MODULE 4

ELECTRICAL POWER DISTRIBUTION

The conductor system by which electrical energy is conveyed from a substation to the consumer is called a distribution system. The distribution system at a medium voltage is called primary distribution and at a low voltage is called secondary distribution.

1. **Primary distribution -** The most commonly used primary distribution voltages are 11 kV, 6·6kV and 3·3 kV. The 11 kV lines run along the important road sides of the city using 3-phase, 3-wire system. Big consumers (having demand more than 50 kW) are generally supplied power at 11 kV for further handling with their own sub-stations.
2. **Secondary distribution -** It consists of many distribution substations that step down the primary distribution voltage 11kV to 400V (440 V between phases and 230 V between any phase and neutral) and is fed to distributors to feed the consumers. The Secondary distribution system consists of distributors and service main. Figure 4.1 shows the layout of a distribution system.

The distribution system consists of feeders, distributors and service main

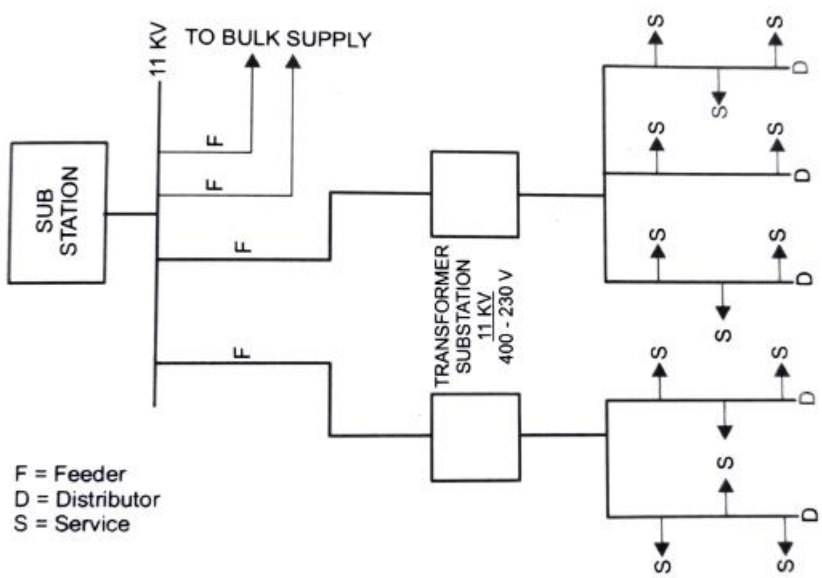


Fig. 4.1

Feeders

A feeder is a conductor which connects the sub-station to the area where power is to be distributed. Feeders have large current carrying capacity. Generally, no tappings are taken from the feeder so that current in it remains the same throughout

Distributor

A distributor is a conductor from which tappings are taken for supply to the consumers. In Figure 4.1, lines marked as D are the distributors. The current through a distributor is not constant because tappings are taken at various places along its length. While designing a distributor, voltage drop along its length is the main consideration (since the statutory limit of voltage variations is ± 6% of rated value at the consumers' terminals).

Service mains

It is generally a small cable which connects the distributor to the consumers' terminals.

CLASSIFICATION OF DISTRIBUTION SYSTEMS:

Distribution of systems can be classified in several ways:

1. As per the type of current

    (i) A.C distribution

    (ii) D.C. distribution

2. According to construction

    (i) Overhead distribution system

    (ii) Underground distribution system

3. According to the service

    (i) General lighting and power

    (ii) Industrial power

    (iii) Railway

    (iv) Street lighting

4. According to the number of wires

    (i) Two wire

    (ii) Three wire

    (iii) Four wire

5. According to scheme of connections

    (i) Radial system

    (ii) Ring system

    (iii) Interconnected system

Radial and Ring System of Distribution:

(i) Radial system

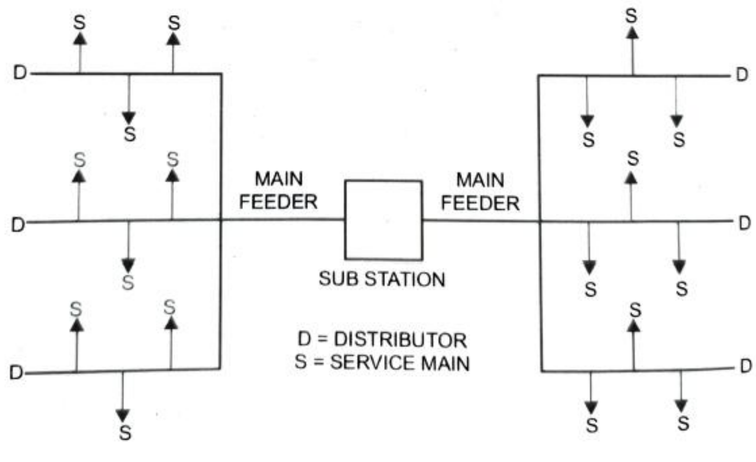
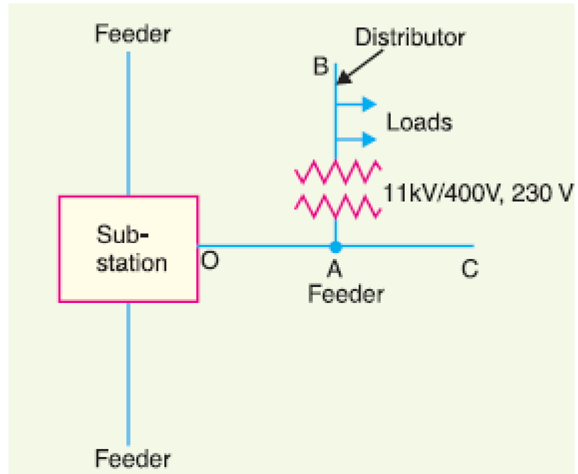


Fig. 4.2



- Separate feeders radiate from a single substation and feed the distributors at one end only
- In figure feeder *OC* supplies a distributor *AB* at point *A*. Distributor is fed at one end only *i.e.*, point *A* .
- Mainly used to serve the light and medium density load areas (small towns and rural areas).

Advantages

✓ Simplicity and low initial cost.

Disadvantages

➢ The consumers are dependent on a single feeder & single distributor - A fault on the feeder or distributor causes the power failure to the consumers after the fault point

➢ The end of the distributor nearest to the supply end would be heavily loaded.

➢ The consumers at the far end of the distributor would be subjected to serious voltage fluctuations with the variations in load.

Due to these limitations, radial system is used for short distances only.

(ii) Ring main system

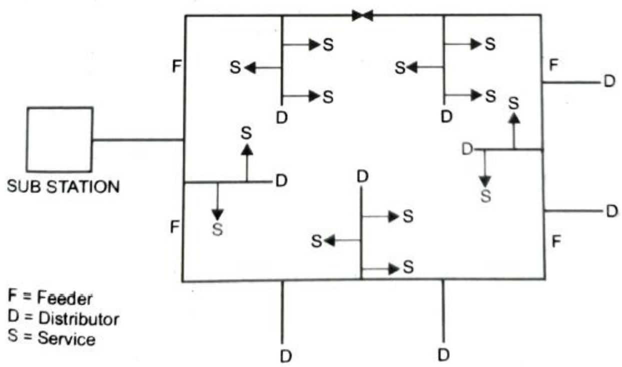
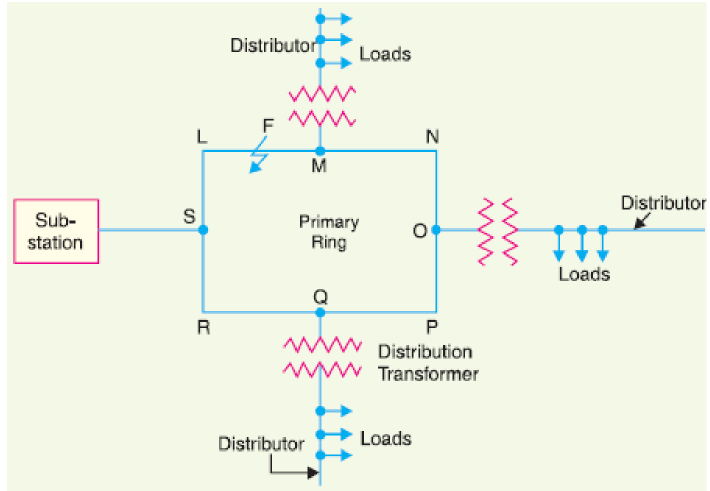


Fig. 4.3

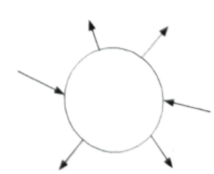


In this system, the primaries of distribution transformers form a loop. The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation. Thus substation supplies the closed feeder LMNOPQRS. The distributors are tapped from different points *M*, *O* and *Q* of the feeder through distribution transformers. Here each distributor is fed by two feeders.

Advantages

- ✓ There are less voltage fluctuations at consumer's terminals.
- ✓ The system is very reliable as each distributor is fed by two feeders. In the event of fault on any section of the feeder, the continuity of supply is maintained.

  (For example, suppose that fault occurs at any point *F* of section SLM of the feeder. Then section SLM of the feeder can be isolated for repairs and at the same time continuity of supply is maintained to all the consumers *via* the feeder *SRQPONM*.)

Sl	RADIAL SYSTEM	RING SYSTEM
1.		
2.	It is an open system.	It is a closed system.
3	Each distributer is fed by a single feeder	each distributor is fed by two feeders
4	Last consumer may suffer from low voltage	less voltage fluctuations at consumer's terminals
5	Less reliable - A fault on the distributor causes the power failure to the consumers after the fault point	More reliable –when fault occurs on the feeder only the faulty section can be isolated and the consumers can be fed from other end of the feeder

Overhead Vs Underground System (OH vs UG)

1. **Public safety -**The UG system is more safe than OH system

   all distribution wiring is placed underground - little chances of any hazard.

2. **Initial cost -** The UG system is more expensive

   high cost of trenching, conduits, cables, manholes and other special equipment.

   initial cost of UG system = 5 to 10 times OH

3. **Flexibility** – OH is more flexible than UG.
   - ✓ In UG - load expansion can only be met by laying new lines.
   - ✓ In OH - poles, wires, transformers etc., can be easily shifted to meet the changes in load conditions.

3. **Faults -** The chances of faults in UG system are very rare as the cables are laid underground - better insulation.

4. **Appearance -** The general appearance of UG is better as all the distribution lines are invisible.

5. **Fault location and repairs**
   - ✓ fault on UG is difficult to locate and repair
   - ✓ fault on OH line is so easy to locate and repair as conductors are visible

6. **Current carrying capacity and voltage drop** –
   - ✓ OH conductor has higher current carrying capacity than an UG cable conductor of the same material and cross-section.
   - ✓ Inductive reactance of UG cable is less than that of an OH conductor due to closer spacing of conductors therefore it has larger voltage drop.

7. **Useful life** – OH -25 years

   UG – more than50 years.

8. **Maintenance cost -** The maintenance cost of UG system is very less than OH system (less chances of faults and service interruptions from wind, ice, lightning as well as from traffic hazards.)

9. **Interference with communication circuits -** no such interference with the underground system

Due to high capital cost, UG system is not use for distribution

Comparison between Underground & Overhead System

S.No.	Particular	Overhead system	Underground system
1.	Public safety	It is less safe.	It is more safe.
2.	Initial cost	It is less expensive.	It is more expensive.
3.	Faults	Faults occur frequently.	Very rare chances of faults.
4.	Appearance	It gives shabby look.	Its appearance is good as wires are not visible.
5.	Flexibility	It is more flexible as new conductors can be laid along the existing conductors.	It is not flexible, as new conductors are to be laid in new channels.
6.	Location of fault	Fault point can be easily located.	Fault point cannot be easily located.
7.	Repair	Can be easily repaired.	Cannot be easily repaired.
8.	Working voltage	It can work upto 400 *kV*.	It can work only upto 66 *kV* due to insulation difficulty.

Requirements of a Distribution System

1. **Proper voltage -** a good distribution system should ensure that the voltage variations at consumers terminals are within permissible limits. The statutory limit of voltage variations is ± 6% of the rated value at the consumer's terminals.

   Thus, if the declared voltage is 230 V, then the highest voltage of the consumer should not exceed 244 V while the lowest voltage of the consumer should not be less than 216 V.

2. **Availability of power on demand -** the distribution system must be capable of supplying load demands of the consumers. This necessitates that operating staff must continuously study load patterns to predict in advance those major load changes that follow the known schedules.

3. **Reliability -** Modern industry, Homes and office buildings are almost dependent on electric power for its operation. Unfortunately, electric power, is not absolutely reliable.

   Reliability can be improved to a considerable extent by (a) interconnected system (b) reliable automatic control system (c) providing additional reserve facilities.

Voltage regulation

When the load on the supply system changes, the voltage at the consumer's terminals also changes. These voltage variations are undesirable and must be kept within the prescribed limits (*i.e.* ± 6% of the declared voltage). This is achieved by installing voltage regulating equipment at suitable places in the power system.

Voltage regulation of a transmission or distribution line is a measure of change of receiving end voltage from no load to full load condition.

$$\% \, Regulation = \frac{No\ load\ receiving\ end\ voltage - Full\ load\ receiving\ end\ voltage}{Full\ load\ receiving\ end\ voltage}$$

$$= \frac{V_s - V_R}{V_R} \times 100\ \%$$

Voltage regulating devices

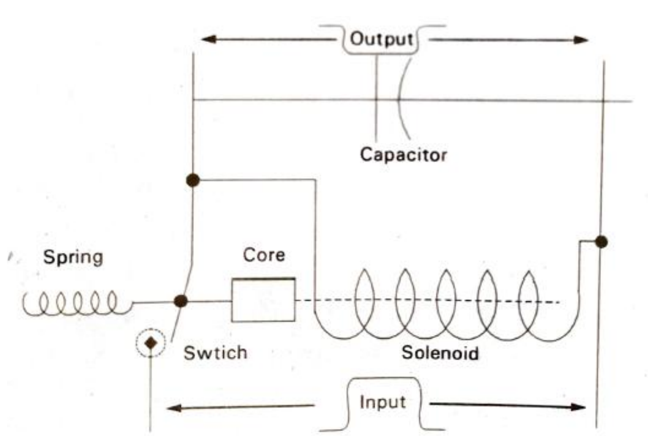
Voltage regulator is designed to automatically maintain a constant voltage level. It may include negative feedback control loop. It may use an electromechanical mechanism or electronic components.

1. Electronic voltage regulators

Simple electronic voltage regulator can be made from a resistor in series with the diode. Due to the logarithmic shape of diode V-I curves, the voltage across the diode changes only slightly due to changes in current drawn or changes in the input.

Feedback voltage regulator - actual output voltage is compared to a fixed reference voltage. Any difference is amplified and used to control the regulator and reduces the output voltage variation.

2. Electromechanical voltage regulator



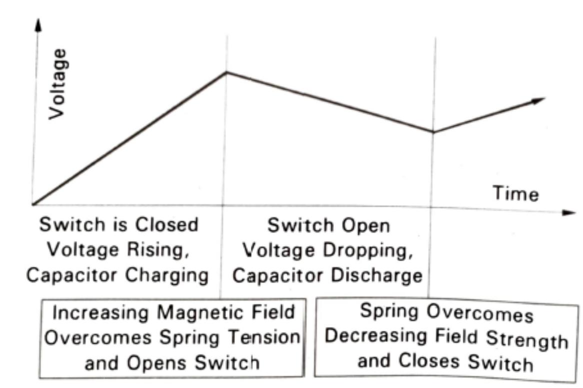


Fig. 4.10 Graph of Voltage output on a Time Scale

It consists of a solenoid and core connected to a spring as shown in figure. A capacitor is connected at the output terminals of the regulator. A mechanical power switch is connected to the core. This switch opens when core moves into the coil.

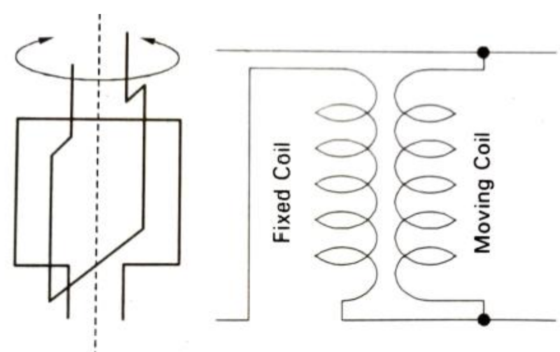
When the input voltage increases current through the coil also increases. This strengthens the magnetic field produced by the coil and the core is pulled towards the coil. Now the mechanical power switch is opened, capacitor discharges and the output voltage of a regulator drops as shown in the graph.

When the input voltage decreases the core moves away from the coil releasing the spring. This closes the switch and the capacitor starts to charge again which helps in increasing output voltage.

3. Automatic voltage regulator (AVR)

It is an active system to control the output voltage of generators in a power station. It has a very complex structure that includes several diodes, capacitors, resistors, potentiometers and microcontrollers.AVR controls the input to the exciter of the generator to correct the generator output voltage. AVR monitors generator output voltage and if there is any variation, AVR will control the DC input to the exciter to get a regulated output voltage. By increasing the excitation voltage, generator output voltage can be increased and vice versa.

4. Coil rotation AC voltage regulator (stabilizer)



This is an older type of regulator used in 1920. It has a fixed and moving coil. Moving coil is placed perpendicular to the fixed coil and it can be rotated on an axis in parallel with the fixed coil. When both the coils are in perpendicular the magnetic forces acting on the moving coil balance each other out and voltage output is constant. Rotating the moving coil in any direction will increase or decrease voltage in the moving coil. Servo control mechanism is used for the adjustment of moving coil position.

5. PWM pulse width modulated static voltage regulator

This is the latest technology of voltage regulation to provide real-time control of voltage fluctuation and also to control other power quality issues like Spikes and EMI/RFI electrical noises.This uses an IGBT regulator engine that generates pulse width modulated AC voltage at high switching frequency. This AC PWM wave is superimposed on the main incoming way through a buck boost transformer to get precisely regulated AC voltage.

6. Active regulator

Active regulator employs at least one active (amplifying) component such as transistor or operational amplifier. They are divided into several classes

- Linear series regulator
- Switching regulator
- SCR regulators

METHODS OF POWER FACTOR IMPROVEMENT IN DISTRIBUTION SYSTEM

Total power (Apparent power (S) in Volt Ampere(VA)) supplied to a circuit has two components

- Real power or active power (P), expressed in watt (W)
- Reactive power (Q), usually expressed in reactive volt-ampere(VAR)

<u>The Power Triangle</u> - We can relate the various components of AC power by using the power triangle. Real power extends horizontally in the i direction as it represents a purely real component of AC power. Reactive power extends in the direction of j as it represents a purely imaginary component of AC power.

Apparent power represents a combination of both real and reactive power, and therefore can be calculated by using the vector sum of these two components. We can conclude that the mathematical relationship between these components is

(Apparent power)2 = (Active power)2 + (Reactive power)2

$$S^2 = P^2 + Q^2$$

$$S = \sqrt{P^2 + Q^2}$$

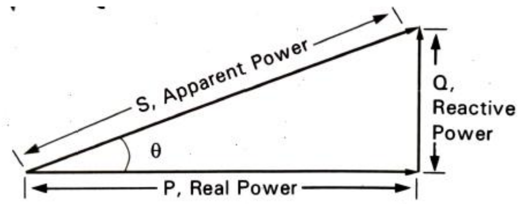


Fig. 4.16 Power Triangle

$$\text{Power factor} = \cos\theta = \frac{\text{P, real power}}{\text{S, apparent power}}$$

The power factor of a circuit can be defined in one of the following three ways :

- Power factor = cosϕ = cosine of angle between V and I
- Power factor = $\frac{R}{Z} = \frac{Resistance}{Impedance}$
- Power factor = $\frac{VI\cos\phi}{VI} = \frac{\text{Active power}}{Apparent\ \ power}$

Increasing the Power Factor: In case of less reactive and more resistive loads

- power factor (i.e. cosϕ) increases,
- ratio of real power to apparent power increases,
- angle ϕ decreases
- Reactive power decreases.

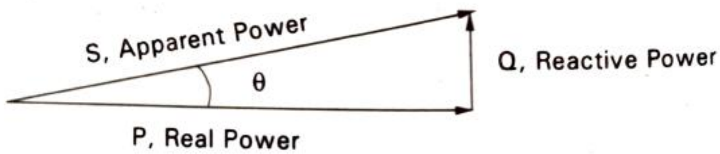


Fig. 4.17 Increasing PF

Decreasing the Power Factor: In case of more reactive and less resistive loads

- power factor decreases
- ratio of real power to apparent power also decreases
- angle ϕ increases
- Reactive power increases.

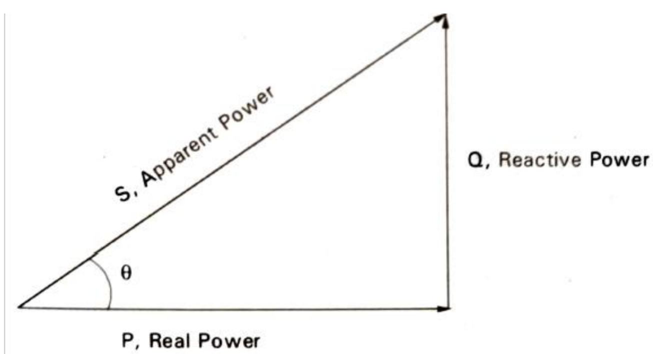


Fig. 4.18 Decreasing PF

Disadvantages of Low Power Factor:

1. Large kVA rating equipment
2. Large conductor size.
3. Large copper/line loss
4. Poor voltage regulation

Causes of low PF

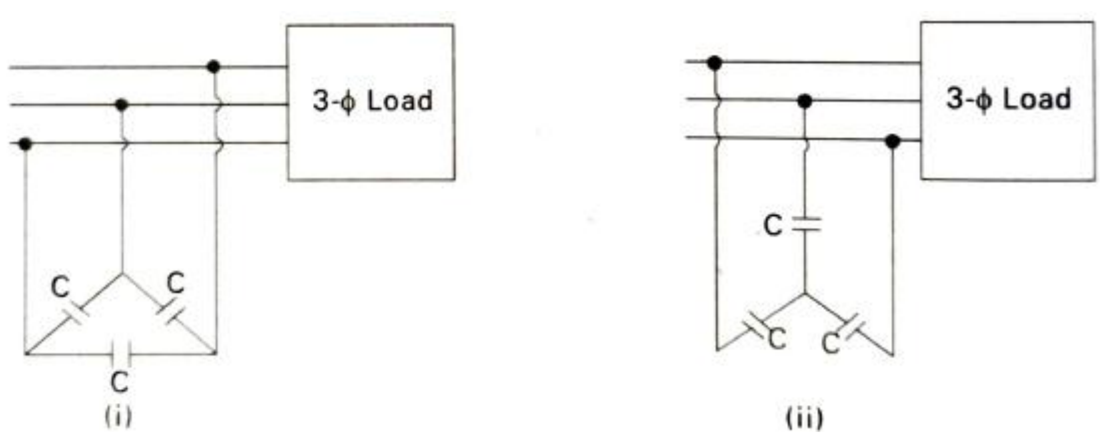
1. Induction motors.
2. Arc and electric discharge lamps
3. Fluorescent lamps
4. Industrial heating furnaces
5. Transformers (welding)

PF Improving Equipment/Devices

1. Static capacitors
2. Synchronous condenser
3. Phase advancer.

1. Static capacitor

The power factor can be improved by connecting static capacitors in parallel with the equipment operating at lagging power factor. Capacitors draw a leading current and partly or completely neutralizes the lagging reactive component of load current. This raises the power factor of the load. For three-phase loads, the capacitors can be connected in delta or star as shown in Fig



Advantages

- They have low losses.
- They require little maintenance as there are no rotating parts.
- They can be easily installed as they are light and require no foundation.
- They can work under ordinary atmospheric conditions.

Disadvantages

- They have short service life ranging from 8 to 10 years.
- They are easily damaged if the voltage exceeds the rated value.
- Once the capacitors are damaged, their repair is uneconomical.

2. Synchronous condenser

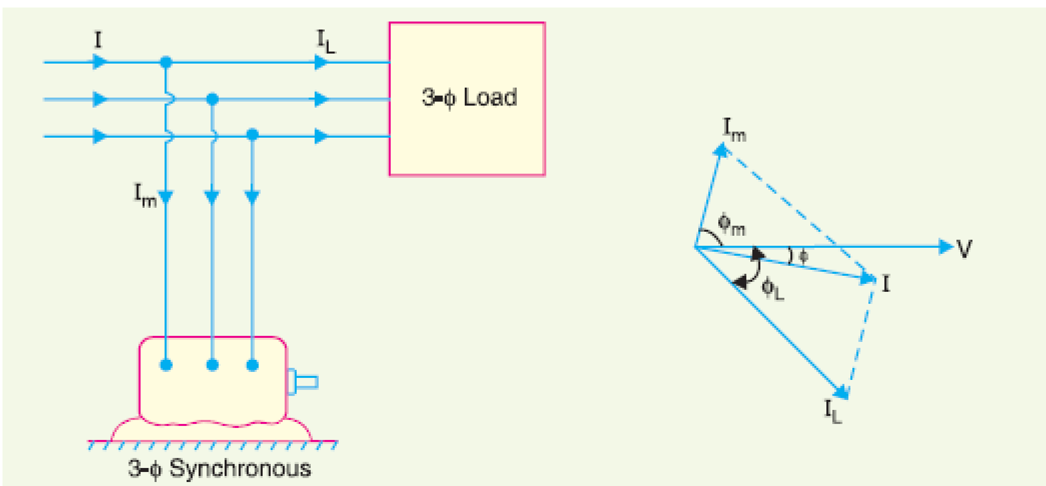


Fig. 6.5

An over-excited synchronous motor running on no load is known as ***synchronous condenser***. When it is connected in parallel with the supply it behaves as a capacitor and takes a leading current which partly neutralizes the lagging reactive component of the load. Thus the power factor is improved.

Fig 6.5 shows the power factor improvement by synchronous condenser method. The 3ϕ load takes current I_L at low lagging power factor cos ϕ_L. The synchronous condenser takes a current I_m which leads the voltage by an angle ϕ_m. The resultant current I is the phasor sum of I_m and I_L and lags behind the voltage by an angle ϕ. It is clear that ϕ is less than ϕ_L so that cos ϕ is greater than cos ϕ_L. Thus the power factor is increased from cos ϕ_L to cos ϕ. Synchronous condensers are generally used at major bulk supply substations for power factor improvement.

Advantages

- By varying the field excitation, the magnitude of current drawn by the motor can be changed by any amount. This helps in achieving stepless control of power factor.
- The motor windings have high thermal stability to short circuit currents.
- The faults can be removed easily.

Disadvantages

- There are considerable losses in the motor.
- The maintenance cost is high.
- It produces noise.
- Except in sizes above 500 kVA, the cost is greater than that of static capacitors of the same rating.
- As a synchronous motor has no self-starting torque, therefore, auxiliary equipment has to be provided for this purpose.

3. Phase advancers

- ✓ Phase advancers are used to improve the power factor of induction motors.
- ✓ The low power factor of an induction motor is due to the **exciting current taken by the stator** winding which lags the supply voltage by 90°.
- ✓ If the exciting ampere turns can be provided from some other a.c. source, then the stator winding will be relieved of exciting current and the power factor of the motor can be improved.
- ✓ This is done by the phase advancer which is simply an **a.c. exciter** mounted on the same shaft as the main motor and is connected in the rotor circuit of the motor.
- ✓ It provides exciting ampere turns to the rotor circuit at **slip frequency**. Thus the induction motor can be made to operate on **leading power factor**

Advantages

- As the exciting ampere turns are supplied at slip frequency, lagging kVAR drawn by the motor are considerably reduced.
- It can be conveniently used where the use of synchronous motors is not possible.

Disadvantage

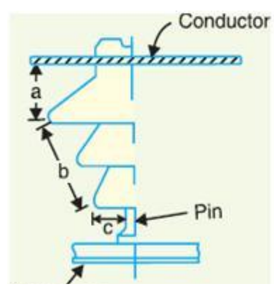
- Not economical for motors below 200 H.P.

Requirement of a good insulator

1) High insulation resistance in order to avoid leakage of current to earth
2) High relative permittivity in order to give high dielectric strength
3) High ratio of rupture strength to flash over voltage
4) It should not be porous
5) Mechanically very strong in order to withstand the load due to the weight of conductor, and vibrating shocks
6) The material should not change in its properties due to change in temperature
7) It must be free from internal impurities, cracks etc
8) It should be impervious (not penetrable) to fluids and gases of the atmosphere

Materials generally used for insulators on overhead lines is **Porcelain, glass, steatite** and **special composition materials**

Causes of insulator failure



1) Deterioration by cracking of the porcelain
2) Porosity
3) Failure from mechanical stresses
4) Short circuits by birds and similar objects
5) Shattering by power arcs
6) **Flash over** caused by dust deposits - In flashover, an arc occurs between the line conductor and insulator pin (*i.e.*, earth) and the discharge jumps across the air gaps, following shortest distance (a+b+c). In case of flash-over, the insulator will continue to act in its proper capacity unless extreme heat produced by the arc destroys the insulator.
7) **Puncture** of weak porcelain - In case of puncture, the discharge occurs from conductor to pin through the body of the insulator and the insulator is permanently destroyed due to excessive heat.

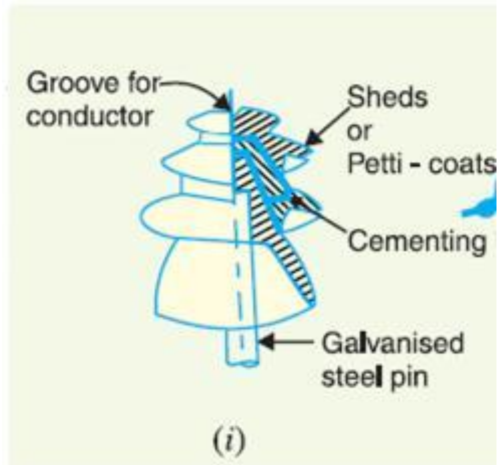
$$\text{Safety factor of insulator} = \frac{\text{Puncture strength}}{\text{Flash - over voltage}}$$

It is desirable that the value of safety factor is **high** so that flash-over takes place before the insulator gets punctured. For pin type insulators, the value of safety factor is about 10.

Types of Insulators

The overhead lines are supported by means of insulators to avoid leakage of current through the supports to the earth. Most commonly used are pin type, suspension type, strain insulator and shackle insulator.

1) Pin type insulators



The pin type insulator is secured to the cross-arm on the pole. There is a groove on the upper end of the insulator for housing the conductor. The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor. It is used for voltages up to 33 kV and is not economical beyond 33 kV.

2) Suspension type insulators

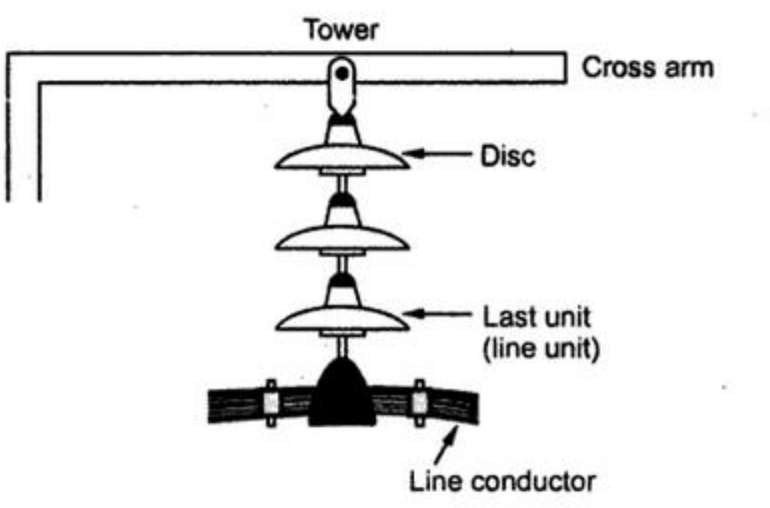


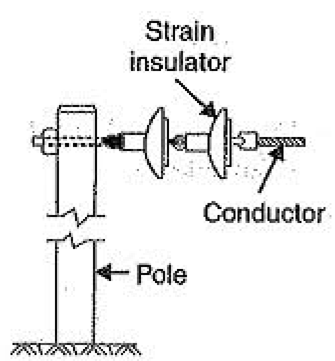
Fig. 2 String of suspension insulator with 3 units

- Used for high voltages (>33 kV)
- Consist of a number of porcelain discs connected in series by metal links in the form of a string.
- The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross-arm of the tower.
- Each unit or disc is designed for low voltage, say 11 kV. The number of discs in series depends upon the working voltage. If the working voltage is 66 kV, then six discs in series will be provided on the string.

Advantages

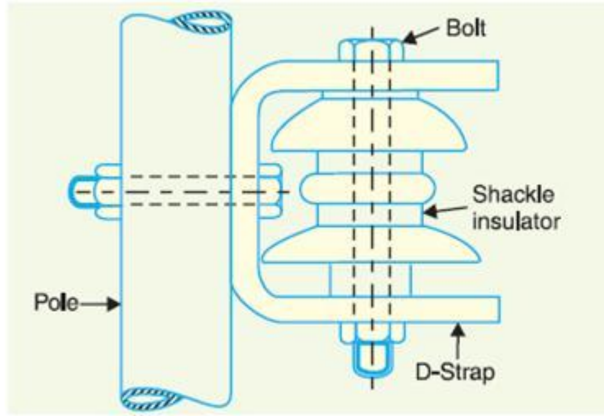
- ✓ Cheaper than pin type insulators for voltages beyond 33 kV.
- ✓ If one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.
- ✓ Insulation capacity can be increased by adding the extra number of discs.
- ✓ The suspension arrangement provides greater flexibility to the line -insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.
- ✓ Provides partial protection from lightning as the conductors run below the earthed cross-arm of the tower

3)Strain insulators



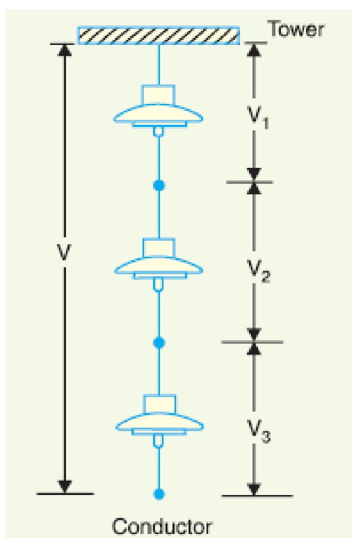
- When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to reduce this excessive tension, strain insulators are used.
- The discs of strain insulators are used in the vertical plane.
- When the tension in lines is exceedingly high, as at long river spans, two or more strings are used in parallel
- For low voltage lines (< 11 kV), shackle insulators are used as strain insulators. For high voltage lines, strain insulator consists of an assembly of suspension insulators

4)Shackle insulators.



- In early days, the shackle insulators were used as strain insulators. But now days, they are frequently used for low voltage distribution lines.
- Can be used either in a horizontal position or in a vertical position. They can be directly fixed to the pole with a bolt or to the cross arm.
- The conductor in the groove is fixed with a soft binding wire.

String Efficiency



The voltage applied across the string of suspension insulators is not uniformly distributed across various units or discs. The disc nearest to the conductor has much higher potential than the other discs. This unequal potential distribution is undesirable and is usually expressed in terms of string efficiency

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as **string efficiency**

$$\text{String efficiency} = \frac{\text{Voltage across the string}}{n \times \text{Voltage across disc nearest to conductor}}$$

where n = number of discs in the string.

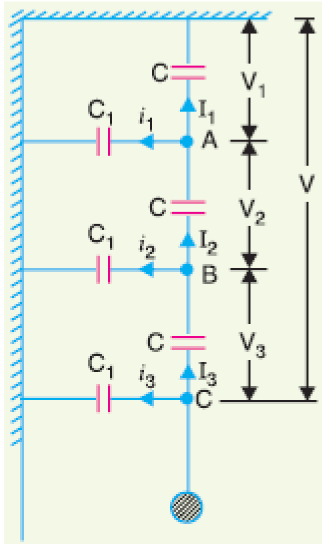


Fig. 8.11

Fig. 8.11 shows the equivalent circuit for a 3-disc string. Let the self capacitance of each disc be C. shunt capacitance be $C_1 = KC$.

$$\text{Voltage across top unit, } V_1 = \frac{V}{(1+K)(3+K)}$$

$$\text{Voltage across second unit from top, } V_2 = V_1(1+K)$$

$$\text{Voltage across third unit from top, } V_3 = V_1(1+3K+K^2)$$

$$\text{\%age String efficiency} = \frac{V}{3 \times V_3} \times 100$$

The following points may be noted

- Disc nearest to the conductor has maximum voltage across it; the voltage across other discs decreasing progressively as the cross-arm in approached.
- The lesser the value of **K (= C_1/C)**, the more uniform is the potential across the discs ($V_1 = V_2 = V_3$) and greater is the string efficiency.
- The inequality in voltage distribution increases with the increase of number of discs in the string. Therefore, shorter string has more efficiency than the larger one.

Methods of Improving String Efficiency

1. By using longer cross-arms.

The value of string efficiency depends upon the value of K i.e., ratio of shunt capacitance to mutual capacitance **($K= C_1/C$)**. The lesser the value of K, the greater is the string efficiency and more uniform is the voltage distribution. The value of K can be decreased by reducing the shunt capacitance. In order to reduce shunt capacitance, the distance of conductor from tower must be increased i.e., longer cross-arms should be used. However, limitations of cost and strength of tower do not allow the use of very long cross-arms. In practice, K = 0·1 is the limit that can be achieved by this method.

2. By grading the insulators

In this method, insulators of different dimensions are so chosen that each has a different capacitance. The insulators are capacitance graded i.e. they are assembled in the string in such a way that the top unit has the minimum capacitance, increasing progressively as the bottom unit (i.e., nearest to conductor) is reached. Since voltage is inversely proportional to capacitance, this method tends to equalise the potential distribution across the units in the string. This method has the disadvantage that a large number of different-sized insulators are required.

3. By using a guard ring

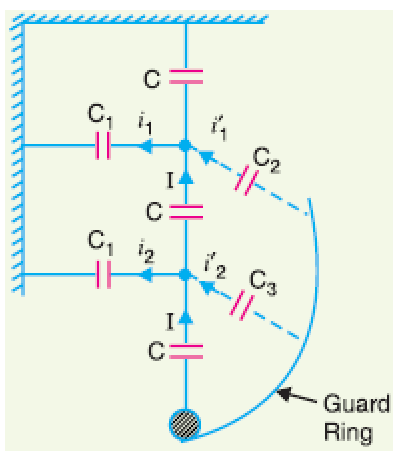
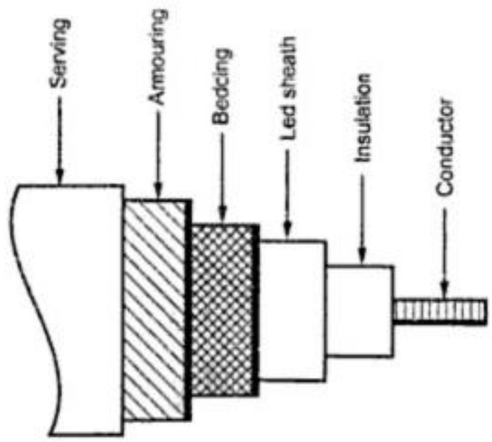


Fig. 8.13

The potential across each unit in a string can be equalised by using a guard ring which is a metal ring electrically connected to the conductor and surrounding the bottom insulator as shown in the Fig. 8.13. The guard ring introduces capacitance between metal fittings and the line conductor. The guard ring is contoured in such a way that shunt capacitance currents i_1, i_2 etc. are equal to metal fitting line capacitance currents i'_1, i'_2 etc. The result is that same charging current I flows through each unit of string. Consequently, there will be uniform potential distribution across the units.

Construction of Cables



1. Cores or Conductors

A cable may have one or more than one core (conductor) depending upon the type of service. The conductors are made of ***tinned copper*** or ***aluminium*** and are usually stranded in order to provide flexibility to the cable.

2. Insulation

Each core or conductor is provided with a suitable thickness of insulation. The thickness depends upon the voltage level of the cable. The commonly used materials for insulation are ***impregnated paper***, ***varnished cambric*** or ***rubber mineral compound***.

3. Metallic sheath

It is made of ***lead*** or ***aluminium*** is provided over the insulation to protect the cable from moisture, gases or other damaging liquids (acids or alkalies) in the soil and atmosphere.

4. Bedding

It is made of a fibrous material like ***jute*** or ***hessian tape*** is provided over the metallic sheath. The purpose of bedding is to protect the metallic sheath against corrosion and from mechanical injury due to armouring.

5. Armouring

It consists of one or two layers of ***galvanised steel wire*** or steel tape and is provided over the bedding. Its purpose is to protect the cable from mechanical injury while laying it and during the course of handling. Armouring may not be done in the case of some cables.

6. Serving

It is a layer of fibrous material (like ***jute***) similar to bedding, provided over the armouring to protect armouring from atmospheric conditions. This is known as *serving*.

Classification of Cables

According to the voltage for which the cables are manufactured they are classified into

1. Low-tension (L.T.) cables — upto 1000 V
2. High-tension (H.T.) cables — upto 11kV
3. Super-tension (S.T.) cables — from 22 kV to 33 kV
4. Extra high-tension (E.H.T.) cables — from 33 kV to 66 kV
5. Extra super voltage cables — beyond 132 kV

The following types of cables are generally used for 3-phase service

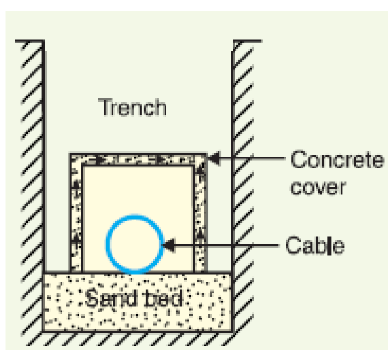
1. Belted cables — upto 11 kV
2. Screened cables — from 22 kV to 66 kV
3. Pressure cables — beyond 66 kV.

Laying of Underground Cables

There are three main methods of laying underground cables

1. Direct laying
2. Draw-in system
3. Solid system.

1. Direct laying



In this method, a trench of about 1·5 metres deep and 45 cm wide is dug. The trench is covered with a layer of fine sand (of about 10 cm thickness) and the cable is laid over this sand bed. The sand prevents the entry of moisture from the ground and thus protects the cable from decay. After the cable has been laid in the trench, it is covered with another layer of sand of about 10 cm thickness The trench is then covered with concrete or bricks to protect the cable from mechanical injury. Cables to be laid in this way must have serving of **bituminised paper** and **hessian tape** so as to provide protection against corrosion and electrolysis.

Advantages

- ✓ It is a simple and cheap.
- ✓ Heat dissipating is good.
- ✓ Free from external disturbances.

Disadvantages

- ➢ Initial cost is very high.
- ➢ The extension of load is possible only by a completely new excavation which may cost as much as the original work.

2. Draw-in system

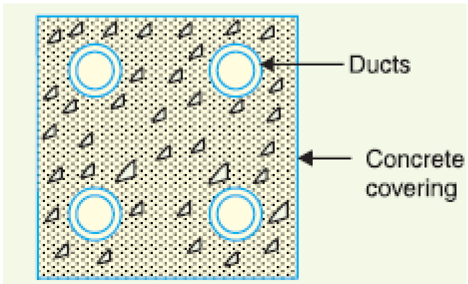


Fig. 11.11

In this method, conduit or duct made of glazed stone or cast iron or concrete are laid in the ground with manholes at suitable positions along the cable route. The cables are then pulled into position from manholes. Fig. 11.11 shows section through four-way underground duct line. Three of the ducts carry transmission cables and the fourth duct carries relay protection connection, pilot wires.

Advantages

- ✓ Laying simple and easy
- ✓ Repairs & addition of cables can be done easily without opening the ground because of manhole.
- ✓ There are very less chances of fault occurrence due to strong mechanical protection

Disadvantages

- The initial cost is very high.
- The current carrying capacity of the cables is reduced due to the close grouping of cables and poor heat dissipation.

3. Solid system

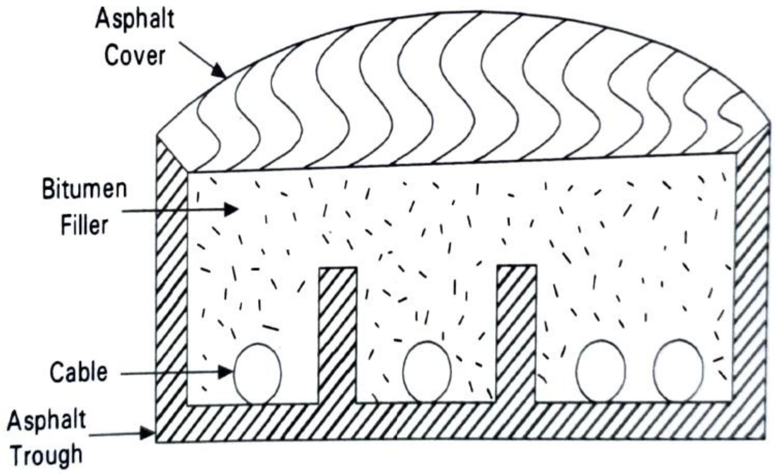


Fig. 4.48 Solid System of Cable Laying

The cable is laid in open pipes or troughs dug out in earth along the cable route. The troughing is made of cast iron, stoneware, asphalt or treated wood. After the cable is laid in position, the troughing is filled with a bituminous or asphaltic compound and covered over.

Advantages

- ✓ The life of the system is more
- ✓ Trough material is cheap & available
- ✓ Provides good mechanical strength

Disadvantages

- It is more expensive than direct laid system.
- It requires skilled labour and favourable weather conditions.
- Due to poor heat dissipation facilities, the current carrying capacity of the cable is reduced.

Grading of Cables

Grading of cable is the process of achieving uniform distribution of dielectric stress or voltage gradient in a dielectric of cable.

The maximum voltage that can be safely applied to a cable depends upon electrostatic stress (g_{max}) at the conductor surface. Voltage gradient or dielectric stress is maximum at the surface of the conductor and goes on decreasing as we move towards the sheath. This non – uniform distribution of dielectric stress leads to insulation break down in the cable. To avoid this insulation break down, it is required to distribute the dielectric stress equally throughout the dielectric. The uniform distribution of dielectric stress is achieved by grading the cables.

There are two methods of grading of cables. They are,

1. Capacitance grading and

2. Inter sheath grading

1. Capacitance Grading

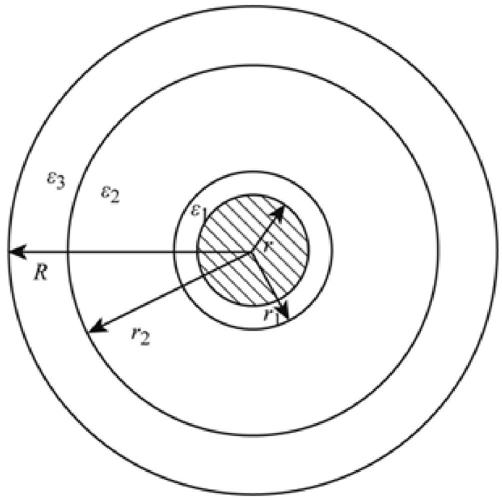


Figure 1

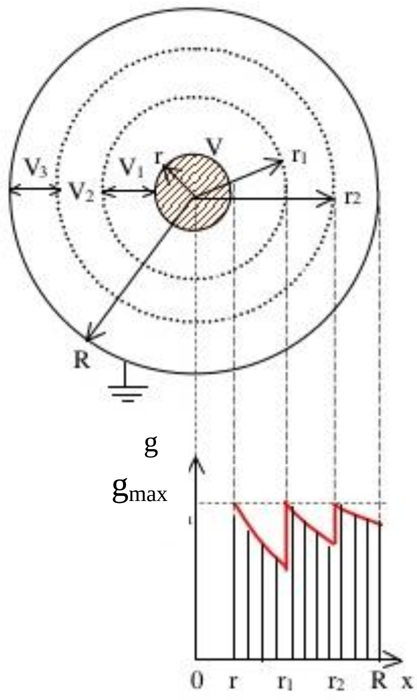
- ✓ The process of achieving uniformity in the dielectric stress by using layers of **different dielectrics** is known as **capacitance grading.**
- ✓ Figure 1 is the capacitance graded cable. Here, the radius of the conductor is r. Three dielectric layers of different permittivity and thickness are used in this cable.
- ✓ The relative permittivity values of each dielectric layer and their distances from centre of the conductor are $\varepsilon_1 > \varepsilon_2 > \varepsilon_3$ and $r_1 < r_2 < R$. The uniform dielectric stress can be achieved by maintaining the product of permittivity and radius of each dielectric as same $\varepsilon_1 r_1 = \varepsilon_2 r_2 = \varepsilon_3 R$.

  Disadvantage - In capacitance grading infinite number of dielectrics will be needed to achieve uniform dielectric stress. But it is not practically possible.

2. Inter sheath grading

In this method of cable grading, same insulating material is used throughout the cable (homogeneous dielectric) is used, but it is divided into various layers by placing metallic intersheaths between the core and lead sheath. These intersheaths are connected to tapping from the supply transformer and are held at suitable potentials such that the maximum dielectric stress in each layer is the same. This arrangement improves voltage distribution in the dielectric of the cable and consequently more uniform potential gradient is obtained.

As the cable behaves like three capacitors in series, therefore, all the potentials are in phase *i.e.* Voltage between conductor and earthed lead sheath is $V = V_1 + V_2 + V_3$



Disadvantages.

- Fixing of potentials at inter sheaths is a difficult task.
- Intersheaths are likely to be damaged during transportation and installation.
- There are considerable losses in the intersheaths due to charging currents.

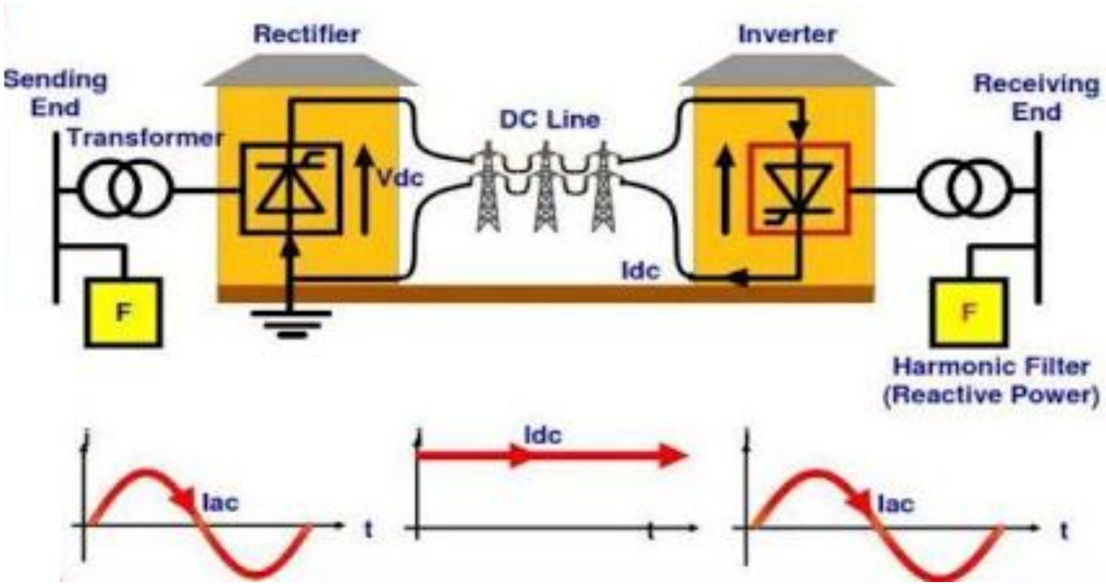
HVAC vs. HVDC

HVAC technology uses AC current to transmit large amount of power. HVAC is more economical for short distance transmission of bulk power.

HVDC (High Voltage DC) technology is used to transmit large amounts of power over long distances by overhead transmission lines or submarine cables with lower capital costs and with lower losses than HVAC. The fundamental process that occurs in HVDC dc system is the conversion of electrical current from AC to DC (rectifier) at the transmitting end and from DC to AC (inverter) at the receiving end.

Components of HVDC Transmission Systems

1. Converters (rectifier & inverter)
2. Smoothing reactors
3. Harmonic filters
4. Reactive power supplies
5. Electrodes
6. DC lines
7. AC circuit breakers



Advantages of HVAC

1. Electrical losses (I^2R or copper losses) will be less
2. Improved voltage regulation.
3. The transmission efficiency increases.
4. With high voltage the material required for conductor is reduced
5. With high voltage system more power can be transmitted
6. Future extension flexibility is more

Disadvantages HVAC

1. Corona loss will be more
2. Ferranti effect
3. Heavy and tall supporting structures,
4. Insulation and switching problems

Advantages of HVDC

1. Power flow is reversible, fully controllable, fast and accurate
2. There is greater power per conductor and simpler line construction
3. The HVDC line is an asynchronous link and it can interconnect two grid systems operating at different frequencies.
4. HVDC is cheaper than HVAC for long distance (more than 700km).
5. Submarine HVDC links is more suitable for connecting offshore wind farms as they are more efficient and cost effective than undersea HVAC cables.
6. Increasing the capacity of an existing power grid in situations where additional wires are difficult or expensive to install
7. Corona loss, radio interference and audible emissions are less as compared to AC
8. There is no charging current and skin effect

Disadvantages of HVDC

1. Conversion, switching, control, availability and maintenance are difficult.
2. Expensive conversion equipments are needed.
3. Converters require considerable reactive power.
4. Harmonics are generated which require filters.
5. Reactive power required by the load is to be supplied locally as no reactive power can be transmitted over a DC link.
6. HVDC is less reliable and has lower availability than AC system, due to extra conversion equipments
7. The systems are costly since the installation of complicated converters and DC switchgear is expensive

Conventional Source	Non-Conventional Source
Conventional sources of energy refer to traditional sources of power like charcoal, firewood, coal, petroleum, etc.	Non- conventional sources of energy are recently developed sources of energy from Sun, wind, water, tides, geothermal, etc.
These sources of energy are non renewable.	These sources are renewable.
Generation of energy is expensive.	Initial cost of generation is high but cheaper in the long run.
They cause large scale pollution.	They are Eco friendly sources of energy.