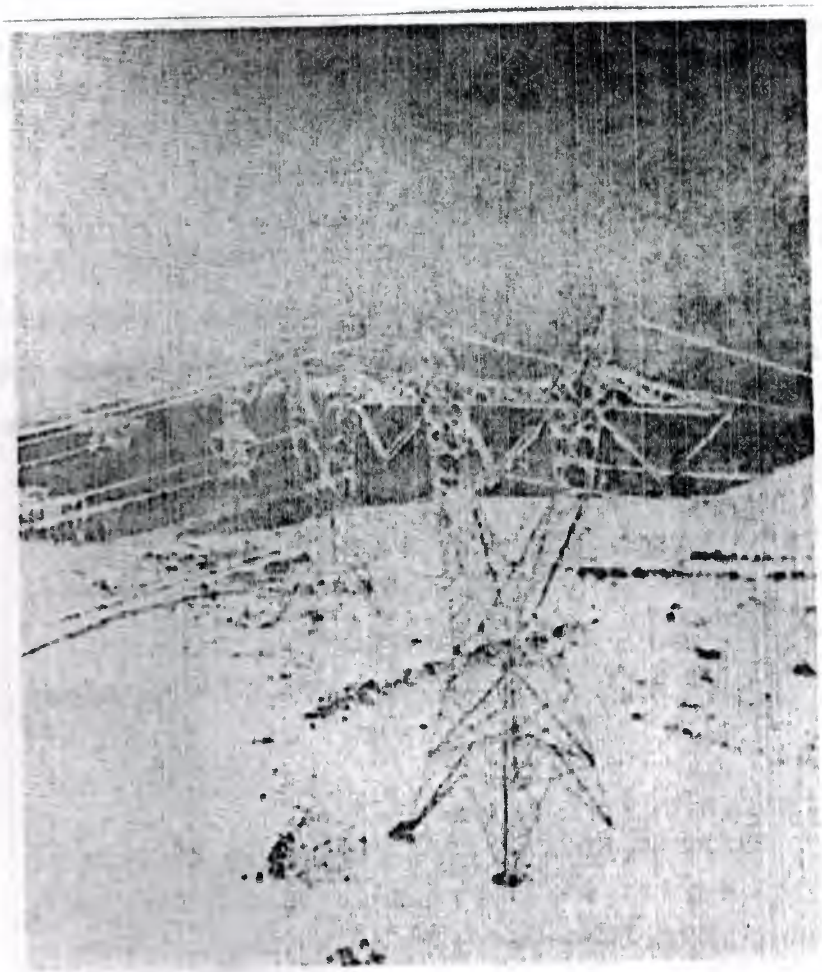


Figure 19 : During winter , steel towers must carry the combined weight of conductors and accumulated ice.

2.3 Fundamental Objectives Of a Energy Transmission Line

The fundamental purpose of a transmission line is to carry active power (kilowatts) from one point to another. If also has to carry reactive power, the latter should be kept as small as possible. In addition, a transmission line should possess the following basic characteristics:

1. The voltage should remain as constant as possible over the entire length of the line, from source to load, and for all loads between zero and rated load.
2. The line losses must be small so as to attain a high transmission efficiency.

3. The I^2R losses must not overheat the conductors

If the line alone cannot satisfy the above requirements, supplementary equipment, such as capacitors and inductors, must be added until the requirements are met.

3.PROBLEMS AND THEIR SOLUTIONS IN ENERGY TRANSMISSION LINES

The problems of a transmission line are corona effect, radio interference, lightning strokes,galloping lines, and pollution. For these problems we use transients and take some cautions to prevent these problems. Let us examine these problems in details.

3.1 Corona Effect and Its Solution

Figure 20 shows a tapered conductor whose diameter at the large end is about 1/2 in. This conductor tapers gradually to a point. It is suspended vertically in air, with its tip about 18 in. From a conducting sheet or plate, which is grounded. The secondary terminals of a high-voltage transformer are connected one to the tappered conductor and the other to the plate.

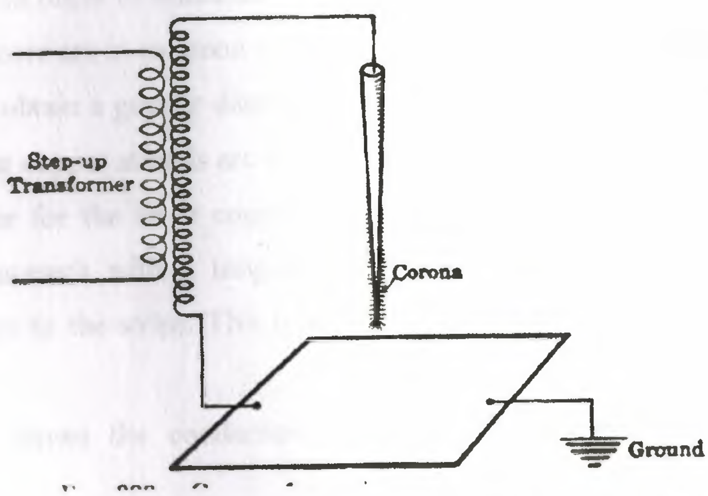


Figure 20 : Corona formation on tapered conductor.

A low voltage is first applied to the transformer, and the voltage is then graudally increased. When the secondary voltage is in the neighborhood of 3000 to 4000 volts, a bluish discharge occurs from the pointed tip of the conductor. This may be plainly seen if the room be darkened. As the voltage is increased, the bluish discharrge forms for a greater distance along the conductor and surrounds it in a ring. When the voltage reaches th eneighborhood of 100,000 volts, this bluish discharge may have formed on the rod up to apoint where the diameter of the rod is about 3/8 in. Meanwhile, the discharge from near the pointed end, nad the accompanying hissing soun, will have become quite vigorous.

This bluish discharge is called *corona.* It occurs when the electrostatic stress in the air exceeds about 75,000 volts maximum per in. 30 kv per cm. or 53,000 volts rms per in.(21 kv per cm.). At this voltage gradient, the number of electrostatic lines per unit area becomes too great for the air to withstand. This is the reason why corona first appears at the sharp point at the bottom of the rod, Fig.20, and then forms along the lower portions, where the radius of curvature is smaller, before forming along the upper portions. When air is so highly ionized that corona forms, its dielectric strength is particularly nil, nad the air may be considered as broken down or distrupted electrically and becomes a partial conductor.

Corona is is always accompanied by the production of ozone, the odor of which is detected readily. In the presence of moisture, nitrous acid forms when corona occurs. The acid and ozone may attack metals and other substances, such as insulating materials. The power loss due to corona may be reduced by increasing the diameter of the conductors and thus increasing their radius of curvature. This fact favors aluminum for transmission-line conductors, other factors being equal. In order to obtainthe requisite tensile strength, aluminum conductors having a steel cable for the core are in common use (ACSR, Aluminum cable, steel-reinforced).

In order to obtain a greater diameter with copper, the Anaconda holow conductor cable is manufactured. The copper strands are twisted about a twisted I-beam copper core, thus giving a far larger diameter for the same copper cross section. A tubular conductor made up of 10 copper-strip segmentseach with a tongues and grooves to interlock, and at the same time imparting a spiral lay to the strips. This type of conductor is used on the 287 kv Boulder Dam lines.

Figure 21 shows the conductors of ahigh-voltage line illuminated by the corona discharge.

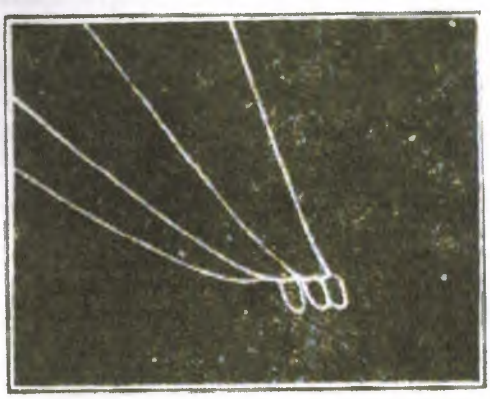


Figure 21: Illumation of transmission line by corona

Corona is accompanied by a dissipation of energy. If a transmission line be operated at a sufficiently high voltage, corona loss occurs. When a line is long, corona loss becomes serious and must be considered when the line is designed.

Corona loss begins when the voltage stress at the surface of the conductor exceeds 21.1 kv per cm at 25^{0}C and at a barometric pressure of 76 cm of the mercury.. With polished wire sthe loss starts somewhat above the effective disruptive critical voltage to neutral, e_0.

The value of e_0 is derived from the equation

$$e_0 = 21.1\, M_0 r \delta\, 2.303 \log(D/r) \quad \text{kv},$$

where M_0 takes account of the condition of the conductor surface; M_0 is 1 for polished wires, 0.93 to 0.98 for weathered wires and 0.83 to 0.87 for 7-strand cables; D is the distance between wire centers in cm; r is the radius of the conductor in cm.; δ is the air-density factor =3.92 b/ (273 + t), where b is the barometric pressure in cm of mercury and t is the temperature in degreees centigrade.

Shortly after the voltage e_0 is reached, the loss increases as the square of the voltage above e_0. The loss for e kv to neutral is given by

$$P = 241\,(f + 25)\,(r/D)^{1/2}\,(e-e_0)^2\, 10^{-5} / \delta \quad \text{kw per km of conductor,}$$

where f is the frequency in cycles per second.

Figure 22 shows the loss for a seven-strand cable with 310 cm spacing.

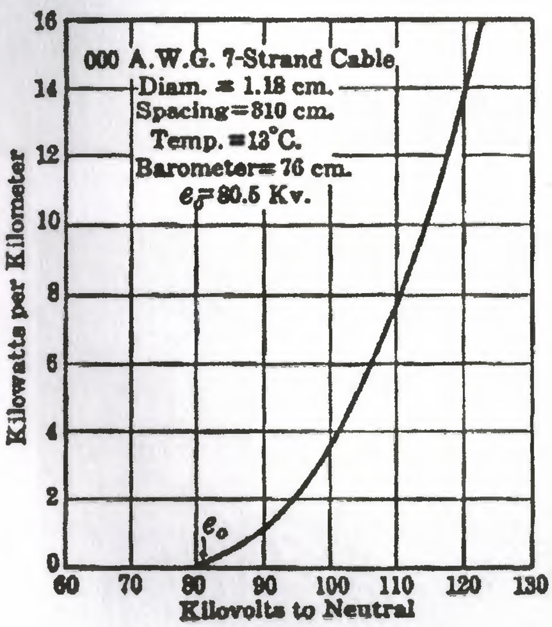


Figure 22 : Corona loss per kilometer for 7-strand cable.

In addition corona emits high frequency noise that interferes with nearby raido receivers and TV sets. To diminish corona, we must reduce the electric field (V/m) around conductors, either by increasing their diameter or by arranging them in sets of two, three, or more bundled conductors per phase (Fig.23a and 23b). This bundling arrangement also reduces the inductive reactance of the line, enabling it to carry more power. This constitutes an important additional benefit.

(a)

(b)

Figure 23 : a) Four bundled conductors make up this phase of a 3-phase,735 kv line.

b) Details of the bundled conductors.

3.2 Galloping Lines

If a coating of sleet is deposited on aline during windy conditions, the line may begin to oscillate. Under certain cinditions, the oscillations may become so large that the line is seen to actually gallop. Galloping lines can produce short-circuits between phases or snap the conductors. To eliminate the problem, the line is sometimes equipped with special mechanical weights, to dampen the oscillations or to prevent them from building up.

3.3 Lightning

During stormy weather by a process not yet fully understood, a charge seperation takes place inside clouds, so that positive charges move to the upper part of the clouds while negative charges stay below. (Fig.24). This transfer of electric charge sets up an electric field within the cloud. Furthermore, the negative charge ta the base of the cloud repels teh free electrons on the ground below. Consequently, region T becomes positively charged, by induction. It follows that an electric field and differnce of potential will be established between the base of the cloud and the earth. Furthermore, another electric field existsbetween the electrons repelled from region T and the positive charge at the top of the cloud.

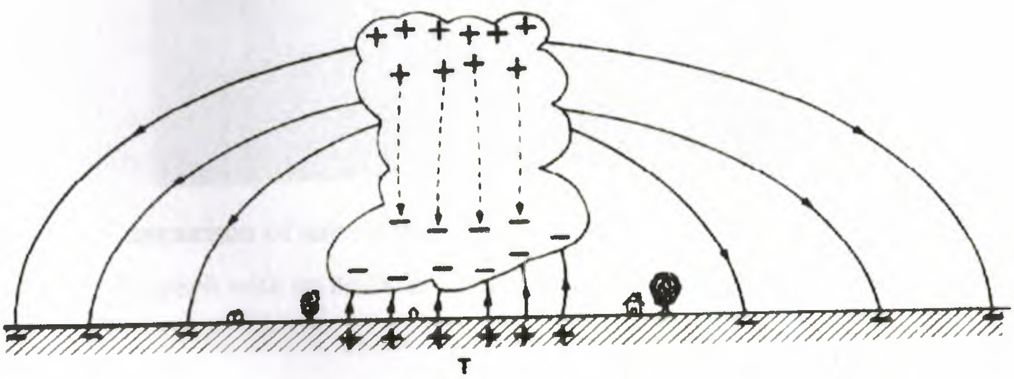


Figure 24 : Electric fields created by a thundercloud.

As more and more positive charges move upward within the cloud, the electric field below the cloud becomes more and more intense. Ultimately, it reaches the critical ionization level where air begins to break down. Ionization takes place first at the tips of church spires and the top of high trees, and may sometimes give rise to a bluish light. Mariners observed this light around the masts of their ships and called St. Elmo's fire.

When the electric field becomes sufficiently intense, lightning will suddenly strike from cloud to earth. A single stroke may involve a charge transfer of from 0.2 to 20 coulombs, under a difference of potential of several hundred million volts. The current per stroke rises to a peak in one or two microseconds and fails to half its peak value in about 50 μs. What is visually observed as a single stroke is often composed of several strokes following each other in rapid succession. The total discharge time may last as long as 200 ms.

Discharges also occur between positive nad negative charges within the cloud, rather than between the base of the cloud and ground.

The thundr we hear is produced by a supersonic pressure wave. It is created by the sudden expansion of air surrounding the intensely hot lightning stroke.

A large proportion of the interruptions to power service, particularly on high-voltage lines , is due to lightning. The mechanism and quantitive effects of became possiple to obtain oscillographic records of actual lightning strokes.(Fig.25)

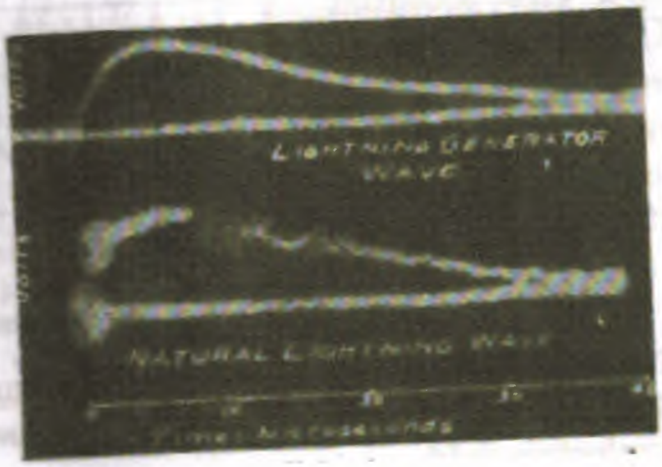


Figure 25 : Comparison of natural lightning wave measured on transmission lines with cathode-ray oscillograph with an artificial lightning wave measured in the same way.

When lightning makes a direct hit on a transmission line, it deposits a large electric charge, producing an enormous overvoltage between the line and ground. The dielectric strength of air is immediately exceeded and a flashover occurs. The line dis charges itself and overvoltage disappears in typically less than 50 μs.

Unfortunately, the arc between the line and ground(initiated by the lightning stroke), produces a highly ionized path which behaves like a conducting short-circuit. Consequently, the normal ac line voltage immediately delivers a large ac current that follows the ionized path. This follow-through current may sustain the arc until the circuit breakers open at the end of the line. The fastest circuit breakers will trip in about 1/15th of a second, which is almost 1000 times longer than the duration of the lightning stroke itself.

Direct hits on a transmission line are rare; more often, lightning will strike the overhead ground wire that shields the line. In the latter case, a local charge still accumulates on the line, producing a very high local overvoltage. This concentrated charge immediately divides into two waves that swiftly move in oposite directions at close to the speed of light(300 m/μs). The height of the impulse wave represents the magnitude of the surge voltage that exists from point to point between the line and the ground (Fig.26). The peak voltage may attain one or two million volts. Wave front **ab** is concentrated over a distance of about 300 m, while tail **bc** may strech out over several kilometers.

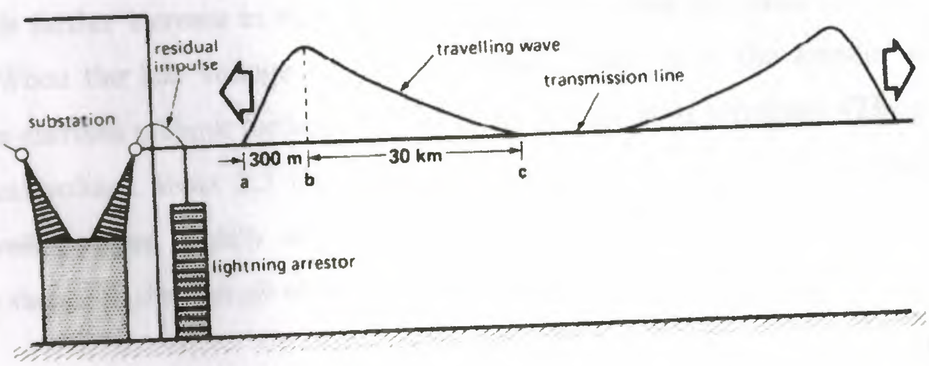


Figure 26 : Flow of electric charge along a transmission line

The wave also represents the point-to-point value of the current flowing in the line. For most aerial lines the ratio between surge voltage and surge current corresponds to a resistance of about 400 Ω. A surge voltage of 800,000 V at a given point is therefore accompanied by a local surge current of 800,000/400 = 2000 A.

As the wave travels along the line, the I^2R and corona losses graudally it to flatten out, and the peak of the surge voltage decreases.

Should the wave encounter a line insulator, the latter will be subjected to a violent overvoltage. The overvoltage period is equal to the time it takes for the wave to sweep past the insulator. The voltage rises from its nominal value to several hundred kilovolts in about 1 μs, corresponding to the length of wave front **ab.** If the insulator cannot withstand this overvoltage, it will flash over, and the resulting follow-through current will cause the circuit breakers to trip. On the other hand, if the insulator does not fail, the wave will continue to travel along the line until it eventually encounters a substation. It is here that the impulse-wave can produce real havoc. The windings of transformers, synchronous condersers, reactors, etc., are seriously damaged when they flash over to ground. Expensive repairs and even more costly shut-downs are incurred while the apparatus is out of service. The overvoltage may also damage circuit breakers, switches, insulators, and relays, that make up a substation. To reduce the impulse voltage on station apparatus, lightning arresters mustbe installed on all incoming lines.

3.4 Lightning Arresters

For the most part, lines and apparatus are protected by lightning arresters. The function of an arrester is to limit the voltage rise across its terminals to a value that is somewhat above the operating voltage of the line. When the voltage across the arrester reaches the critical value, the function of the arrester is to prevent further rise. This requires that the arrester pass a very large current with little further increase in itts voltage. In Fig.27 is shown the characteristic *aa'* of an ideal arrester. When the line voltage reaches the critical value at *a*, the arrester discharges indefinitely large currents without further increase in the voltage at its terminals. (The practise is to set the critical voltage about 2.5 times the peak operating voltage.) In the actual arrester, however, the voltage rises slightly with increase in current, owing to resistance drop. This characteristic is shown by the part *ab* of the actual characteristic *abc*.

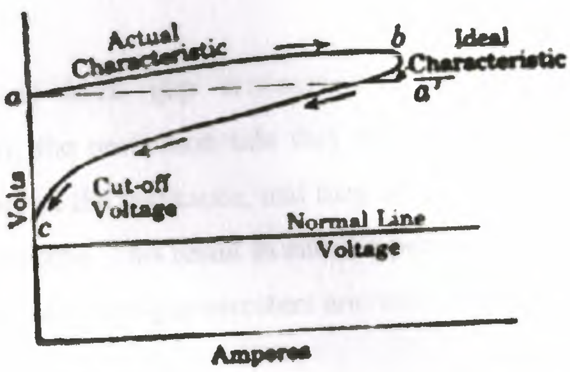


Figure 27 : Lightning-arrester characteristics.

When the voltage returns to normal, the arrester must cut off the current well above the peak operating voltage as at c, Fig.27. Otherwise , the power voltage will sustain a dynamic discharge. In addition, under normal conditions the arrester must be an open circuit. On discharge it must absorb the energy of the discharge, as otherwise the energy will tend to oscilliate as voltage and current waves.

Since the damage due to lightning occurs for the most part in the immediate vicinity of the stroke, the arrester should be connected near the apparatus that it is intended to protect.

Horn gaps are one of the earliest arresters used for high voltages. This consist of two horns, each mounted on an insulator, the gap itself being located between the lower parts of the horns. One horn is connected directly to the line to protected, and the other is connected to ground usually through resistance to limit the discharge current Fig.28. The gap is set so that ordinary operating voltages cannot jump it. When a surge reaches 150 to 200 percent of the normal line voltage , it discharges across the gap and goes to ground. The function of the horns is to break the arc. An arc tends to rise because of its heat and also, because of the well-known fact that a current forms a loop as large as possible, in order to make the permeance of the magnetic circuit a maximum.

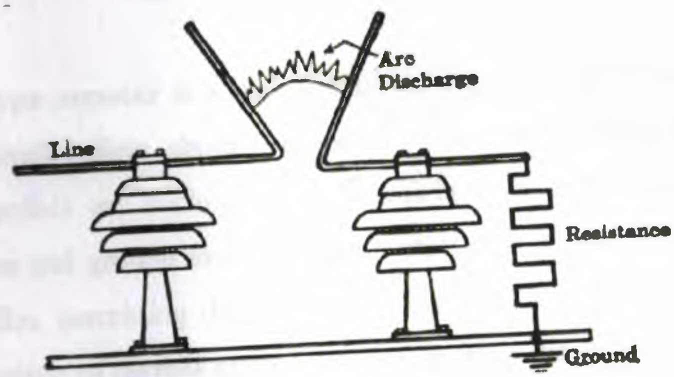
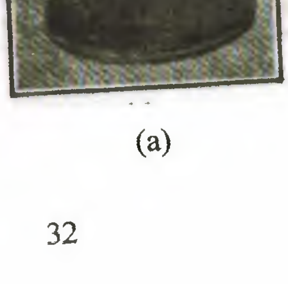
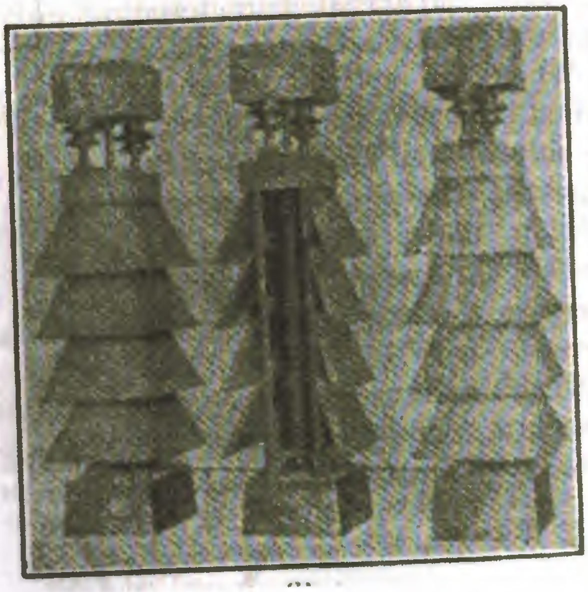


Figure 28 : Horn-gap arrester.

Simple horn gap arresters are far from satisfactory, for they often arc over unnecessarily, the protection taht they afford is not adequate because of the comparatively low discharge rate of the resistance, and they do not always suppress the dynamic arc that follows the transient discharge. This result in either a permanent arcing ground or the destruction of the gap. For these reasons horn-gap arresters are now almost obsolete for lightning protection.



(a)



(b)

Figure 29 : Oxide-film lightning arrester

The pellet –type arrester is a modification of the oxide-film arrester. The peroxide of lead is made up into small pellets, about the size of ordinary pills, which are coated with a thin insulating film. The pellets are enclosed in a porcelain tube and through suitable leads are connected between line and ground in series with a short gap. A high-voltage discharge breaks down the insulating film, permitting the discharge to ground. As with the oxide film, the heat developped by the passage of current reseals the films to stop the flow of dynamic current. This type of arrester is simple, easy to repair, and inexpensive. It is used extensively with distribution transformers.

SV Autovalve lightning arrester supersedes the original autovalva arrester, which consisted of carbon disks separated by thin mica washers as spacers. The SV arrester consists of one or more circular porous blocks in series, the number of blocks depending on the rating of the complete arrester. The blocks are made up of ceramic material and conducting particles fabricated into a uniform mixture. The blocks are formed by heavy hydraulic pressure and then are fired in the electric furnace. The physical characteristics of the materials are such that myriads of pores are formed within the finished blocks. For making electrical contact, two parallel surfaces are sprayed with copper by the Schoop spray process.

The principle of operation is based on the fact that the voltage necessary to start and maintain a discharge confined within narrow passages is much higher than when the discharge is not restricted . The passages can be so adjusted in size that the voltage necessary to initiate and maitain a discharge is represented by the part *ab* of the arrester discharge curve, Fig. 27. When the voltage drops below this value, the discharge diminishes until the cut-off voltage is reached. The cut-off voltage is well above the voltage at which the sytem operates, so that the dynamic power arc does not follow.

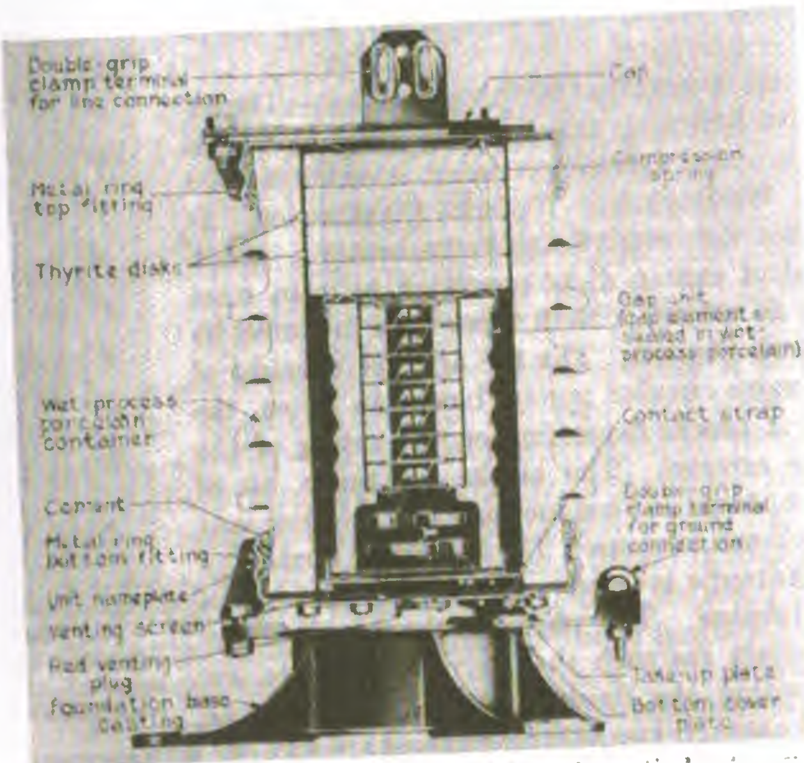
Each block is 1 inch thick and the diameters are 2 inchand 4.5 inch. Each block is rated at 3,000 volts rms. The blocks are assembled or stacked within porcelain tubes, Fig.30, to form elements. There are approximately 24blocks in the element, Fig.30, so that each element is rated at approximately 72 kv.

Figure 30 : Auto valve lightning arrester.

Thyrite is a nonporous ceramic material and is an excellent insulator until a crştical voltage is reached; the resistance then suddenly decreases, and the material becomes capable of discharging large currents with small increases in voltage. The current increases 12.6 times for each time the voltage is doubled. When the voltage returns normal, the arrester cuts off and prevents the flow of dynamic current. These properties of thyrite make it well adapted to lightning-arrester service.

Thyrite is made in disks with the two opposite surfaces sprayed with copper for electrical contact, Fig.31a. An 11.5 kv unit, is given in Fig.31b. A number of gaps in series with the thyrite disks maintain thearrester in an open-circuit condition until a discharge occurs. The characteristics of thyrite remain constant under many different conditions of operation, such as direct current, alternating current, or lightning, and it has no appreciable time lag.

(a)



(b)

Figure 31 : a) Standard 6 inch thyrite disk, having "mullite" insulating collar.

b) Thyrite lightning arrester unit, 11.5 kv.

Because of their cost, it is not practiable to use autovalve and thyrite lightning arresters to any great extent for protecting line insulators. However , **protector tubes** that are compact and relatively inexpensive . A typical tube is shown in Fig.32. It is made up of fiber and micarta tubes with ferrules on top and bottom; there are upper and lower electrodes within the tube. An arcing horn is mounted on the top ferrule, and the tubes are mounted so that a horn is just below each line conductor, these forming a series gap. The lower electrode is grounded. When a flashover occurs , the discharge jumps to the horn and goes down within the tube between the upper and lower electrodes. The temperature of the discharge , or arc, raises the pressure within the tube, which tends to suppres the arc. However, the predominant effect in suppressing the arc is the fact that its heat drives the gases from the organic material forming the micarta and fiber tube. This de-ionized gas intermingles freely with the ionized gas of the arc, de-ionizing it and thus destroying its conductance, so that the power arc that tends to follow the transient discharge does not restrike during the next current cycle.

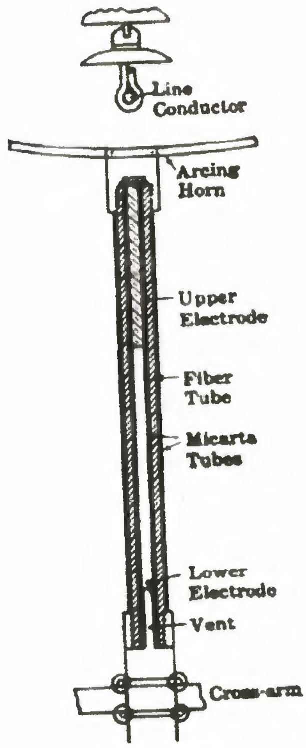


Figure 32 : Protector tube

Lightning arrester connections; lightning arresters should be connected as near as possible to the apparatus that they are designed to protect. For example, lightning arresters now are usually mounted directly on power transformers. Similarly the pellet type is mounted at the terminals of distribution transformers. Where an arrester is to protect a station, it should be mounted at the termination of the incoming or outgoing line as close as possible to the station apparatus. Station are connected with underground cables generally are not provided with arresters, for the large capacitance of the cables reduces materially the voltage of the surge.

However, lightning arresters are frequently connected at the junction of an overhead line and cables, to prevent high-voltage surges entering the cables.

3.5 Tower Grounding

In Fig. 19 we see two bare conductors supported at very top of the transmission-line towers. These conductors, called *ground wires*, serve to shield the line and intercept lightning strokes so they do not hit the current-carrying conductors below. Grounding wires normally do not carry current; consequently, they are often made of steel. They are solidly connected to ground at each tower.

Transmission line towers are always solidly connected to ground. Great care is taken to ensure that the ground resistance is low. In effect, when lightning hits a line, it creates a sudden voltage rise across the insulators as the lightning current discharges to ground. Such a voltage rise may produce a flash-over across the insulators and a consequent line outage.

3.6 Pollution

Dust,acids, salts and other pollutants in the atmosphere settle on insulators and reduce their insulating properties. Insulator pollutionmay produce short-circuits during storms or under momentary overvoltage conditions. The possibility of service interruption and the necessity to clean insulators periodically is therefore a constant concern to the utility company.

REFERENCES

[1] Hildreth H. , "Electrical and Electronic Engineering Series" , Mcgraw-Hill , 1951

[2] Rashid M. H., "Power Electronics" , Prentice Hill, 1988

[3] Uman M.A., "Lightning" , McGraw , 1969

[4] Federal Power Commission , "Electrical Power Statistics" , 1978

[5] Russel C. R.,"Elements of Energy Conversion" , Pergamon Press,1967

[6] WILDI T. , " Electrical Machines, Drivers and Power Systems " ,Third Edition, 1997

[7] Dawes C. L. ,"Dawes Electrical Engineering" , Vol 2 , 1956

[8] Westinghouse , "Electrical Transmission and Distribution Reference Book", 1964