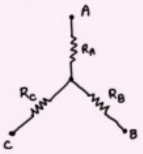
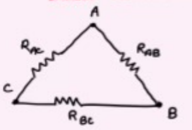
Unit - 1

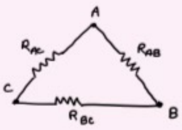
Star Connection



Delta Connection



Delta to Star Conversion



A to B ⇒ 2 paths

$$R_A + R_B = \frac{R_{AB} * (R_{BC} + R_{AC})}{R_{AB} + (R_{BC} + R_{AC})} \longrightarrow (1)$$

$$\left[R_{eq} = \frac{R_a * R_b}{R_a + R_b}\right]$$

Similarly,

B to C,

$$R_B + R_C = \frac{R_{BC} * (R_{AB} + R_{AC})}{R_{BC} + (R_{AB} + R_{AC})} \longrightarrow (2)$$

And,

A to C,

$$R_A + R_C = \frac{R_{AC} * (R_{AB} + R_{BC})}{R_{AC} + R_{AB} + R_{BC}} \longrightarrow (3)$$

Now, (1) − (2) + (3)

$$2R_A = \frac{R_{AB}\cancel{R_{BC}} + R_{AB}R_{CA} - R_{BC}\cancel{R_{AB}} - R_{BC}\cancel{R_{CA}} + \cancel{R_{CA}}R_{BC} + R_{AC}R_{AB}}{R_{AB} + R_{BC} + R_{AC}}$$

$$R_A = \frac{R_{AB} \cdot R_{AC}}{R_{AB} + R_{BC} + R_{AC}} \longrightarrow (4)$$

Similarly, $R_B = \dfrac{R_{AB} \cdot R_{BC}}{R_{AB} + R_{BC} + R_{AC}} \longrightarrow (5)$, $R_C = \dfrac{R_{AC} \cdot R_{BC}}{R_{AB} + R_{BC} + R_{AC}} \longrightarrow (6)$

Star to Delta Conversion

(4) * (5) + (5) * (6) + (6) * (4)

$$\frac{R_{ab}^2 R_{ac} R_{bc} + R_{ab} R_{ac} R_{bc}^2 + R_{ab} R_{ac}^2 R_{bc}}{(R_{ab} + R_{bc} + R_{ca})^2}$$

$$R_A R_B + R_B R_C + R_C R_A = \frac{R_{ab} * R_{bc} * R_{ca}}{R_{ab} + R_{bc} + R_{ca}}$$

$$R_A R_B + R_B R_C + R_C R_A = R_A * R_{bc}$$

$$R_{bc} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_A} \longrightarrow (7)$$

Similarly,

$$R_{ab} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_C} \longrightarrow (8)$$

$$R_{ca} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_B} \longrightarrow (9)$$

Q.

A

Superposition Theorem

→ In a linear network with 1 or more than 1 independant source, the total response in any element is the algebraic sum of individual responses causes by each independant source acting alone, while all other independant sources are replaced by their internal resistances i.e, all other ideal voltage sources with short circuit & all other ideal current sources with open circuit

8. Thevenin's theorem

→ A linear network with a large number of independant and dependant sources and resistors b/w 2 terminals can be replaced with a simple 2 element series equivalent in which a voltage source called 'Thevenin's Equivalent Voltage' (V_{TH}) is in series with a resistance called 'Thevenin's Equivalent Resistance' (R_{TH})

Unit - 2

General AC Circuit

$$\rightarrow P = \frac{1}{T}\int_0^T v(t) * i(t)\, dt$$

$$= \frac{1}{T}\int_0^T V_m I_m \sin\omega t . \sin(\omega t + \phi)\, d\omega t$$

$$= \frac{1}{T}\int_0^T V_m I_m \sin\omega t . (\sin\omega t \cos\phi + \sin\phi \cos\omega t)\, d\omega t$$

$$= \frac{1}{T}\int_0^T V_m I_m (\sin^2\omega t \cos\phi + \sin\phi \sin\omega t . \cos\omega t)\, d\omega t$$

$$= \frac{1}{T}\int_0^T V_m I_m \left(\frac{1-\cos 2\omega t}{2} \cos\phi + \sin\phi . \frac{\sin 2\omega t}{2} \right) d\omega t$$

$$= \frac{V_m I_m}{T}\left[\cos\phi\left(\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right) + \sin\phi \frac{\cos 2\omega t}{4}\right]_0^T$$

$$= \frac{V_m I_m}{T}\left[\cos\phi\left[\frac{T}{2} - 0\right] + \cancel{\frac{\sin\phi}{4}}\overset{0}{\cancel{(1-1)}}\right]$$

$$= \frac{V_m I_m}{2} \times \cos\phi \times \frac{\cancel{T}}{\cancel{T}} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}} \cos\phi = VI\cos\phi$$

Similarly

$Q = VI \sin\phi$

$S = VI$

Importance of P.F

→ I^2R losses is reduced

→ Reactive power is reduced

→ higher PF helps using full capacity of electrical system

→ Improves the performance of motor

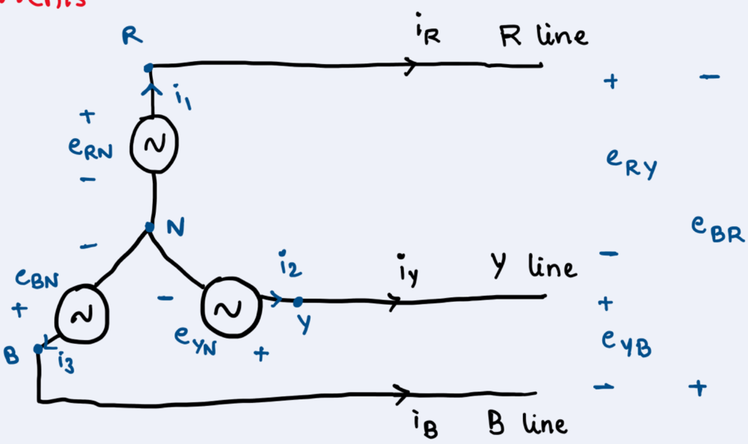
→ PF improved by placing capacitor in $||^{el}$

(or)

inductor in series

Unit -3

Relation b/w line & phase currents



→ Line current = Phase current

$i_1 = i_R$; $i_2 = i_Y$; $i_3 = i_B$

→ Applying KVL on RYNR,

$$-e_{RY} - e_{YN} + e_{RN} = 0$$

$$e_{RY} = e_{RN} - e_{YN}$$

$$\bar{E}_{RY} = \bar{E}_{RN} - \bar{E}_{YN}$$

$$= \frac{E_m}{\sqrt{2}} \angle 0 - \frac{E_m}{\sqrt{2}} \angle -120$$

$$= E_{ph} \angle 0 - E_{ph} \angle -120$$

$$= E_{ph}\left(\frac{3}{2} + j\frac{\sqrt{3}}{2}\right)$$

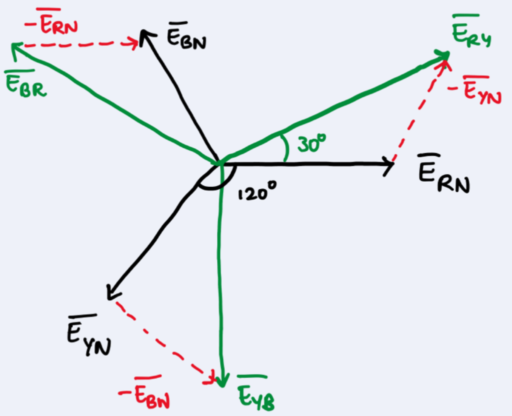
$$= \sqrt{3}\, E_{ph} \angle 30°$$

Simillarly, $\bar{E}_{YB} = \bar{E}_{YN} - \bar{E}_{BN} = \sqrt{3}\, E_{Ph} \angle -90$

$\bar{E}_{BR} = \bar{E}_{BN} - \bar{E}_{RN} = \sqrt{3}\, E_{Ph} \angle -210$

→ Magnitude of RMS Voltage = $\sqrt{3}$ (Magnitude of Phase Voltage)

→ Line voltage leads phase voltage by 30°



Relation b/w line & phase currents

→ $e_{RR'} = e_{RY}$; $e_{YY'} = e_{YB}$; $e_{BB'} = e_{BR}$

→ Applying KCL at R,

$\dot{i}_1 = \dot{i}_R + \dot{i}_3$

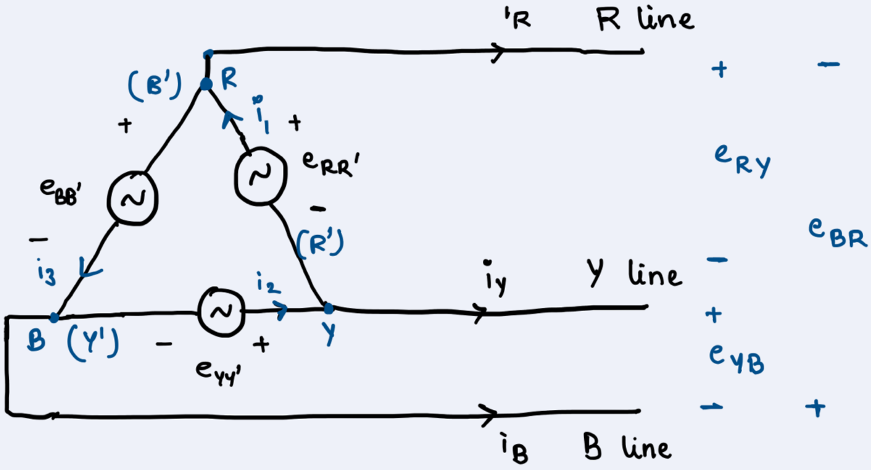
$\dot{i}_R = \dot{i}_1 - \dot{i}_3$

$= \frac{I_m}{\sqrt{2}} \angle 0 - \frac{I_m}{\sqrt{2}} \angle -240$

$= I_{ph} \angle 0 - I_{ph} \angle -240$

$= I_{ph} \left(\frac{3}{2} - \frac{\sqrt{3}}{2} i \right)$

$= \sqrt{3}\, I_{ph} \angle -30$



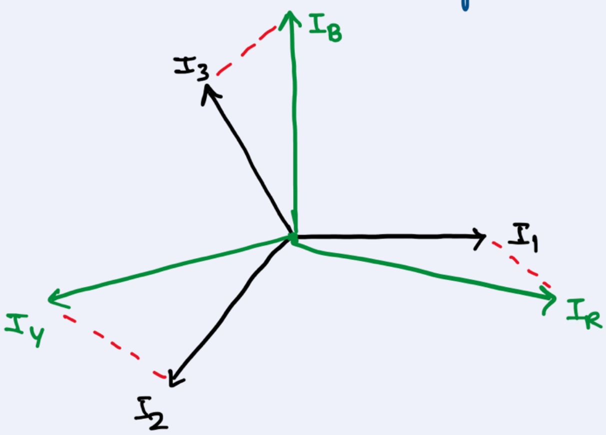
Similarly,

$I_B = \dot{i}_3 - \dot{i}_2 = \sqrt{3}\, I_{ph} \angle 90$

$I_Y = i_2 - i_1 = \sqrt{3}\, I_{ph} \angle -150$

→ Magnitude of RMS Current $= \sqrt{3}$ (Magnitude of Phase Current)

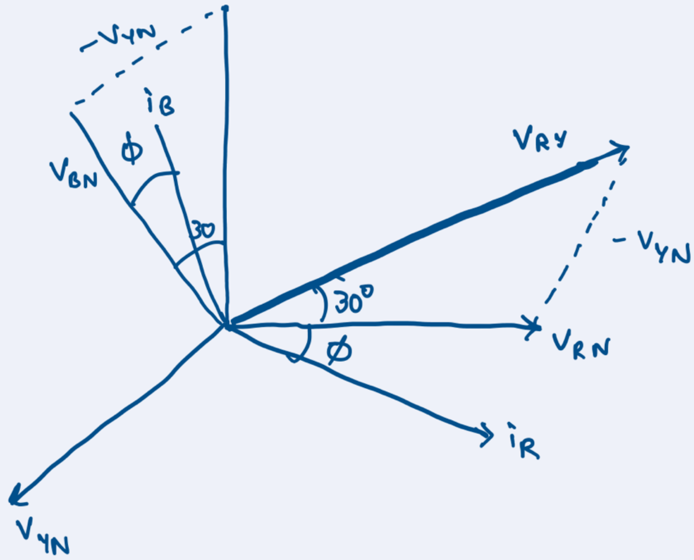
→ Line current lags phase current by $30°$



Inductive Load Wattmeter

$W_1 = V_{RY} . I_R \cos \angle V_{RY} I_R = V_L I_L \cos(30+\phi)$

$W_2 = V_{BY} I_B \cos \angle V_{BY} . I_B = V_L I_L \cos(30-\phi)$



$\bar{V}_{RY} = \bar{V}_{RN} - \bar{V}_{YN}$

$$W_1 + W_2 = V_{RY} I_R + V_{YB} + I_B$$

$$= V_L I_L \left(\cos(30+\phi) + \cos(30-\phi)\right)$$

$$= V_L I_L \left(\cos 30 \cos\phi - \sin 30 \sin\phi + \cos 30 \cos\phi + \sin 30 \sin\phi\right)$$

$$= V_L I_L \left(2 \times \frac{\sqrt{3}}{2} \times \cos\phi\right) = \sqrt{3} V_L I_L \cos\phi = P_{3\phi}$$

$$W_2 - W_1 = V_L I_L \sin\phi \Rightarrow \sqrt{3}(W_2 - W_1) = \sqrt{3} V_L I_L \sin\phi = Q_{3\phi}$$

$$\frac{Q_{3\phi}}{P_{3\phi}} = \tan\phi = \frac{\sqrt{3}(W_2 - W_1)}{(W_2 + W_1)} \Rightarrow \phi = \tan^{-1}\left(\frac{\sqrt{3}(W_2 - W_1)}{W_1 + W_2}\right)$$

ϕ	PF	W_1	W_2	Comments
0	1	$\frac{\sqrt{3} V_L I_L}{2}$	$\frac{\sqrt{3} V_L I_L}{2}$	$W_1 = W_2$
30	0.86	$\frac{V_L I_L}{2}$	$V_L I_L$	$W_1 = \frac{W_2}{2}$
60	0.5	0	$\frac{\sqrt{3} V_L I_L}{2}$	$W_1 = 0$, $W_2 = P_{3\phi}$
$> 60^\circ$	< 0.5	$-ve$	$+ve$	$W_1 = -ve$, $W_2 = +ve$

Capacitive Load Wattmeter

$$W_1 = V_L I_L \cos(30-\phi)$$

$$W_2 = V_L I_L \cos(30+\phi)$$

$$W_1 + W_2 = V_L I_L \left(\cos(30-\phi) + \cos(30+\phi)\right)$$

$$= \sqrt{3}\, V_L I_L \cos\phi = P_{3\phi}$$

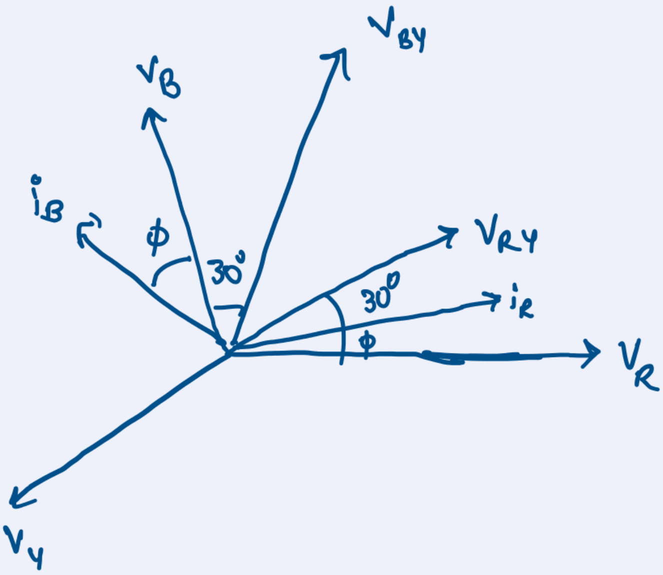
$$W_1 - W_2 = V_L I_L \left(\cos(30-\phi) - \cos(30+\phi)\right)$$

$$= V_L I_L \sin\phi$$

$$\sqrt{3}\, W_1 - W_2 = \sqrt{3}\, V_L I_L \sin\phi = Q_{3\phi}$$

$$\frac{Q_{3\phi}}{P_{3\phi}} = \tan\phi = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$$

$$\phi = \tan^{-1}\left(\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right)$$



ϕ	PF	W_1	W_2	Comments
0	1	$\frac{\sqrt{3} V_L I_L}{2}$	$\frac{\sqrt{3} V_L I_L}{2}$	$W_1 = W_2$
30	0.86	$V_L I_L$	$\frac{V_L I_L}{2}$	$W_1 = 2W_2$
60	0.5	$\frac{\sqrt{3} V_L I_L}{2}$	0	$W_2 = 0$, $W_1 = P_{3\phi}$
> 60°	< 0.5	+ve	−ve	$W_1 = +ve$, $W_2 = -ve$

Advantages of 3ϕ over 1ϕ

1) For certain amount of power to be transmitted over certain distance, 3 phase system requires less conductor material compared to single phase

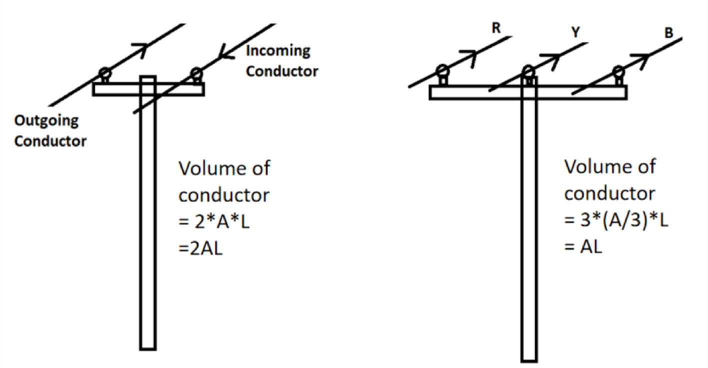


Fig: Single Phase Transmission Line

Fig: Three Phase Transmission Line

2) For same frame size, 3ϕ can handle higher amount of power compared to 1ϕ counterpart

$P_{1\phi} = V_L I_L \cos\phi$ $P_{3\phi} = \sqrt{3}\, V_L I_L \cos\phi$

3) 1ϕ power is pulsating in nature
3ϕ power is almost constant at every instant $\Rightarrow$ smoother, less noisy & better lifespan

4) 3ϕ induction motors are self starting
1ϕ induction motors aren't,
So, 3ϕ widely popular in industrial drives

Summary

MCB (Miniature Circuit Breaker)

Characteristics
Rated current not more than 100 A.
Trip characteristics normally not adjustable.
Thermal or thermal-magnetic operation.

MCCB (Moulded Case Circuit Breaker)
Characteristics
Rated current up to 1000 A.
Trip current may be adjustable.
Thermal or thermal-magnetic operation.

RCD (Residual Current Device / RCCB (Residual Current Circuit Breaker)
Characteristics
Phase (line) and Neutral both wires connected through RCD. It trips the circuit when there is earth fault current. The amount of current flows through the phase (line) should return through neutral. It detects by RCD any mismatch between two currents flowing through phase and neutral detect by RCD and trip the circuit within 30Miliseconed. RCDs are an extremely effective form of shock protection the most widely used are 30 mA (milliamp) and 100 mA devices. A current flow of 30 mA (or 0.03 amps) is sufficiently small that it makes it very difficult to receive a dangerous shock. Even 100 mA is a relatively small figure when compared to the current that may flow in an earth fault without such protection (hundred of amps)

ELCB (Earth Leakage Circuit Breaker)
Characteristics
Phase (line), Neutral and Earth wire connected through ELCB.
ELCB is working based on Earth leakage current.
Operating Time of ELCB:

The safest limit of Current which Human Body can withstand is 30ma sec.
Suppose Human Body Resistance is 500Ω and Voltage to ground is 230 Volt.
The Body current will be 500/230=460mA.
Hence ELCB must be operated in 30maSec/460mA = 0.65msec

Difference between ELCB and RCCB
ELCB is the old name and often refers to voltage operated devices that are no longer available and it is advised you replace them if you find one.
RCCB or RCD is the new name that specifies current operated (hence the new name to distinguish from voltage operated). The new RCCB is best because it will detect any earth fault. The voltage type only detects earth faults that flow back through the main earth wire so this is why they stopped being used. The easy way to tell an old voltage operated trip is to look for the main earth wire connected through it. RCCB will only have the line and neutral connections.
ELCB is working based on Earth leakage current. But RCCB is not having sensing or connectivity of Earth, because fundamentally Phase current is equal to the neutral current in single phase. That's why RCCB can trip when the both currents are deferent and it withstand up to both the currents are same. Both the neutral and phase currents are different that means current is flowing through the Earth. Finally both are working for same, but the thing is connectivity is difference. RCD does not necessarily require an earth connection itself (it monitors only the live and neutral).In addition it detects current flows to earth even in equipment without an earth of its own. This means that an RCD will continue to give shock protection in equipment that has a faulty earth. It is these properties that have made the RCD more popular than its rivals. For example, earth-leakage circuit breakers (ELCBs) were widely used about ten years ago. These devices measured the voltage on the earth conductor; if this voltage was not zero this indicated a current leakage to earth. The problem is that ELCBs need a sound earth connection, as does the equipment it protects. As a result, the use of ELCBs is no longer recommended.

Electrical Wires & Cables

More often than not, the terms wire and cable are used to describe the same thing, but they are actually quite different. Wire is a single electrical conductor, whereas a cable is a group of wires swathed in sheathing. The term cable originally referred to a nautical line of multiple ropes used to anchor ships, and in an electrical context, cables (like wires) are used to carry electrical currents.

Whether indoors or outdoors, proper wire and cable installation is of paramount importance - ensuring a smooth electricity supply, as well as passing electrical inspections. Each wire and cable needs to be installed carefully, from the fuse box to the outlets, fixtures and appliances. The National Electrical Code (NEC) and Local Building Codes regulate the manner of installation and the types of wires and cables for various electrical applications.

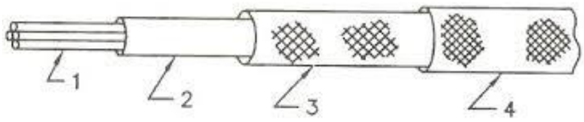
- Wires/cables are conducting materials which are made of copper, aluminum, silver, iron, and alloyed metals like nichrome wire, constantan, and German silver wire.
- It is used to conduct power from the point where it is generated to the point where it is used.
- Wires/cables are all electric conductors but not all conductors are wires. These wires are either made of solid or stranded. Most wires are round although square and rectangular forms are also used in specific applications. These wires are manufactured with or without insulation depending upon the application.
- Copper or aluminum wires without insulation are usually used for grounding connection and also for high tension or high voltage transmission lines.
- Nichrome wire, constantan, manganin, and German silver wires are used as r esistance wires in electrical equipment and appliances.
- All wires/cables have resistances that oppose the unlimited flow of current and causes voltage drop resulting in the eventual heat developed in the wire. The heat developed varies according to the square of the current in amperes.
- There is a limit to the degree of heat that various types of wire insulation and sizes can safely withstand. They should not be allowed to reach a temperature that might cause a fire.
- The Electrical Code specifies the maximum current-carrying capacity in amperes that is safe for wires of different with different insulations and under different circumstances and conditions.

Types of Wires

- ❖ Vulcanised Indian Rubber wire (V.I.R)
- ❖ Tough Rubber Sheathed wire (T.R.S)
- ❖ Poly Vinyl Chloride wire (P.V.C.)
- ❖ Lead Alloy Sheathed wire
- ❖ Weather Proof wires
- ❖ Mineral Insulated Copper Covered wire

Vulcanised Indian Rubber wire (V.I.R)

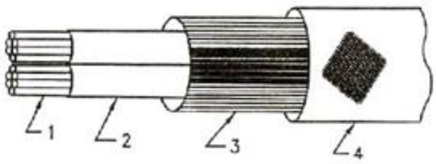
- A VIR wire mainly consists of a tinned conductor having rubber coating.
- Tinning of the conductor prevents the sticking of rubber to the conductor.
- Thickness of the rubber mainly depends on the operating voltage to which the wire is designed.
- Cotton braiding is done over the rubber insulation to protect the conductor from the moisture.
- Finally the wire is finished with the wax for cleanliness.
- They are suitable for low and medium voltage only.
- Now a days this type of wires are not in use since a better quality wires are available at cheaper rate



1. CONDUCTOR 2. RUBBER INSULATION 3. BRAIDING
4. SECOND LAYER OF BRAIDING

Cabe tyre sheath wire (CTS)/Tough Rubber Sheathed wire (T.R.S)

- This type of wire is modification of VIR wire. It consists of the ordinary rubber coated conductors with additional sheath of tough rubber.
- This layer provides better protection against moisture and wear and tear. Also it provides an extra insulation.
- These wires are generally available in single conductor,2 conductor or 3 conductor

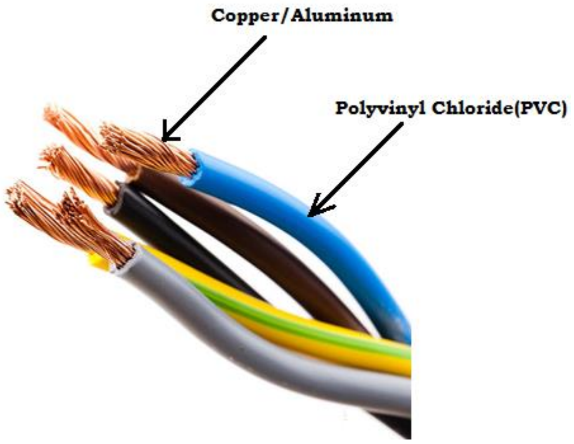


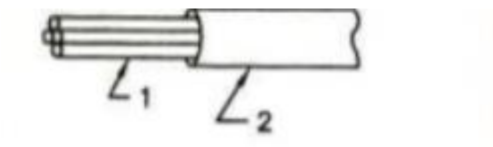
1. CONDUCTOR 2. RUBBER INSULATION 3. RUBBER SHEATH
4. BRAIDING

Poly Vinyl Chloride wire (P.V.C.)

- This is most commonly used wire for wiring purpose.
- Conductor is insulated by poly vinyl chloride (insulating material)
- PVC has following properties:
    - Moisture free
    - Tough
    - Durable
    - Chemically inert
    - High life
    - High dielectric strength
    - No disturb in vibration

- But it softens at high temperatures therefore not suitable for connection to heating appliances
- Available in 600V,660V,1100V,widely used long life durable against water, heat, oil, UV light

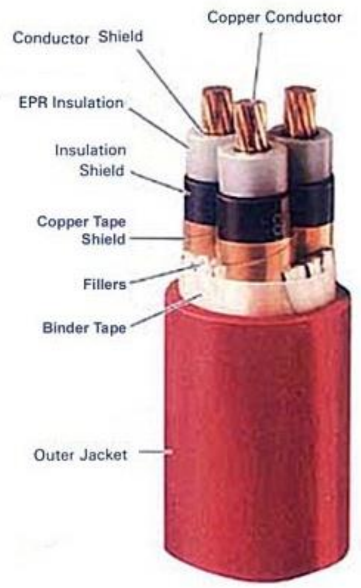




1. CONDUCTOR 2. PVC INSULATION

Lead Alloy Sheathed wire

- The ordinary wires can be used only at dry places but for damp places these wires are covered with continuous lead sheaths.
- The layer of lead covering is very thin like 0.12 cm thick.
- These wires provide little mechanical protections to the wires.



Weather Proof wires

- These types of wire are used outdoors i.e. providing a service connection from overhead line to building, etc.
- In this type of wire the conductor is not tinned and the conductor is covered with three braids of fibrous yarn and saturated with water proof compound.

Fig: Weather Proof wires

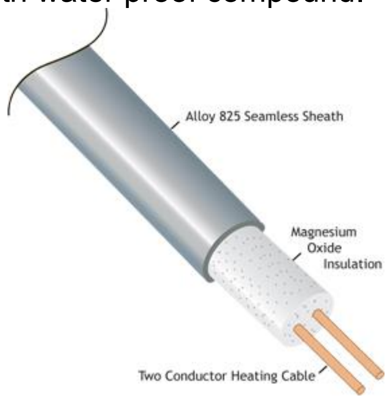


Fig: MICC wire

Mineral Insulated Copper Covered (MICC) wire

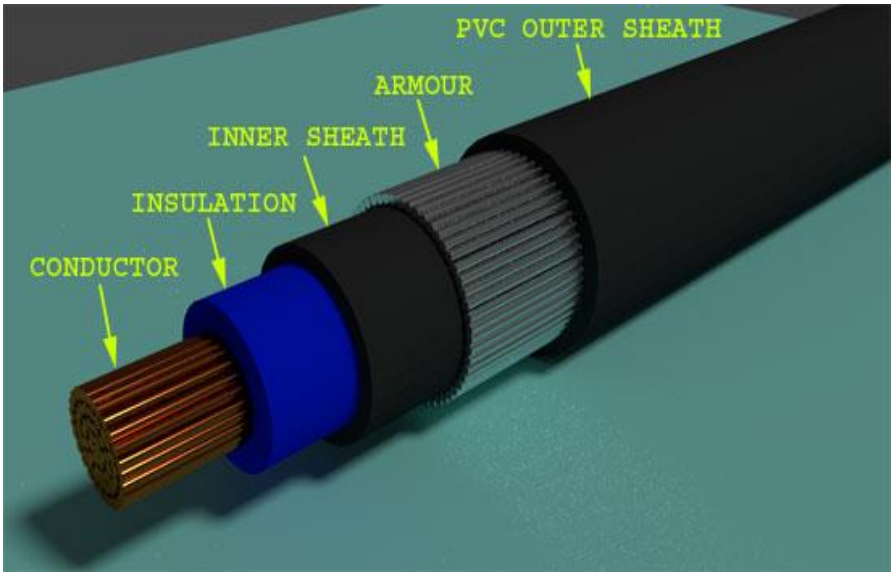
In this type wire copper conductor is coated with magnesium oxide and after that copper coating is done on it. In case of moisture weather PVC coating (serving) is coated on it. It is used in mines, factory, furnace, boiler, rolling mills, etc. magnesium oxide is used for avoiding moisture problems.

CABLES

A power cable is an assembly of two or more electrical conductors, usually held together with an overall sheath. The assembly is used for transmission of electrical power. Power cables may be installed as permanent wiring within buildings, buried in the ground, run overhead, or exposed. Flexible power cables are used for portable devices, mobile tools and machinery.

Construction

The power cable mainly consists of three main components, namely, conductor, dielectric, and sheath. The conductor in the cable provides the conducting path for the current. The insulation or dielectric withstands the service voltage and isolates the conductor with other objects. The sheath does not allow the moistures to enter and protects the cables from all external influences like chemical or electrochemical attack, fire, etc. The main components of electrical power cables are explained below in details.



Conductor

Coppers and aluminum wires are used as a conductor material in cables because of their high electrical conductivity. Solid or number of bare wires made of either copper or aluminum is used to make a power cable.

Insulation

The most commonly used dielectric in power cables is impregnated paper, butyl rubber, polyvinyl chloride cable, polyethylene, cross-linked polyethylene. Paper insulated cables are mostly preferred because their current carrying capacity is high, generally reliable and having a long life. The dielectric compound used for the cable should have following properties.

- The insulator must have high insulation resistance.
- It should have high dielectric strength so that it does not allow the leakage current to pass through it.
- The material must have good mechanical strength.
- The dielectric material should be capable of operating at high temperature.
- It should have low thermal resistance.
- It should have a low power factor.

Inner Sheath

- It is used for protecting the cable from moistures which would affect the insulation. Cable sheath is made up of lead alloy, and these strengths withstand the internal pressures of the pressurized cables. The material used for inner sheath should be nonmagnetic material.
- The aluminum sheath is also used in a power cable because it is cheaper, smaller in weight and high mechanical strength than the lead sheath. In oil-

filled cables and telephone, cables corrugated seamless aluminum sheath is used because it has better-bending properties, reduced thickness, and lesser weight.

Armouring

Armouring is the process in which layers of galvanized steel wires or two layers of metal tape are applied over sheath for protecting it from mechanical damage. The steel wires are normally used for armouring because it has high longitudinal strength. Armouring is also used for earthing the cable. When the fault occurs in the cable (due to insulation failure) the fault current flows through the armour and get earthed.

Over Sheath

It gives the mechanical strength to the cables. It protects the cable from overall damage like moisture, corrosion, dirt, dust, etc. The thermosetting or thermoplastic material is used for making over the sheath.

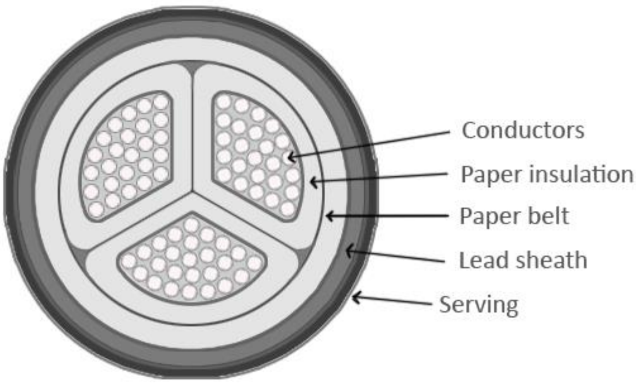
Classification Based Upon Voltage Rating Of the Cable

1. **Low tension cables**: These have a maximum voltage handling capacity of 1000 V (1 kV)
2. **High tension cables**: These have a maximum voltage handling capacity of 11 kV.
3. **Super tension cables**: These have a maximum voltage handling capacity of 33 kV.
4. **Extra high tension cables**: These have a maximum voltage handling capacity of 66 kV.
5. **Extra super voltage cables**: These are used for applications with voltage requirement above 132 kV.

Classification Based Upon Construction of the Cable

1. **Belted Cable**

In such cables, the conductors (usually three) are bunched together and then bounded with an insulating paper 'belt'. In such cables, each conductor is insulated using paper impregnated with a suitable dielectric. The gaps between the conductors and the insulating paper belt are filled with a fibrous dielectric material such as Jute or Hessian. This provides flexibility as well as a circular shape. As we discussed earlier (in Construction of Cables), the jute layer is then covered by a metallic sheath and armouring for protection. One particular specialty of this cable is that its shape may not be perfectly circular. It is kept non-circular to use the available space more effectively.



There are some limitations of such construction. Since the electric field is tangential, the insulation provided is stressed. As a result, the dielectric strength falls over time. Hence, such construction isn't preferred for voltage levels above 11 kV.

2. **Pressure Cables**

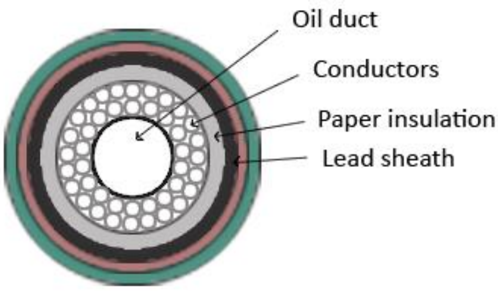
For voltages beyond 66 kV, the electrostatic stresses in the cables exceed the acceptable values and solid cables become unreliable. This occurs mainly because voids are created when voltages exceed 66 kV. Hence, instead of solid cables, we use Pressure cables. Typically, such cables are either oil filled or gas filled.

- **Oil Filled Cables**

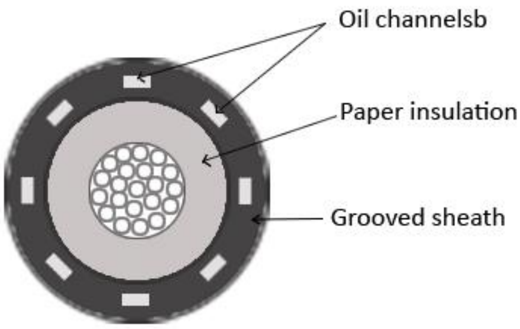
Oil is circulated under suitable pressure through ducts provided for such purpose. This oil supply and pressure are maintained through reservoirs kept at proper distances. The oil used is the same that is employed for impregnation of paper insulators.

- **Gas Filled Cables**

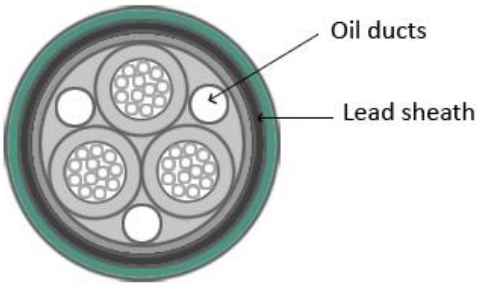
Pressurized gas (usually dry nitrogen) is circulated around cables in an air-tight steel pipe. Such cables are cable of carrying higher values of load current and can operate at higher values of voltage. But the overall cost is more.



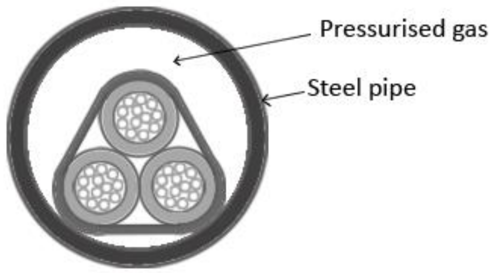
Single core conductor channel oil filled cable



Single core sheath channel oil filled cable



Three core oil filled cable



Three core gas pressure cable

Earthing

Earthing or grounding is the process of transferring the immediate discharge of electricity directly to the earth plate, by means of low resistance electrical cables or wires. Earthing really is one of the most important aspects of electric networks, since it makes the most readily available and dangerous source of power much safer to use.

In case of a short circuit due to leakages arising from weak insulation or damage, the grounding wire safely removes excess electricity and passes it on to the ground

Earthing or Grounding in an electrical network works as a safety measure to protect human life as well as equipment, the main objective of the Earthing system is to provide an alternative path for dangerous currents to flow so that accidents due to electric shock and damage to the equipment can be avoided.

Metallic parts of equipment are grounded or connected to the earth and if the equipment insulation fails for any reason, then the high voltages that can be present in the equipment covering or outer box need some path to get discharged. If the equipment is not earthed, these dangerous voltages can be transferred to anyone who touches it resulting in an electric shock.

The circuit gets shorted and the fuse will blow immediately, in case a live wire touches the earthed case.

Why Do You Need an Earthing System in an Electrical Network?

This question generally arises when you have all the right equipment, wires, sockets and well maintained electrical devices. Yet, why is there a need for an Earthing system?

The answer is very simple…

Earthing system makes the equipment electrically shock free and gives you a safe place to stay.

Here are some advantages of the Earthing system:

1. **Safety for Human Life, Electrical Devices and Buildings**

It saves the human life from the danger of electrical shock which can cause death, by blowing a fuse. It protects your electric equipment or devices. It provides a safe path for lighting and short circuit currents and saves the building from structural damage.

2. **Voltage Stabilization**

Electricity comes from many sources, every transformer can be considered as a separate source. If there is no point which will act as a common point, then it is impossible to make a calculation between these sources.

In an electrical distribution system, Earth is the omnipresent conductive surface, which makes it a universal standard for all-electric systems.

3. Over Voltage Protection

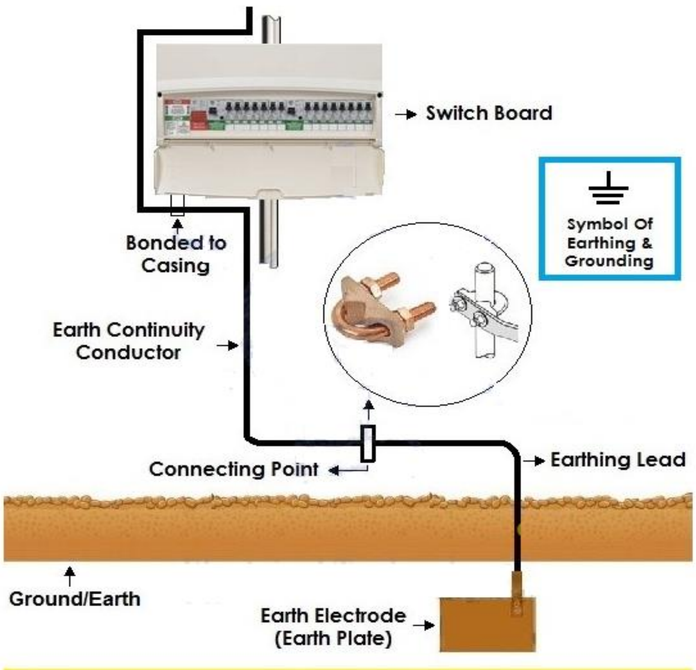
Earthing System provides an alternative path in the electrical system to minimize the dangerous effect in the electrical system which happens at the time of lighting and unintentional contact with high voltage lines.

Now that you have got an idea of the Earthing system, it is time to know how to set up an Earthing or Grounding system at your home, office or shop.

Components of Earthing System

A complete electrical earthing system consists on the following basic components.

- Earth Continuity Conductor
- Earthing Lead
- Earth Electrode



Components of an Earthing/Grounding System

Earth Continuity Conductor or Earth Wire

That part of the earthing system which interconnects the overall metallic parts of electrical installation e.g. conduit, ducts, boxes, metallic shells of the switches, distribution boards, Switches, fuses, Regulating and controlling devices, metallic parts of electrical machines such as, motors, generators, transformers and the metallic framework where electrical devices and components are installed is known as earth wire or earth continuity conductor as shown in the above fig.

The resistance of the earth continuity conductor is very low. According to IEEE rules, resistance between consumer earth terminal and earth Continuity conductor (at the end) should not be increased than 1Ω. In simple words, **resistance of earth wire should be less than 1Ω**.

Size of Earth Continuity Conductor

The cross sectional area of the **Earth Continuity Conductor** should not be less than the half of the cross sectional area of the thickest wire used in the electrical wiring installation.

Earthing Lead or Earthing Joint

The conductor wire connected between earth continuity conductor and earth electrode or earth plate is called earthing joint or "Earthing lead". The point where earth continuity conductor and earth electrode meet is known as "connecting point" as shown in the above fig.

Earthing lead is the final part of the earthing system which is connected to the earth electrode (which is underground) through earth connecting point.

There should be minimum joints in earthing lead as well as lower in size and straight in the direction. Generally, copper wire can be used as earthing lead but, copper strip is also used for high installation and it can handle the high fault current because of wider area than the copper wire. A hard drawn bare copper wire is also used as an earthing lead. In this method, all earth conductors connected to a common (one or more) connecting points and then, earthing lead is used to connect earth electrode (earth plat) to the connecting point.

To increase the safety factor of installation, two copper wires are used as earthing lead to connect the device metallic body to the earth electrode or earth plate. I.e. if we use two earth electrodes or earth plats, there would be four earthing leads. It should not be considered that the two earth leads are used as parallel paths to flow the fault currents but both paths should work properly to carry the fault current because it is important for better safety.

Size of the Earthing Lead

The size or area of earthing lead should not be less than the half of the thickest wire used in the installation.

Earthing Electrode or Earth Plate

A metallic electrode or plate which is buried in the earth (underground) and it is the last part of the electrical earthing system. In simple words, the final underground metallic (plate) part of the earthing system which is connected with earthing lead is called earth plate or earth electrode.

A metallic plate, pipe or rode can be used as an earth electrode which has very low resistance and carry the fault current safely towards ground (earth).

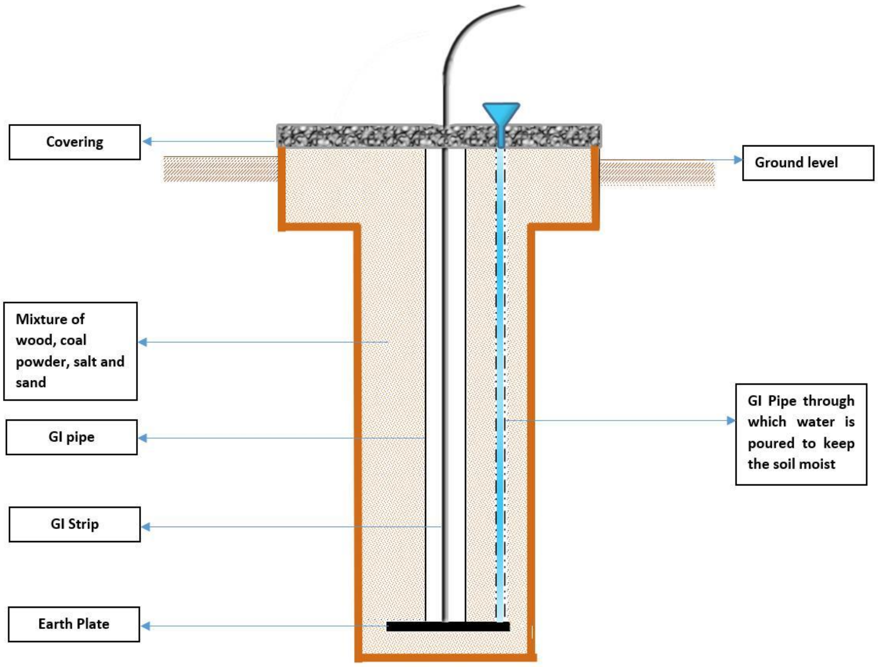
Size of Earthing Electrode
Both copper and iron can be used as earthing electrode.
The size of earth electrode (In case of copper)
2×2 (two foot wide as well as in length) and 1/8 inch thickness i.e. 2' x 2' x 1/8". (600x600x300 mm)
In case of Iron
2' x2' x ¼" = 600x600x6 mm
It is recommended to bury the earth electrode in the moisture earth. If it is not possible, then put water in the GI (Galvanized Iron) pipe to make possible the moisture condition.
In the earthing system, put the earth electrode in vertical position (underground) as shown in the above fig. Also, put a 1 foot (about 30cm) **layer of powdered charcoal and lime mixture** around the earth plate (don't confuse with earth electrode and earth plate as both are the same thing).
This action makes the possible increase in the size of the earth electrode which leads a better continuity in the earth (earthing system) and also helps to maintain the moisture condition around earth plate.

General method of Earthing / Proper Grounding Installation (Step by Step)

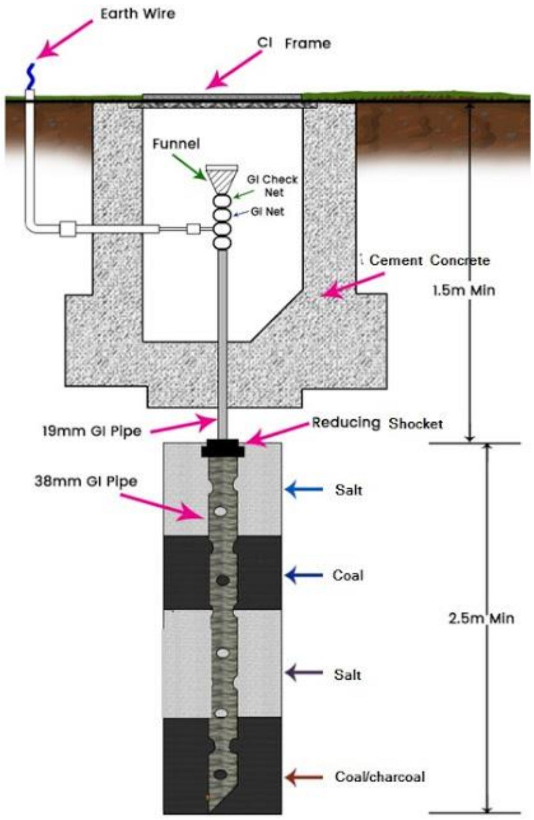
The usual method of earthing of electric equipments, devices and appliances are as follow:

1. First of all, dig a 5x5ft (1.5×1.5m) pit about 20-30ft (6-9 meters) in the ground. (Note that, depth and width depends on the nature and structure of the ground)
2. Bury an appropriate (usually 2' x 2' x 1/8" (600x600x300 mm) copper plate in that pit in vertical position.
3. Tight earth lead through nut bolts from two different places on earth plate.
4. Use two earth leads with each earth plate (in case of two earth plates) and tight them.
5. To protect the joints from corrosion, put grease around it.
6. Collect all the wires in a metallic pipe from the earth electrode(s). Make sure the pipe is 1ft (30cm) above the surface of the ground.
7. To maintain the moisture condition around the earth plate, put a 1ft (30cm) layer of powdered charcoal (powdered wood coal) and lime mixture around the earth plate of around the earth plate.
8. Use thimble and nut bolts to connect tightly wires to the bed plates of machines. Each machine should be earthed from two different places. The minimum distance between two earth electrodes should be 10 ft (3m).
9. Earth continuity conductor which is connected to the body and metallic parts of all installation should be tightly connected to earth lead.
10. At last (but not least), test the overall earthing system through earth tester. If everything is going about the planning, then fill the pit with soil. The maximum allowable resistance for earthing is 1Ω. If it is more than 1 ohm, then increase the

size (not length) of earth lead and earth continuity conductors. Keep the external ends of the pipes open and put the water time to time to maintain the moisture condition around the earth electrode which is important for the better earthing system.



PROCEDURE FOR PIPE OR ROD ELECTRODE EARTHING



- Make a borehole of 500 mm diameter and 3.5 meters deep or as per the approved design and drawing.
- Lower the Pipe electrode made of a 65 mm diameter GI perforated pipe of 3.0-meter length attached at the top with a funnel covered with wire mesh. A G.I. strip is fixed to the electrode to act as an earthing connection. For rod earthing, a copper rod of required diameter is used in place of the pipe.
- Fill the annular space between the electrode and borehole walls with alternating layers of coke or charcoal and common salt.
- Inspection chamber: Construct brick chamber of size 450 x 450 x 450 mm with 100 mm thick brick walls over a P.C.C. layer. Keep 100 mm of the chamber above ground level. Cover the top with a cast iron (CI) cover.
- Follow the approved design and drawing for fixing and laying of earth wires or GI/copper strips between the earth electrode and the electrical room.

SUGGESTED ITEM DESCRIPTION FOR G.I. PIPE ELECTRODE EARTHING:

Supply and erection of G.I. earth pipe electrode 65 mm diameter, at least 3.0 meter below ground with 40 Kg alternate layers of charcoal and salt with and with wire mesh funnel for watering, 230 brick masonry chamber (450 mm x 450 mm x 450 mm), C.I. cover 300mm x 300mm (10 Kg) complete with necessary length of double G.I. earth wire no. 6 SWG bolted with lug to the plate and covered in 12 mm dia G.I. pipe 3.0 meter long complete connected to the nearest switchgear with end socket and duly tested by earth tester and

Unit -4

EMF equation of DC Generator

→ P : No. of poles in stator

→ ϕ : Flux per pole (Wb)

→ A : No. of parallel paths → lap ⇒ $A = P$; wave ⇒ $A = 2$

→ N : Speed of armature (rpm)

→ E_g : EMF induced in any parallel path

→ Z : Total no. of conductors

The flux cut by a conductor in 1 rev $= P\phi$

Time taken to complete 1 revolution $= \frac{60}{N}$ secs

EMF induced in 1 conductor per sec, $E_g = \frac{P\phi}{60/N} = \frac{P\phi N}{60}$ Volts

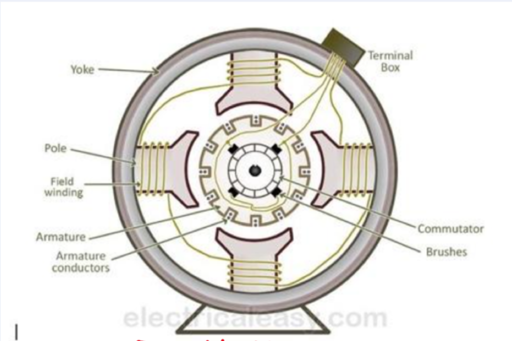
EMF induced for all conductors per parallel path, $E_g = \frac{P\phi N}{60} \times \frac{Z}{A}$ Volts

For lap winding, $A = P$ ⇒ $E_g = \frac{P\phi NZ}{60P}$ Volts

For Wave winding, $A = 2$ ⇒ $E_g = \frac{P\phi NZ}{120}$ Volts

DC Machines

→ Principle of Operation :



DC Machine

→ DC Motor converts electrical energy into mechanical energy . Construction is similar to DC Generator

→ Whenever a current carrying conductor is placed in a magnetic field, it experiences force

$$\underbrace{F}_{\text{Force}} = \overbrace{B}^{\text{Flux Density } (wb/m^2)} \cdot \underbrace{I}_{\text{Current } (A)} \cdot \overbrace{L}^{\text{Length of conductor } (m)} = BIL\sin\theta$$

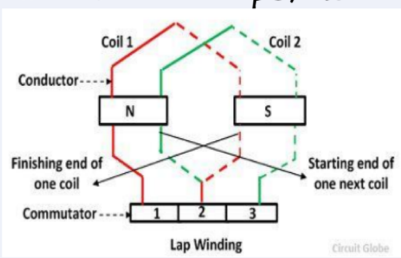
Lap Winding

→ Used for high current, low voltage devices

→ Used to increase no. of $\parallel^{el}$ paths enabling armature current to increase

→ Used to improve commutation as current per conductor decreases

$\underbrace{A}_{\text{No. of Parallel paths}} = P \Rightarrow$ No. of poles



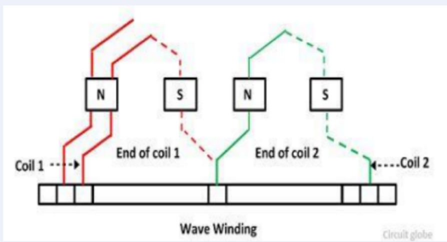
Wave Winding

→ Used for low current, high voltage devices

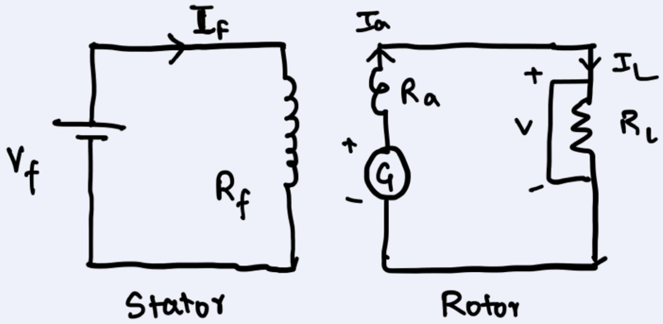
→ No. of parallel paths (A) is fixed to 2

→ No. of brushes = No. of parallel paths

→ No. of poles can be anything



Equivalent Circuit for seperately excited DC Generator



$$E_g = V + I_a R_a \quad (KVL)$$

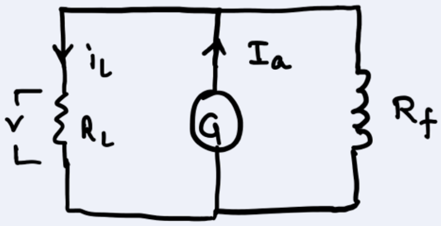
$$I_a E_g = V I_a + I_a^2 R_a$$

$$P_i = P_o + P_L$$

Potential drop due to brush contact

and, $I_a E_g = I_a V + I_a^2 R_a + \underbrace{I_a V_{Brush}}_{\text{loss}}$

Equivalent Circuit of Parallel Generator Machine



$$I_a = i_L + i_f \quad (KCL)$$

$$i_L = \frac{V}{R_L}$$

$$i_f = \frac{V}{R_f}$$

$$I_a = \frac{P_L}{V} + \frac{V}{R_f}$$

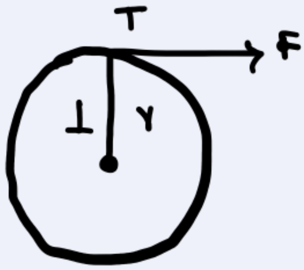
Torque equation

→ Turning moment about its axis

τ = Force x distance

$= F \times r$

$F = \dfrac{\tau}{r}$



$$P_a = I_a E_g = \text{Work done} \times \text{time}$$

$$= F \times 2\pi r \times \frac{N}{60}$$

$$= \frac{\tau}{\cancel{r}} \times 2\pi \cancel{r} \times \frac{N}{60}$$

$$\Rightarrow \tau = \frac{I_a E_g \times 60}{2\pi N} = T_a$$

$$T_a = \frac{I_a \times P\phi N Z \times 60}{2\pi \times 60 \times AN}$$

$$T_a = \frac{I_a P\phi Z}{2\pi A}$$

- Loses in DC Machines
  - Copper Loss
    - Armature Copper Loss $\rightarrow I_a^2 R_a$
    - Series Field Copper Loss $\rightarrow I_a^2 R_a$
    - Parallel/ Shunt Field Copper Loss $\rightarrow I_f^2 R_f$
  - Iron Loss
    - Eddy Current Loss
    - Hysteresis Loss
  - Mechanical loss
    - Friction Loss
    - Windage Loss

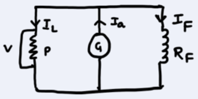
Variable Losses, $W_v = I_a^2 R_a$

Total Cu Loss = $I_a^2 R_a + I_f^2 R_f$

Constant Losses

= Iron Loss + Parallel Field Cu loss + Mech los

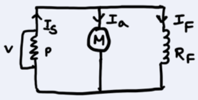
= Iron Loss + $I_f^2 R_f$ + Mech Loss



Generator

$I_a = I_L + I_F$

$= \frac{P}{V} + \frac{V}{R_F}$



Motor

$I_a = I_S - I_F$

$= I_S - \left(\frac{V}{R_F}\right)$

EMF eq. in transformer

$$E_1 = -N_1 \frac{d\phi}{dt}$$

$$-N_1 \phi_m \cos wt \times w$$

$$-N_1 w \phi_m (\sin(90 - wt))$$

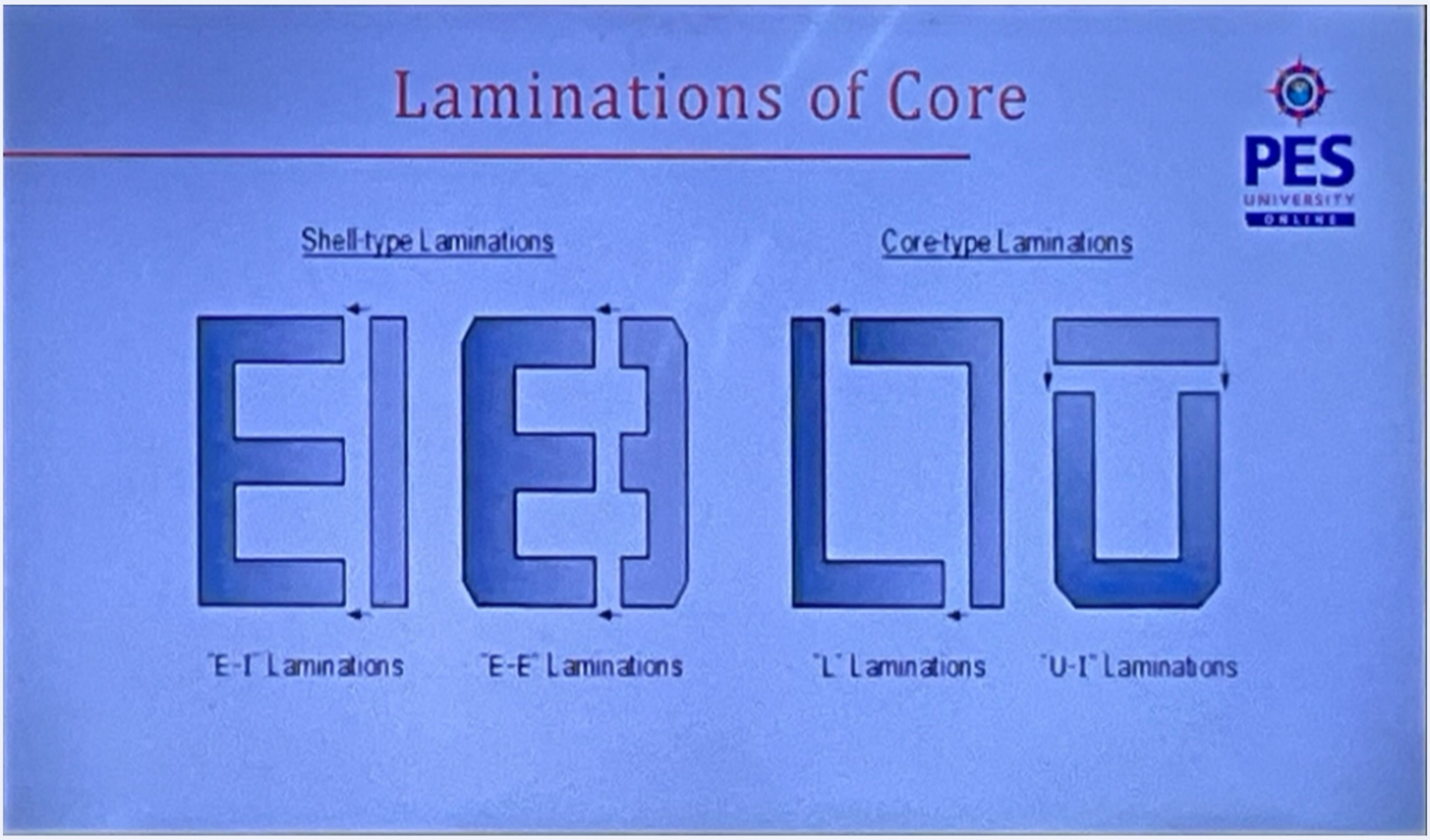
$$N_1 w \phi_m \sin(wt - 90)$$

$$2N_1 \pi f \phi_m \sin(wt - 90)$$

$$E_m = 2N_1 \pi f \phi_m$$

$$E_{rms} = \frac{2N_1 \pi f \phi_m}{\sqrt{2}} = 4.44 N_1 f \phi_m$$

Core v/s Shell Type



Core	shell type.
1) The winding encircles the core	1) The core encircles most of the winding
2) It has single magnetic ckt	2) It has double.
3) The core has two limbs	3) 3 limbs.
4) cylindrical coils are used	4) multilayer disc coils are used
5) The windings are uniformly distributed on two limbs hence. natural cooling is effective	5) natural cooling does not exist. as the windings are surrounded by the core.
6) The coils can be easily removed for maintainance	6) The coils cannot be removed Easily.
7) prefered for HV LC	7) preferred for LV HC

3 Phase induction motor

Advantages -

i) Simple & rugged

ii) Low cost & reliable

iii) High efficiency

iv) Low maintainance cost

v) Self - starting motor

vi) Can be manufactured to suit industry requirements

vii) Most widely used motors

→ It has 2 Main Parts

i) Rotor (Rotating Part) (ii) Stator (stationary Part))

→ Squirrel Cage motor

- Rotor winding is compared of Cu bars embedded in rotor slots & shorted at both ends of rings
- Simple, low cost, robust, low maintainance

→ Phase wound rotor / slip ring motor

- Rotor windings are wound by wires. The winding terminals can be connected to external circuits through slip rings & brushes
- More expensive

→ RMF = Rotating Magnetic Field

N_s = Synchronous speed / RMF speed

$N_s = \frac{120f}{P}$ (f = freq, P = poles)

→ Working

- RMF is setup in stator when 3ϕ supply is given
- Stationary motor conductors cuts revolving field due to EMI, & emf is induced in motor conductors
- As motor conductors are short circuited, current flows through them
- Hence, it becomes a current carrying conductor in magnetic field, which experiences the force & starts rotating