***Manonmaniam Sundaranar University,***

***Directorate of Distance & Continuing Education,***

***Tirunelveli - 627 012 Tamilnadu, India***

***OPEN AND DISTANCE LEARNING (ODL) PROGRAMMES***

*(FOR THOSE WHO JOINED THE PROGRAMMES FROM THE ACADEMIC YEAR 2023–2024)*

# *M.Sc. Physics*

# *Course Material*

## *Home Electrical Installation*

## *JSPH21*

***Prepared***

***By***

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# B.Sc. Physics I Year

# HOME ELECTRICAL INSTALLATION

## Syllabus

| HOME ELECTRICAL INSTALLATION | |
|---|---|
| **Learning Objective:** The students will get knowledge on electrical instruments, installations and domestic wiring techniques with safety precautions and servicing. | |
| **UNITS** | **COURSE DETAILS** |
| **UNIT-I** | **SIMPLE ELECTRICAL CIRCUITS: c**harge, current, potential difference, resistance – simple electrical circuits – DC ammeter, voltmeter, ohmmeter – Ohm's law – difference between DC and AC – advantages of AC over DC – electromagnetic induction - transformers – inductors/chokes – capacitors/condensers – impedance – AC ammeter, voltmeter –symbols and nomenclature |
| **UNIT-II** | **TRANSMISSION OF ELECTRICITY:** production and transmission of electricity – concept of power grid – Series and parallel connections – technicalities of junctions and loops in circuits –transmission losses (qualitative) – roles of step-up and step-down transformers – quality of connecting wires – characteristics of single and multicore wires |
| **UNIT-III** | **ELECTRICAL WIRING:** different types of switches – installation of two way switch – role of sockets, plugs, sockets - installation of meters – basic switch board – electrical bell – indicator – fixing of tube lights and fans – heavy equipment like AC, fridge, washing machine, oven, geyser, jet pumps – provisions for inverter – gauge specifications of wires for various needs |
| **UNIT-IV** | **POWER RATING AND POWER DELIVERED:** conversion of electrical energy in to different forms – work done by electrical energy – power rating of electrical appliances – energy consumption – electrical energy unit in kWh – calculation of EB bill – Joule's heating – useful energy and energy loss – single and three phase connections – Measures to save electrical energy – energy audit |

| | |
|---|---|
| **UNIT-V** | **SAFETY MEASURES:** insulation for wires – colour specification for mains, return and earth – Understanding of fuse and circuit breakers – types of fuse: kit-kat, HRC, cartridge, MCB, ELCB – purpose of earth line – lighting arrestors – short circuiting and over loading – electrical safety – tips to avoid electrical shock – first aid for electrical shock – fire safety for electric current |
| **TEXT BOOKS** | 1. Wiring a House: 5th Edition by Rex Cauldwell, (2014).<br>2. Black and Decker Advanced Home Wiring, 5th Edition: Backup Power - Panel Upgrades - AFCI Protection - "Smart" Thermostats, by Editors of Cool Springs Press, (2018).<br>3. Complete Beginners Guide to Rough in Electrical Wiring: by Kevin Ryan (2022). |

# UNIT I

# SIMPLE ELECTRICAL CIRCUITS

## CHARGE

Electric Charge is the basic property of the material that is responsible for the electrostatic property of the material. Electric charge, which can be positive or negative, occurs in discrete natural units and is neither created nor destroyed.

Many fundamental, or subatomic, particles of matter have the property of electric charge. For example, electrons have negative charge and protons have positive charge, but neutrons have zero charge. The negative charge of each electron is found by experiment to have the same magnitude, which is also equal to that of the positive charge of each proton. Charge thus exists in natural units equal to the charge of an electron or a proton, a fundamental physical constant.

1. **Magnitude**: Electric charge exists in discrete quantities, and the smallest unit of charge is the charge of an electron or proton, which is approximately $1.6\times10^{-19}$ coulombs (C). Charges can be positive or negative. The charge of an electron is considered negative, while the charge of a proton is considered positive.
2. **Conservation**: Electric charge is conserved in isolated systems. This means that the total electric charge within a closed system remains constant over time. In any process, the total amount of positive charge must equal the total amount of negative charge.

3. **Additivity**: Electric charge is additive. The total charge of a system is the algebraic sum of the charges of its constituents. For example, if two objects carry charges of +3C and -2C respectively, the net charge of the system is +1C.

4. **Quantization**: Electric charge comes in discrete packets. The charge of any object is always an integer multiple of the elementary charge, *e*, which is the charge of a single proton or electron.

5. **Attraction and Repulsion**: Charged objects exert forces on each other according to Coulomb's law. Like charges repel each other, while opposite charges attract each other. The magnitude of the force is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them.

6. **Mobility**: Electric charge can move through conductive materials, such as metals or electrolytes, under the influence of an electric field. This movement of charge is what constitutes an electric current.

## Current

When charge is flowing in a circuit, current is said to exist. An electric current is the physical phenomenon of the displacement or flow of an electric charge, usually of electrons, by means of a conductive material. In order for there to be an electric current, the electrons furthest from the nucleus of an atom of a certain material must detach and circulate freely through a conductor in an electrical circuit.

Mathematically, current describes the rate at which charge flows through a conductor.

The intensity of the electric current is determined by the amount of charge passing through a conductor in a unit of time. The intensity is measured in coulombs per second (C/s), which is equivalent to one ampere (A).

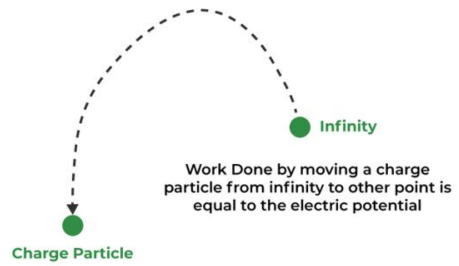
1. **Direction**: Electric current flows from the positive terminal to the negative terminal in a circuit. This convention is opposite to the actual movement of electrons, which flow from negative to positive.
2. **Magnitude**: The magnitude of electric current is measured in amperes. One ampere is equivalent to the flow of one coulomb of charge per second.
3. **Resistance**: The opposition to the flow of electric current in a material is known as resistance. It is measured in ohms (Ω). Ohm's law states that the current flowing through a conductor between two points is directly proportional to the voltage across the two points and inversely proportional to the resistance between them.
4. **Voltage**: Electric current flows in response to a potential difference, or voltage, between two points in a circuit. Voltage is measured in volts (V) and represents the energy per unit charge.
5. **Power**: The rate at which electric energy is transferred by an electric circuit is known as electric power. It is measured in watts (W) and can be calculated as the product of voltage and current ($P = VI$) or as the square of current multiplied by resistance ($P = I^2R$).

6. **Conductivity**: The ability of a material to conduct electric current is termed as conductivity. Materials with high conductivity, such as metals, allow electric current to flow easily, while insulators have low conductivity, impeding the flow of current.

7. **Temperature Dependence**: The resistance of a material typically increases with temperature. This property is used in devices like thermistors and resistive heating elements.

## Potential Difference

Electric potential difference is also known as voltage. The electric potential difference is the work done per unit charge to move a unit charge from one point to another in an electric field. The energy possessed by Electric charges is known as electrical energy. A charge with higher potential will have more potential energy, and a charge with lesser potential will have less potential energy. The current always moves from higher potential to lower potential. The difference in these energies per unit charge is known as the electric potential difference. In order to create electricity and the flow of current, a potential difference is always required, which is maintained by a battery or a cell.




Electric Potential Difference Formula

$V_{xy} = V_x - V_y = [W_x - W_y]/q$

The SI Unit of Electrical potential difference is the same as the electric potential, i.e, Voltage or Volts.

## Resistance

Electrical resistance is defined as the obstruction by the material in the flowing of the current through the material. Thus, the higher the resistance the lower the amount of current passes through it. it is the property of a material that tells us about the flow of the current through the material. The substances that easily conducts the electric current are called conductors and they have very low electrical resistance, on the contrary, the substance that does not easily conducts the electric current are called insulators and they have very high resistance.

Georg Simon Ohm was a German physicist who gave a law which is known as Ohm's law. According to Ohm's law, the current flowing through a conductor is directly proportional to the potential difference across it.

$$V \propto I$$

$$V = IR$$

**Factors Affecting Resistance**

There are various factors that affect the resistance of the conductor, these factors are:

- **Material of the Conductor**

  As resistance is the physical property of a material, different materials can have different values of resistance. Conductors have less resistance compared to semiconductors and insulators.

- **Length of the Conductor**

  By the relation between resistance and resistivity, the resistance of the conductor is directly proportional to the length of the conductor i.e., the longer the length of the wire the more resistance it will offer in the circuit.

- **Cross-Sectional Area of the Conductor**

  As the relation between Specific Resistance or resistivity and Resistance is given by $R = (\rho \times L)/A$. In which, the resistance R of the conductor and cross-sectional area A of the conductor are inversely proportional to each other i.e., if one increases the other should decrease if all other things remain constant. Thus, by increasing cross sectional area of the conductor the resistance of it decreases.

- **Temperature of the Conductor**

  The resistance of the conductor and temperature both are directly proportional to each other i.e., as the temperature of the conductor rises, its resistance increases due to variations in its resistivity.

## Simple Electrical Circuits

A simple electric circuit can consist of a battery (or other energy source), a light bulb (or other device that uses energy), and conducting wires that connect the two terminals of the battery to the two ends of the light bulb. In the scientific model for this kind of simple circuit, the moving charged particles, which are already present in the wires and in the light bulb filament, are electrons.

A simple electric circuit typically consists of a few basic components:

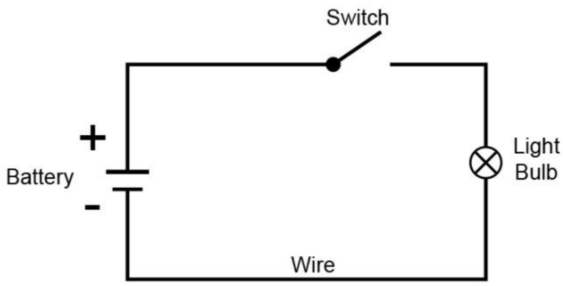
1. **Power Source**: This provides the energy for the circuit to operate. It could be a battery, a generator, or a power supply from an outlet.

2. **Conductors**: These are materials that allow the flow of electric current. Wires are the most common conductors used to connect the various components of a circuit.

3. **Load**: The load is the component of the circuit that consumes electrical energy to perform a task. It could be a light bulb, a motor, or any other device that converts electrical energy into another form, such as light, motion, or heat.

4. **Switch**: A switch is a device that can open or close a circuit, controlling the flow of electricity. It can be manually operated or automatically controlled.

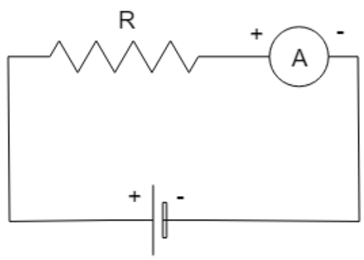
Electrons are negatively charged. The battery pushes the electrons in the circuit away from its negative terminal and pulls them towards the positive terminal. Any individual electron only moves a short distance. While the actual direction of the electron movement is from the negative to the positive terminals of the battery, for historical reasons it is usual to describe the direction of the current as being from the positive to the negative terminal (the so-called 'conventional current').




The energy of a battery is stored as chemical energy. When it is connected to a complete circuit, electrons move and energy is transferred from the battery to the components of the circuit. Most energy is transferred to the light globe (or other energy user) where it is transformed to heat and light or some other form of energy. A very small amount is transformed into heat in the connecting wires.

## DC Ammeter

A DC ammeter is an instrument which is used to measure the amount of DC current flowing in a circuit. The DC ammeter has a scale which represents current in ampere. The instrument got its name ammeter from ampere meter because it measures the amount of current in ampere. For measuring large amounts of DC current, we can use DC ammeters. In cases where the current flowing in the circuit is very small, that is in the range of milliampere or microampere, then we should use an ammeter in that range.

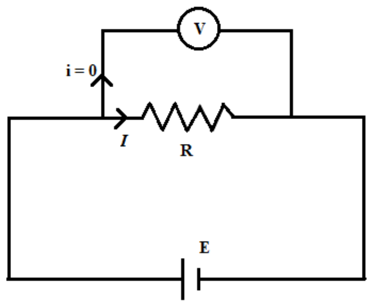



A DC ammeter should always be connected in series with the circuit for measuring DC current. In terms of a circuit diagram, the ammeter is represented by a circle with the letter A. In this case, consider the following circuit with a resistor R and a voltage source. In order to measure the DC current, the DC ammeter should always be connected in a series combination. Modern DC ammeters can come in analog or digital forms, with digital ones offering more precision and often additional features like data logging or connectivity options.

## Voltmeter

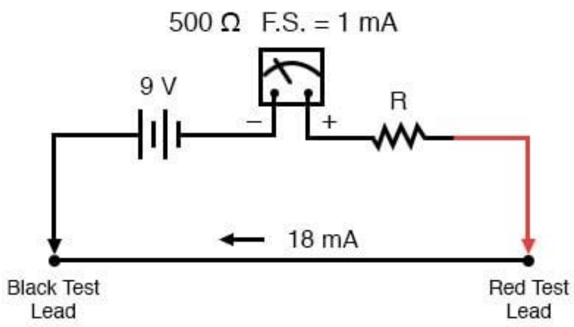
The voltmeter is used to measure the electrical potential difference between two points of an electrical circuit. It is used to measure both direct and alternating electric current. A voltmeter is a current-controlled device, which means it needs a current to function. To measure the potential difference, the voltmeter is connected in parallel with the electrical circuit.

A voltmeter has high resistance so that it consumes less current to function. That is why the Current consumption by the voltmeter doesn't affect the circuit current. In the parallel connection, the high resistance of the voltmeter gives almost the same impedance as the impedance of the load resistance. The voltage in the parallel circuit and the voltage between the voltmeter and the load become the same. Thus, the voltmeter measures the voltage of the electrical circuit. They are essential tools for electrical testing and troubleshooting in various applications, from household electronics to industrial machinery.




## Ohmmeter

An ohmmeter can be defined as, it is one kind of electronic device mainly used for calculating electrical resistance of a circuit, and the unit of resistance is ohm. Electrical resistance is a calculation of how much an object resists allowing the flow of current through it. There are different types of meters available with different sensitivity levels such as micro, mega and milli-ohmmeters. The micro-ohmmeter is used for calculating very low resistances with high precision at specific test currents, and this ohmmeter is used in bonding contact applications.

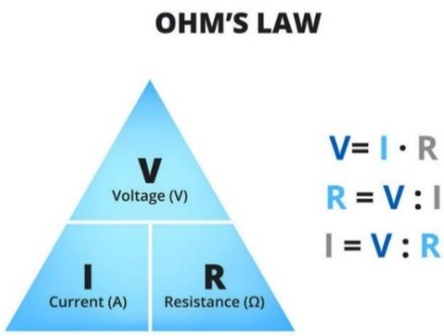


The working principle of ohmmeter is, it comprises of a needle and two test leads. The needle deflection can be controlled with the battery current. Initially, the two test leads of the meter can be shorted together to calculate the resistance of an electrical circuit. Once the two leads of the meter are shorted, then the meter can be changed for appropriate action in a fixed range. The needle comes back to the highest point on the meter scale, and the current in the meter will be highest.

The classification of this meter can be done based on the application in three types namely series type ohmmeter, shunt type ohmmeter, and multi-range type ohmmeter.

## Ohm's Law

Ohm's law states that the voltage across a conductor is directly proportional to the current flowing through it, provided all physical conditions and temperatures remain constant.




Hence, according to Ohm's Law, the current flowing through the conductor is directly proportional to the voltage across the circuit, i.e. **V ∝ I.** Thus, as Ohm's Law provides the basic relation between the voltage applied and current through the conductor, it is considered as the basic law which helps us in dealing electric circuit. Ohm's Law states that the current follows a linear relationship with voltage.

Ohm's Law is one of the fundamental laws of electrostatics which state that, the voltage across any conductor is directly proportional to the current flowing in that conductor. We can define this condition as,

**V ∝ I**

Removing the proportionality sign,

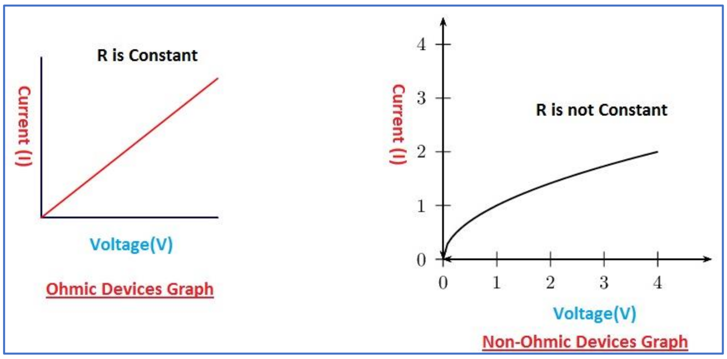
***V = RI***

where **R** is the proportionality constant and is called the Resistance of the material. The resistance of the material is calculated as,

***R = V/I***

Resistance is measured in Ohms. It is denoted by the symbol Ω.

Ohm's Law holds good when physical conditions like temperature and others are constant. This is because of the fact that the current flowing through the circuit varies by changing the temperature. Therefore, in such cases when physical factors like temperature come into play, Ohm's law violates. For example, in the case of a Light bulb, where temperature increases when the current flowing through it rises. Here, Ohm's Law doesn't follow.




**Vector Form of Ohm's Law**

The relation between current and voltage is established by, Ohm's law, and its vector form is,

$$\vec{j} = \sigma \vec{E}$$

*Where,*

- $\vec{j}$ *is Current Density vector,*
- $\vec{E}$ *is Electric Field vector, and*
- $\sigma$ *is conductivity of material.*

**Resistivity**

The hindrance faced by the electrons while moving in any material is called the resistivity of the material.

Let a resistor of a length of 'l' and the cross-sectional area of 'A' has a resistance be R. Then we know,

Resistance is directly proportional to the length of the resistor, i.e. $R \propto l$, . . .(1)

Resistance is inversely proportional to the cross-section area of the resistor, i.e. $R \propto 1/A$ . . .(2)

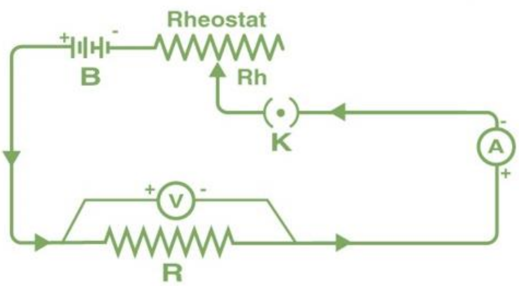
combining eq. (1) and eq.(2)

$$R = \rho l / A$$

Where $\rho$ is the proportionality constant called coefficient of resistance or resistivity.

## Experimental Verification of Ohm's Law

The key K is closed initially and the rheostat is adjusted such that the reading in ammeter A and voltmeter V is minimum. The current is then



increased in the circuit by adjusting the rheostat, and the current at various values of the rheostat and their respective voltage is recorded. Now for different values of voltage(V) and current(I) and then calculate the ratio of V/I. After calculating all the ratios of V/I for different values of voltage and current, we notice that the value is almost constant. Now plotting a graph of the current against the potential difference we get a straight line. This shows that the current is directly proportional to the potential difference and its slope is the resistance of the wire.

## Difference between DC And AC

DC refers to Direct Current in which there is no change in the Direction of Current flow. Hence, the major difference between AC and DC Current is the electric current flows only in One Direction in a stable voltage in DC Current. One of the major uses of DC is to charge batteries and supply power for electrical devices. In the DC circuit, electrons emerge from the negative side and move towards the positive side. The basic source of DC is produced by photovoltaic cells, batteries, or electrochemical cells. Some of the examples of DC include flashlights, mobile phone batteries, electric vehicles, and more.

The term AC refers to Alternating Current in Physics, which is highly preferred electric power for office, household equipment, and more. The critical difference between Alternating Current and Direct Current lies in the Direction in which electric charges flow. In AC, electrons continuously change their Directions from forward to backward periodically. As compared to DC Current, it’s easy to generate and transport AC across large distances. Hence, Alternating Current is widely used in buildings, powerhouses, and more.

**Differentiate Between AC and DC Current**

| Points of Difference | Alternating Current (AC) | Direct Current (DC) |
|---|---|---|
| Travelling Distance | It's safe to transfer Alternating Current over long distances and maintain electric power. It can transfer between two cities. | From comparing AC and DC Current, it's found that DC cannot travel for far distances. It's because DC loses electric power. |
| Electron Flow | In AC, electrons keep switching their Direction from frontward to backward. | Electrons only move in a forward Direction in a DC Motor. |
| Frequency | The frequency of the Alternating Current is generally between 50 to 60 Hz. Moreover, it's frequency depends upon the country. | The Direct Current has no or zero frequency. |
| Source of Availability | The source of availability for AC Current is AC generators. | The source of availability for DC Current is either battery, electrochemical cell, or photovoltaic cell. |
| Types | Generally, AC Current is of sinusoidal type. Its other types can be triangular and square trapezoidal. | The DC Current is of pure and pulsating form. |
| Flowing Direction | There is a change in the Direction of the Current electricity flow due to the rotating magnets. | The Direct Current flows in a single direction due to steady magnetism. |
| Applications | From the AC Current and DC Current difference, it can be said that AC is capable of powering electric Motors used on washing machines, refrigerators, and so on. | The Direct Current is preferably used in cellphones—flat-screen TVs, and so on. |
| Loss of Energy | As compared to DC, the loss of energy during the transmission in AC voltage is low. | DC involves a high loss of energy and is hence not preferred when transformers are at a distance. |

## Advantages of AC Over DC

There are following advantages of alternating current over direct current

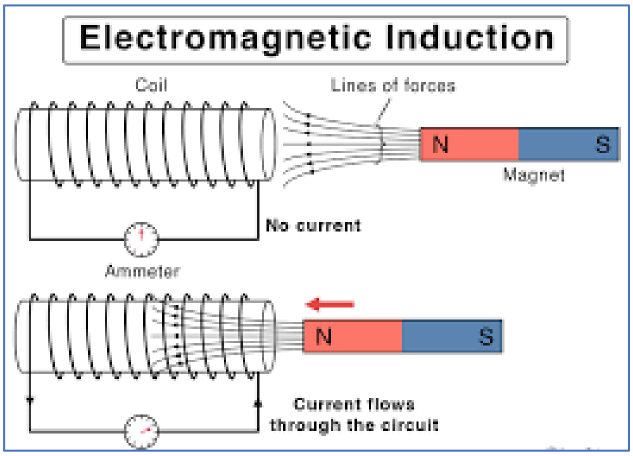
1. Long distance transmission can be done at high voltages, thereby reducing the current, and consequently losses in transmission.
2. Generation of alternating current is easier, and so is transmission.
3. Generation and transmission can be at high voltages, so the fact that it can be stepped up and down from level to other easily and efficiently.
4. Cable sizes for AC are quite lighter in the comparison of D.C.
5. Power loss in AC is less as compared to DC during transmission.
6. AC can be easily converted into DC.
7. Voltage at which power can be sent can be higher in AC. These levels can be dangerous in DC.

## Electromagnetic Induction

Electromagnetic induction is the production of electromotive force otherwise known as voltage across an electrical conductor where the magnetic field changes. For the discovery of induction, Micheal Faraday was awarded this credit in 1831. Here, Faraday's law of induction was described by Maxwell in mathematical terms. Take for example any conductor and place it in a specific position. Here the process of electromagnetic induction will let the conductor vary keeping the magnetic field stationary.

Principle of Electromagnetic Induction states that the emf induced in a loop due by a changing magnetic flux is equal to the rate of change of the magnetic flux threading the loop. When it comes to the principle of electromagnetic induction, it will enable the transformers, motors, electric generators and other rechargeable items such as wireless communication devices or electric toothbrushes to adopt the principle. Apart from that, your rice cooker works by using induction. Now let's learn how induction cooktops are heated by using induced current.

Faraday's Law is the equation that mathematically describes electromagnetic induction. It states that voltage (EMF) will be induced when there is a change in the magnetic environment of a coiled wire. Many ways were discovered by Faraday for this to happen. For example: by changing the magnetic field strength by moving a magnet over a coil of wire or by moving a coil of wire through a magnetic field, etc. The voltage (EMF) generated can be explained by the help of the following equation,




EMF=-N∆(BA)∆t

Where, N is the number of turns in the wire. ∆(BA) is the difference in magnetic flux. ∆t is the difference in time. Faraday's methods found the change in flux and can be expressed with the help of this equation. But because of Lenz's Law, this equation is negative, as it requires the change in magnetic flux to be reproduced in equal strength and the opposite direction by the wire. For many electromagnetic applications around the world, including cars, Faraday's Law is important. For example, in a car the ignition system, the internal combustion engine takes only 12 volts from the battery and ramps it up to 40000 volts. The use of magnetic flux through a wire is stated by Faraday's Law of electromagnetic induction. The magnetic flux is defined as:

$$\phi_B = \int B.dA$$

Here $\Phi$B is the magnetic flux

dA is the surface of the element

B is the magnetic field.

According to Faraday's Law of induction, when there is a change in the flux through the surface, the wire coil obtains the electromagnetic force. The rate of variation in magnetic flux, which is surrounded by the circuit, is equal to the induced electromotive force in a closed circuit as per the Law.

$$\epsilon = -N\frac{d\phi B}{dt}$$

Here $\epsilon$ is EMF

$\phi_B$ Is the magnetic flux and t is the time.

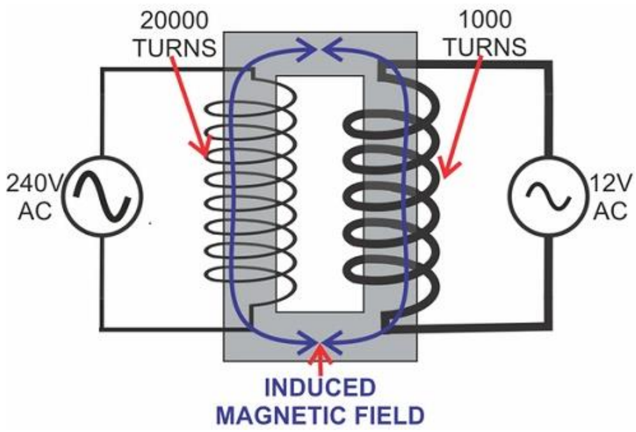
With the help of Lenz's Law, the direction of the electromotive force is given. It states that when an electric current is induced by changing the magnetic field of a source, it will always create a counterforce opposing the force induced in it. The Law explains such phenomena as diamagnetism and the electrical properties of inductors.

With the help of variation in magnetic flux through the surface of a wire loop, an EMF can be generated.

- The magnetic field B variations.
- The wire loop is misshapen, and the surface Σ changes.
- The alignment of the surface dA changes

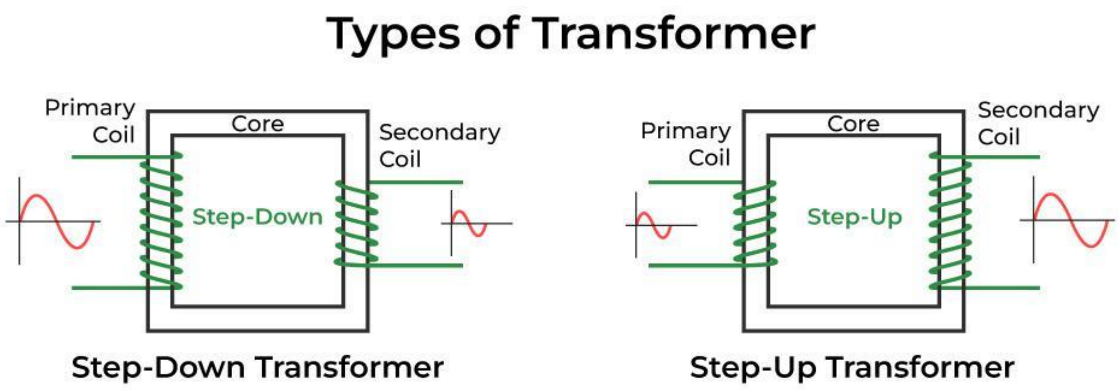
## Transformers

**Transformer** is the simplest device that is used to transfer electrical energy from one alternating-current circuit to another circuit or multiple circuits, through the process of electromagnetic induction. A transformer works on the principle of **electromagnetic induction** to step up or step down voltage. Transformer either increases AC voltage (Step-up transformer) or decreases AC voltage (Step-down transformer). Transformer which is normally utilized in the transmission and distribution of alternating current power is fundamentally a voltage control device. Transformer are used for a wide range of purposes, including increasing the voltage from electric generators to enable long-distance transmission of electricity and decreasing the voltage of conventional power circuits to run low-voltage devices like doorbells and toy electric trains.




*A transformer is a static electrical device that transmits AC power from one circuit to another at a constant frequency, but the voltage level may be changed, implying the voltage can be increased or decreased depending on the requirement.*

There are primarily two types of transformers based on the operating voltage. The following are some of them:




- **Step-down Transformer:** The primary voltage is converted to a lower voltage across the secondary output using a step-down transformer. The number of windings on the primary side of a step-down transformer is more than on the secondary side. As a result, the overall secondary-to-primary winding ratio will always be less than one. Step-down transformer are used in electrical systems that distribute electricity over long distances and operate at extremely high voltages to ensure minimum loss and economical solutions. Step-down transformer are used to change high-voltage into low-voltage supply lines.

- **Step-up Transformer:** The secondary voltage of a step-up transformer is raised from the low primary voltage. Because the primary winding has fewer turns than the secondary winding in this sort of transformer, the ratio of the primary to secondary winding will be greater than one. Step-up transformer are frequently used in electronics stabilizers, inverters, and other devices that convert low voltage to a significantly higher voltage. A step-up transformer is also used in the distribution of electrical power. For applications connected to power distribution, high voltage is necessary. In the grid, a step-up transformer is used to raise the voltage level prior to distribution.

**Transformer Types based on Core Material**

Different types of Transformers are used in the power and electronics industries, depending on the core materials, which are

- Iron Core Transformer
- Ferrite Core Transformer
- Toroidal Core Transformer
- Air Core transformer

The fundamental principle of how the transformer functions are mutual induction between the two coils or Faraday's Law of Electromagnetic Induction. Only alternating current can be used because mutual induction between the two windings requires an alternating flux.

A transformer majorly consists of three parts:

**Core**

The transformer core serves as a support for the winding. Additionally, it offers a magnetic flux flow channel with minimal resistance. As seen in the image, the winding is looped around the core. To cut down on losses in a transformer, it has a laminated soft iron core. Core composition is determined by variables including operational voltage, current, and power, among others. The core diameter is negatively correlated with iron losses and directly correlated with copper losses.

**Windings**

The copper wires that are wound over the transformer core are known as windings. Copper cables are used because Copper's high conductivity reduces transformer loss because resistance to current flow lowers as conductivity rises. And copper's high degree of ductility makes it possible to produce incredibly thin wires out of it.

The two basic types of windings are. windings for the primary and secondary coils. The primary winding is the group of winding turns that receive supply current. The number of winding turns from which output is derived is known as secondary winding. Insulation coating agents are used to insulate the primary and secondary windings from one another.

**Insulation Agents**

Transformer require insulation to keep the windings apart and prevent short circuits. This makes mutual induction easier. Transformer stability and durability are influenced by insulation agents. In a transformer, the following are employed as insulating mediums: Insulating fluid, tape, Paper, and Lamination made of wood.

**Tank**

A transformer main tank serves two purposes:

- The core and the windings are protected from the elements, such as rain and dust.

- It functions as an oil container as well as a support for all other transformer attachments.

**Transformer Oil**

The majority of the huge transformer are submerged in oil. The transformer oil adds insulation between the conductors, improves heat dissipation from the coils, and has fault-detecting capabilities. Transformer oil is typically made of hydrocarbon mineral oil.

*The induced emf or voltage ($\varepsilon_s$) in the secondary with $N_s$ turns is then calculated.*

$\varepsilon_s = -N_s \times d\phi/dt$ ......(1)

*In addition, the alternating flux generates a reverse emf in the main. This is it.*

$\varepsilon_p = -N_p \times d\phi/dt$ ......(2)

*And for an ideal transformer,* $\varepsilon_p = V_p$

*By approximation, if the secondary is an open circuit or the current drawn from it is modest,* $\varepsilon_s = V_s$.

*The voltage across the secondary coil is $V_s$. As a result, Equations (1) and (2) may be written as*

$V_s = -N_s \times d\phi/dt$ ......(3)

$V_p = -N_p \times d\phi/dt$ ......(4)

*From Equations (3) and (4), we have*

$\mathbf{V_s / V_p = N_s / N_p}$ ......(5)

*The above equation is known as* ***Transformer Equation*** *or* ***Transformer Formula****.*

The following three assumptions are used to get the previous relationship:

- The primary and secondary coils' electrical resistances are insignificant.
- The flux connectivity to both the primary and secondary coils is the same, or very few fluxes escape from the core.
- The secondary current is insignificant.

**Efficiency of Transformer**

The efficiency of a transformer is also known as **commercial efficiency**. It is represented by the letter 'η'. The efficiency of a Transformer is described as the ratio of output (in W or kW) to input (in W or kW).

Hence, the efficiency of transformer may be expressed as follows:

***Efficiency (η) = (Power Output / Power Input)***

The above equation can be used for an ideal transformer in which there are no transformer losses and all input energy is transferred to the output. As a result, the following equation is mostly used if transformer wastes are taken into account and the efficiency of the transformer is evaluated across the practical states.

*Efficiency = ((Power O/P) / (Power O/P + Losses)) × 100%*

*or*

*Efficiency = (Power i/p – Losses) / Power i/p × 100 = 1- (Losses/ i/p Power) × 100*

**Energy Losses in a Transformer**

We used an ideal transformer in the previous equations (without any energy losses). However, some energy losses do occur in actual transformer for the following reasons:

- **Flux Leakage:** Because some flux leaks from the core, not all flux generated by the primary coil make it to the secondary coil. This occurs as a result of the core's inadequate design or the presence of air holes in the core. It is possible to lower it by wrapping the primary and secondary coils over each other. It can also be lowered if the core is well-designed.
- **Windings Resistance:** Because the wire used for the windings has some electrical resistance, energy is wasted as a result of the heat generated in the windings. These are mitigated in high current, low voltage windings by utilizing thick wire with a high conductive substance.
- **Eddy Currents:** The alternating magnetic flux creates eddy currents in the iron core, resulting in energy losses through heating. By using a laminated core, the impact is decreased.
- **Hysteresis Loss:** In each AC cycle, the alternating magnetic field reverses the magnetization of the core. The loss of energy in the core occurs as heat owing to hysteresis loss, which is minimized by employing a magnetic material with a low hysteresis loss.

**Application of Transformer**

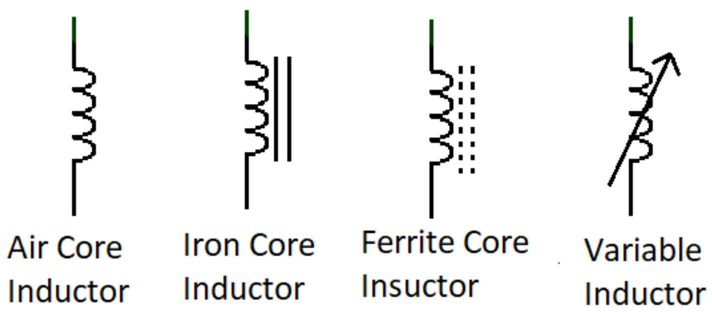
The following are some of the most common uses for transformer:

1. Increasing or reducing the voltage level in an AC circuit to ensure the correct operation of the circuit's various electrical components.
2. It stops DC from flowing from one circuit to another.
3. It separates two separate electric circuits.
4. Before transmission and distribution can take place, the voltage level at the electric power plant must be increased.

## Inductors/Chokes

**Inductors** are electrical components that create a magnetic field when an electric current is passed through them. Inductors are most commonly coil-like structures in electronic circuits that are mostly used to reduce or control electrical spikes in a circuit. There are various types of inductors including, Iron Core and Air Core Inductors. Its main functions include controlling signals and storing energy.

Inductor is a passive electronic component which stores energy in the form of a magnetic field. In simple words, an inductor consists of just a wire loop or coil that is used to control electric spikes by temporarily storing energy and then releasing it back into the circuit through an electromagnetic field.



Inductance is directly proportional to the number of turns in the coil. It also depends on other things such as the radius of the coil and the type of material around which the coil is wound.

Inductor is made of a wire whose property is inductance, i.e. it opposes the flow of current. The inductance of the wire increases when the number of turns is increased. Inductance is represented by the alphabet 'L' and it is measured in Henry. The formula of Inductance can be given by the ratio of flux and the current in the circuit. It is represented as:

***L = Φ/I***

*where,*

- ***L** is Inductance*
- ***Φ** is Flux*
- ***I** is Current*

Unit of inductance is 1 henry (H). The unit is symbolized by the letter H. An inductor be a passive electronic component that is more often used to gain energy in form of magnetic field. This is a measure of amount of energy stored in an inductor, which depends on the amount of inductance.

The voltage (V) across an inductor is directly proportional to the rate of change of current (I) flowing through it:

*V(t) = L dI(t)/dt*

*Where:*

- *V(t) is the inductive voltage at time t*

- *L is the inductor inductance*
- *dI(t)/dt denotes the speed of change of current over time 't'*

Construction of an inductor consists of a coil that is formed by twisting wire into circles wrapped around a core and is used to store energy in a magnetic field while electricity runs through it.

**Different Types of Inductors**

The different types of inductors include the following:

- Iron Core Inductor
- Coupled Inductor
- Air Core Inductor
- Iron Powder Inductor
- Variable Inductor
- Ferrite Core Inductor
- Choke

**Choke**

A choke inductor, more commonly called a "choke," is an electrical component used chiefly for choking off or blocking alternating current (AC) while allowing direct current (DC) to pass with relatively little resistance. This sort of inductor has a high impedance to AC signals, so it effectively filters or isolates them from circuits.

Chokes are most commonly used in electronic circuits for filtering and noise suppression as well as to separate AC and DC signals.

**Controlling Signals**

Controlling signals is one of the primary functions of an inductor. It is used to handle electric or digital signals to get specific results, like changing frequency and filtering them.

The frequency of the current passing in an inductor plays a vital role in controlling the signals within an inductor. It is helpful in blocking AC and allows the DC to pass through it. This is possible because higher frequency symbols are passed easily inside an inductor thus allowing DC currents to pass through them easily.

**Storing Energy**

In an inductor, the core is used to store energy. Inductors store energy in the form of magnetic fields. Energy storage is the process of adding and maintaining power to a system or gadget for future use. This aids in managing, balancing, and controlling the energy consumption of many systems, including buildings and automobiles.

## Capacitors/Condensers

The capacitor is an electric component that has the ability to store energy in the form of electrical charges that creates a potential difference, which is a static voltage, much like a small rechargeable battery. The most basic design of a capacitor consists of two parallel conductors (Metallic plate), separated with a dielectric material.  When a voltage source is attached across the capacitor, the capacitor plate gets charged up. The metallic plate attached to the positive terminal will be positively charged, and the plate attached to the negative terminal will be negatively charged.

**Types of Capacitors**

**Film Capacitors:** Film capacitors are the ones that use plastic film as the dielectric medium. They are available in nearly any value and voltages up to 1500 volts. They range from 10% to 0.01% in any tolerance. Additionally, film condensers arrive in a combination of shapes and case styles. There are two types of film condensers, radial type lead, and axial type lead.

**Ceramic Capacitors:** Ceramic capacitors are the ones that use ceramic as the dielectric material. It is used in high-frequency circuits such as audio to RF. In ceramic capacitors, one can develop both high capacitance and low capacitance by altering the thickness of the ceramic disc.

**Electrolytic Capacitors:** Electrolytic capacitors are the ones that use the oxide layer as the dielectric material. It has a wide tolerance capacity. There are mainly two types of electrolytic capacitors, tantalum, and aluminum. They are available with working voltages of up to approximately 500V, but the maximum capacitance values are not available at high voltage, and higher temperature units are available but are rare.

**Variable Capacitor:** Variable capacitors mostly use air as the dielectric medium. A Variable Capacitor is one whose capacitance can be mechanically adjusted several times. For example, this form of the capacitor is used to set the resonance frequency in LC circuits to change the radio to match impedance in antenna tuner devices.

The accumulation of charges in the conductors causes a potential difference across the capacitor. The amount of charge accumulated is called the charge holding capacity of the capacitor. This charge holding capacity is what is known as capacitance. The accumulated charge in the capacitor is directly proportional to the voltage developed across the capacitor:

$Q \propto V$

$Q = CV$

$C = Q/V$

C is the constant of proportionality, also called the capacitance of a capacitor. The unit of capacitance is Farad(F) - 1 coulomb per volt.

The value of capacitance depends upon the physical features, area of the capacitor plates 'A', distance between the plates 'd', and the permittivity of the dielectric medium 'ε'.

$$C=\varepsilon\times(A/d)$$

The energy is stored in joules and is equal to half of the capacitance times the square of the capacitor's voltage. $E=1/2\ (C\times V^2)$

**Factors affecting Capacitance**

Surface Area: The surface area of the two plates affects the capacitance value. Higher the value of the surface area, the higher the capacitance.

Distance: The distance between the plates affects the value of the capacitance. Lower the value of distance, the higher the capacitance.

Dielectric Medium: The type of material separating the two plates called "the dielectric." The higher the dielectric's permittivity, the higher the capacitance value.

**Uses of a Capacitor**

The capacitors have both electrical and electronic applications. They are used for several things such as filters, energy storage systems, engine starters, signal processing devices, etc. Capacitors are used for storing energy, which can be used by the device for temporary power outages whenever they need additional power. Capacitors are used for blocking DC current after getting fully charged and yet allow the AC current to pass through the circuit of a circuit. Capacitors are used as sensor for several things like measuring humidity, fuel levels, mechanical strain, etc. Capacitors can be used in a time-dependent circuit. This could be connected to any LED or loudspeaker system, and it's likely that any flashing light/regular beeping uses a timing capacitor.

## Impedance

Electrical impedance, measure of the total opposition that a circuit or a part of a circuit presents to electric current. Impedance includes both resistance and reactance. The resistance component arises from collisions of the current-carrying charged particles with the internal structure of the conductor. The reactance component is an additional opposition to the movement of electric charge that arises from the changing magnetic and electric fields in circuits carrying alternating current. Impedance reduces to resistance in circuits carrying steady direct current.

The magnitude of the impedance Z of a circuit is equal to the maximum value of the potential difference, or voltage, V (volts) across the circuit, divided by the maximum value of the current I (amperes) through the circuit, or simply Z = V/I. The unit of impedance, like that of resistance, is the ohm. Depending on the nature of the reactance component of the impedance (whether predominantly inductive or capacitive), the alternating current either lags or leads the voltage. The reciprocal of the impedance, 1/Z, is called the admittance and is expressed in terms of the unit of conductance, the mho unit (ohm spelled backward).

**Capacitive Reactance**

When a capacitor is connected to a circuit with AC supply, there is no simultaneous change in the capacitor voltage and capacitor current. The potential difference across the capacitor is dependent on the AC power supply. Below is the graph illustrating the change in current and potential difference. The current is maximum when the potential difference is at zero.

The capacitive reactance for a capacitor with capacitance C connected in the circuit along with AC power supply is given as:

$X_C = 1/(2\pi fC)$

Where,

- $X_C$ is the capacitive reactance
- f is the frequency of AC power supply
- C is the capacitance

**Inductive Reactance**

In inductive reactance, the current across an inductor change when potential difference develops across it. The potential difference and rate of change of current are proportional to each other.

The inductive reactance for an inductor with inductance L connected in the circuit along with AC power supply is given as:

$X_L = 2\pi fL$

Where,

- $X_L$ is the inductive reactance
- L is the inductance of the inductor
- f is the frequency of the alternating current

In phasor terms, impedance Z is represented as a combination of resistance R and reactance X as:

$Z = R + jX$

Where reactance X is a combination of Inductive $X_L$ and capacitive $X_C$

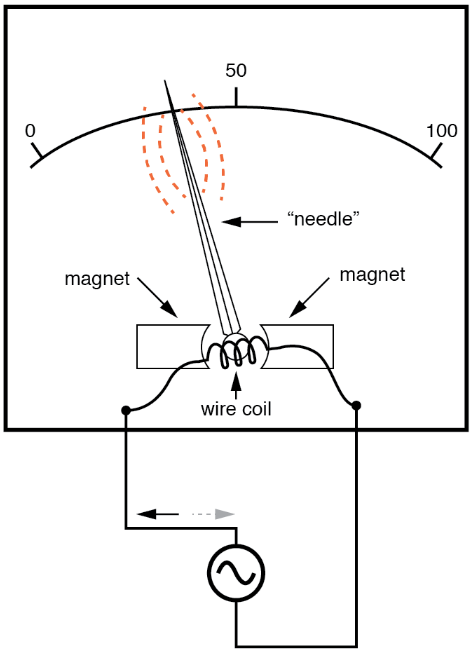
$X = X_L + X_C$

**Difference between Resistance and Reactance**

| **Parameter** | **Resistance** | **Reactance** |
|---|---|---|
| **Variation of current** | Resistance is a property of an electrical component which opposes the flow of current | Reactance is a property of an electrical component which opposes the change in current |
| **Power dissipation** | Resistance leads to power dissipation | Reactance does not lead to power dissipation |
| **Denoted by** | Resistance is denoted by R | Reactance is denoted by X |

## AC Ammeter, Voltmeter

AC electromechanical meter movements come in two basic arrangements: those based on DC movement designs, and those engineered specifically for AC use.



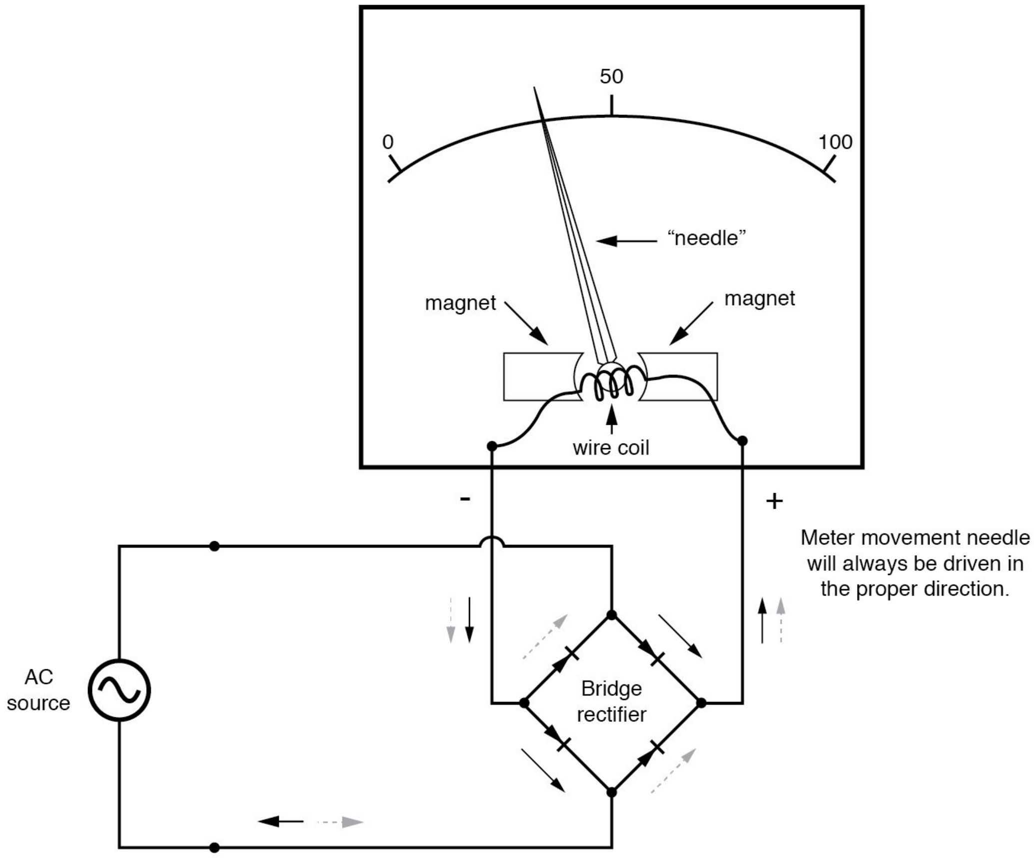

Permanent-magnet moving coil (PMMC) meter movements will not work correctly if directly connected to alternating current, because the direction of needle movement will change with each half-cycle of the AC.

Permanent-magnet meter movements, like permanent-magnet motors, are devices whose motion depends on the polarity of the applied voltage.

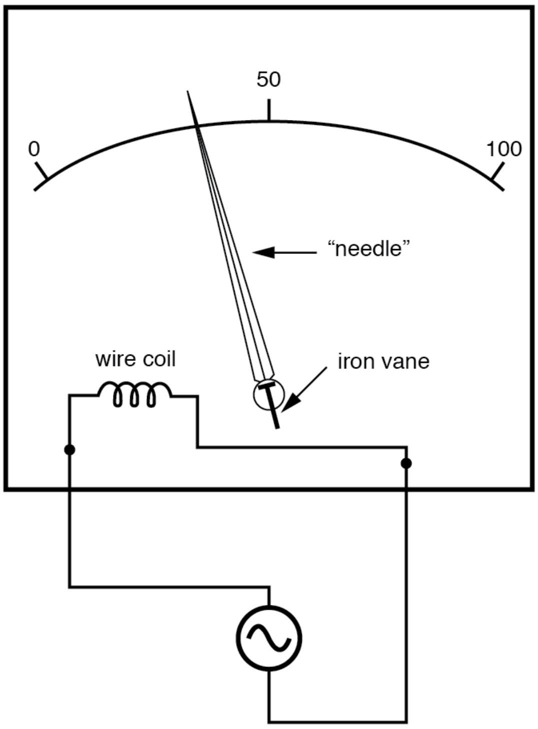
In order to use a DC-style meter movement such as the D'Arsonval design, the alternating current must be rectified into DC.

This is most easily accomplished through the use of devices called diodes. We saw diodes used in an example circuit demonstrating the creation of harmonic frequencies from a distorted (or rectified) sine wave. Without going into elaborate detail over how and why diodes work as they do, just remember that they each act like a one-way valve for current to flow.

The arrowhead in each diode symbol points in the permitted direction of current flow.




Arranged in a bridge, four diodes will serve to steer AC through the meter movement in a constant direction throughout all portions of the AC cycle:

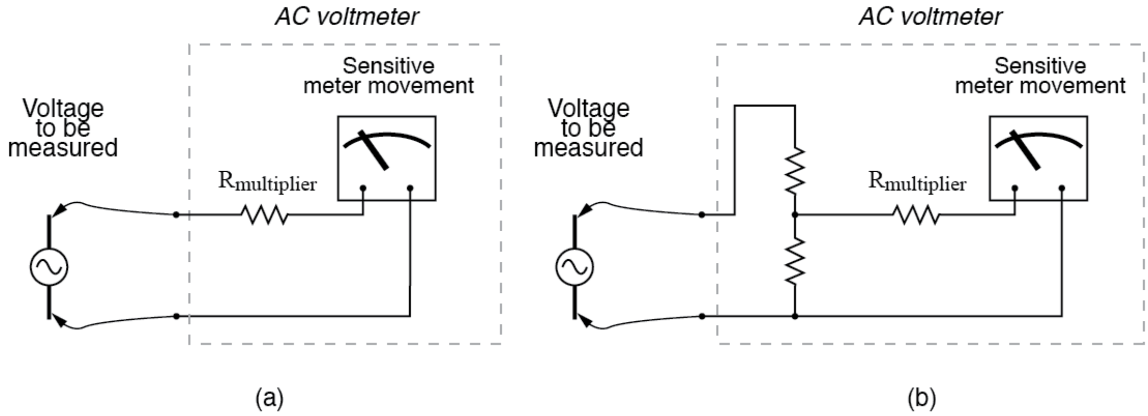



Another strategy for a practical AC meter movement is to redesign the movement without the inherent polarity sensitivity of the DC types.

This means avoiding the use of permanent magnets. Probably the simplest design is to use a nonmagnetized iron vane to move the needle against spring tension, the vane being attracted toward a stationary coil of wire energized by the AC quantity to be measured.

Electrostatic attraction between two metal plates separated by an air gap is an alternative mechanism for generating a needle-moving force proportional to applied voltage.

This works just as well for AC as it does for DC. The forces involved are very small, much smaller than the magnetic attraction between an energized coil and an iron vane, and as such these “electrostatic” meter movements tend to be fragile and easily disturbed by physical movement.

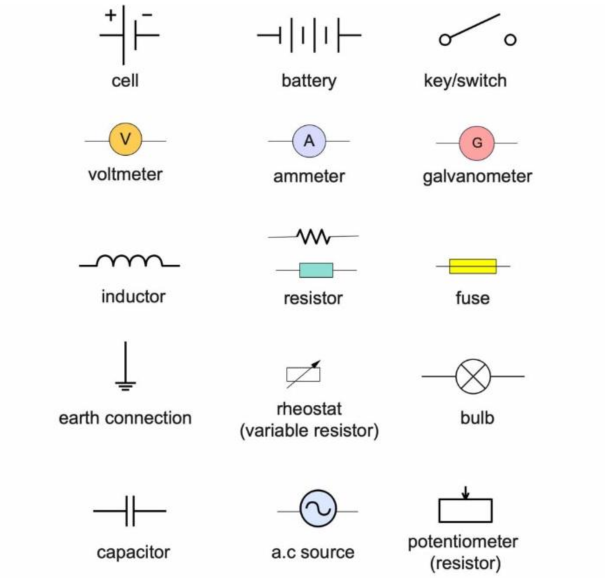


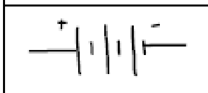
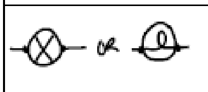
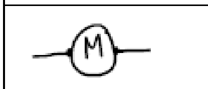
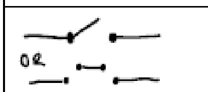
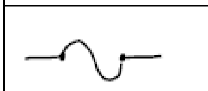
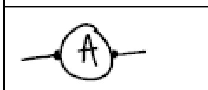
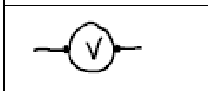
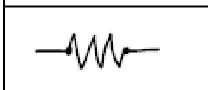
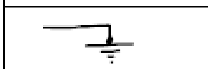

But, for some high-voltage AC applications, the electrostatic movement is an elegant technology.

If nothing else, this technology possesses the advantage of extremely high input impedance, meaning that no current need be drawn from the circuit under test. Also, electrostatic meter movements are capable of measuring very high voltages without need for range resistors or other, external apparatus.

When a sensitive meter movement needs to be re-ranged to function as an AC voltmeter, series-connected “multiplier” resistors and/or resistive voltage dividers may be employed just as in DC meter design.

## Symbols and Nomenclature




| Symbol | Function | Description |
|---|---|---|
|  | Cell | • Source of current electricity |
|  | **Battery** | • Two or more cells joined together.<br>• This battery is made of three cells. |
|  | **Light Bulb** | • Converts electrical energy into light & thermal energy |
|  | **Motor** | • Converts electrical energy into mechanical energy |
|  | **Switch**<br>• Knife or button | • Can be opened to stop a current or closed to allow current to flow. |
|  | **Fuse** | • Prevents too much current from flowing through a circuit<br>• Will break during a surge and protect the circuit |
|  | **Ammeter** | • Measures current (amperage)<br>  ○ Flow of electrons |
|  | **Voltmeter** | • Measure voltage (volts)<br>  ○ Potential energy |
|  | **Resistor** | • A device the impedes (slows) the flow of electrons |
|  | **Ground Connection** | • Connects the circuit to the earth |

# Unit II

# TRANSMISSION OF ELECTRICITY

## Production and Transmission of Electricity

There are three stages of electric power supply; generation, transmission and distribution. Power plants are the most commonly used energy conversion technology to create electricity from primary energy. Common types of power plants include coal, nuclear, and hydro.

Electrical power generation is based on Faraday's law of mutual electromagnetic induction. In an electrical circuit moving (for example rotating) so that it cuts magnetic lines of force, an electromotive force (emf) is generated that is proportional to the rate at which unit lines of force are cut. The magnetic field is generated by direct current excitation current in a primary circuit, produced by rectifying alternate current from a subsidiary generator geared mechanically to the main alternator. According to Lenz's law, the direction of the current set up in the subsidiary circuit is such that electromagnetic interaction between the two circuits tends to hinder the motion setting up the emf in the secondary circuit.

Most electricity is generated from power plants that utilize steam turbines to convert mechanical (also called kinetic) energy into electrical energy. The rotation of the turbine spins the rotor, a set of magnets or electromagnets, inside the core of the stator, a coil of wires. This rotational movement generates a changing electromagnetic field, or voltage, which creates an electric current when run through a conductor. The electric current can then be delivered from the plant via power lines to provide electricity to homes and businesses.

Power plant output is measured in megawatts, and a megawatt (M.W.) is one million watts. Electrical output, the amount of electricity generated, varies depending on the size of a power plant. The average coal-fired plant generates about 750MW of electricity.

The rotation of the turbines can be fueled from several sources including wind, water, and heat.

**Thermal power plants**

Where does most electricity come from? Currently, most of the world's electricity is produced by thermal power plants that burn fossil fuels such as coal, oil, or natural gas to heat water and produce steam. The steam then drives a turbine connected to an electric generator, converting the mechanical energy into electricity.

**Hydroelectric power plants**

These large power plants can use the energy from flowing or falling water to drive a turbine connected to a generator. The kinetic energy of the moving water is converted into mechanical energy in the turbine and then into electrical energy in the generator.

**Wind turbines**

Wind turbines convert the kinetic energy in wind into electrical energy. As the wind turns the blades of the turbine, the mechanical energy generated drives an electric generator.

**Solar power plants**

Solar power plants convert sunlight directly into electricity using photovoltaic (PV) cells. When sunlight hits the PV cells, electrons are knocked loose and flow through the cells, generating an electric current.

**Nuclear power plants**

In nuclear power plants, nuclear reactions release energy in the form of heat, which is then used to produce steam from water. The steam drives a turbine connected to an electric generator, converting the mechanical energy into electricity.

Currently, nuclear power plants are powered by fission reactions (splitting atoms), but scientists are working hard to generate consistent electricity using fusion reactions (combining atoms).

**Geothermal power plants**

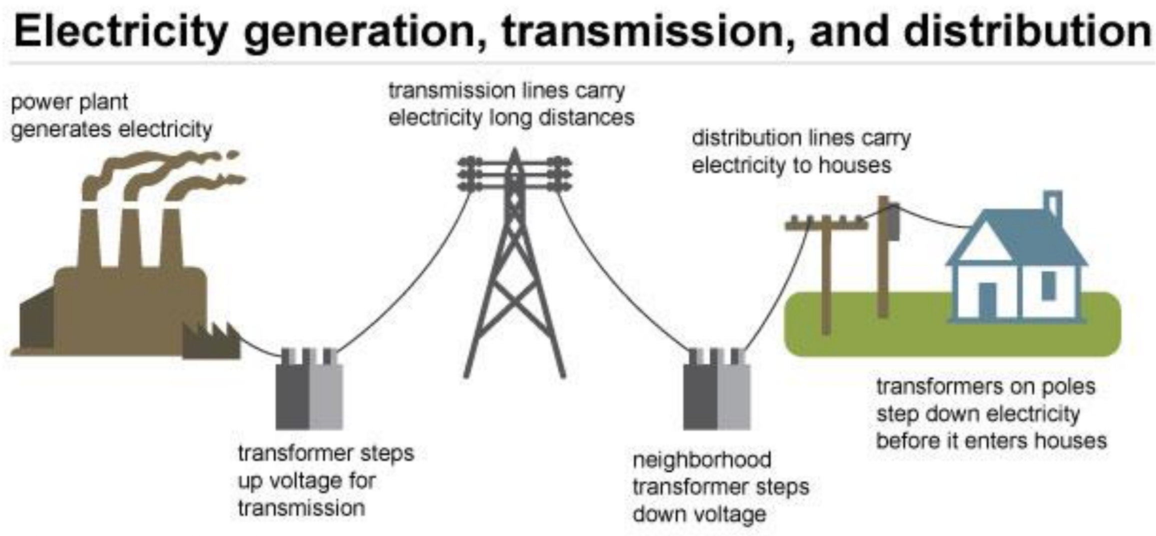
These power plants generate electricity by tapping into the Earth's internal heat. They use hot water or steam from the Earth's interior to produce electricity to drive a turbine connected to an electric generator.

**Biomass power plants**

Biomass power plants burn organic materials such as wood, agricultural waste, and animal waste to produce steam. The steam drives a turbine connected to an electric generator, which generates electricity by converting the mechanical energy into electricity.

**Ocean energy**

This includes both wave power, which uses the energy from waves to generate electricity, and tidal power, which uses the energy from rising and falling tides.



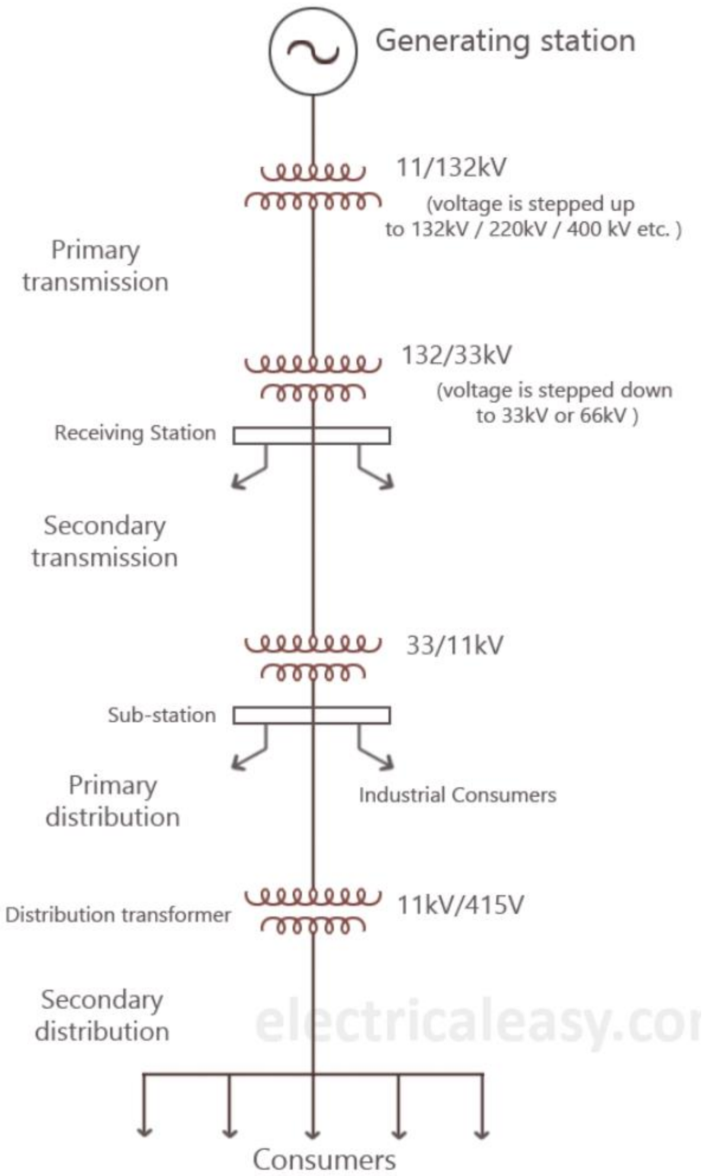

**Transmission**

After electrical power is generated, it is transmitted over distances using transmission lines. Transmission lines are constructed between transmission substations located at electric generating stations. Transmission lines may be supported overhead on towers or they may be underground. They are operated at high voltages. They send out large amounts of electrical power and extend over considerable distances.

Electrical energy, after being produced at generating stations (TPS, HPS, NPS, etc.) is transmitted to the consumers for utilization. This is due to the fact that generating stations are usually situated away from the load centers. The network that transmits and delivers power from the producers to the consumers is called the **transmission system**. This energy can be transmitted in AC or DC form. Traditionally, AC has been used for years now, but HVDC (High Voltage DC) is rapidly gaining popularity.

**Single Line Diagram of AC Power Transmission System**

A typical single line diagram that represents the flow of energy in a given power system is shown below:



Electric power is commonly (or usually) generated at 11 kV in generating stations in India and Europe. While in some cases, generation voltage might be higher or lower. Generating machines, to be used in power stations, are available between 6 kV to 25 kV from some big manufacturers. This generating voltage is then stepped up to 132kV, 220kV, 400kV or 765kV etc. Stepping up the voltage level depends upon the distance at which power is to be transmitted. Longer the distance, higher will be the voltage level. Stepping up of voltage is to reduce the $I^2R$ losses in **transmitting the power** (when voltage is stepped up, the current reduces by a relative amount so that the power remains constant, and hence $I^2R$ loss also reduces). This stage is called as **primary transmission**.

he voltage is the stepped down at a receiving station to 33kV or 66kV. **Secondary transmission** lines emerge from this receiving station to connect substations located near load centers (cities etc.).

The voltage is stepped down again to 11kV at a substation. Large industrial consumers can be supplied at 11kV directly from these substations. Also, feeders emerge from these substations. This stage is called as **primary distribution**.

Feeders are either overhead lines or underground cables which carry power close to the load points (end consumers) up to a couple of kilometers. Finally, the voltage is stepped down to 415 volts by a pole-mounted distribution transformer and delivered to the distributors. End consumers are supplied through a service mains line from distributors. The **secondary distribution** system consists of feeders, distributors and service mains.

**Different Types of Transmission Systems**

1. Single phase AC system
2. Two phase AC system
3. Three phase AC system
4. DC system

**Electric power transmission** can also be carried out using underground cables. But, construction of an underground transmission line generally costs 4 to 10 times than an equivalent distance overhead line. However, it is to be noted that, the cost of constructing underground transmission lines highly depends upon the local environment. Also, the cost of conductor material required is one of the most considerable charges in a transmission system. Since conductor cost is a major part of the total cost, it has to be taken into consideration while designing. The choice of transmission system is made by keeping in mind various factors such as reliability, efficiency and economy. Usually, overhead transmission system is used.

**Main Elements of a Transmission Line**

Due to the economic considerations, three-phase three-wire overhead system is widely used for electric power transmission. Following are the main elements of a typical power system.

- **Conductors:** three for a single circuit line and six for a double circuit line. Conductors must be of proper size (i.e. cross-sectional area). This depends upon its current capacity. Usually, ACSR (Aluminium-core Steel-reinforced) conductors are used.

- **Transformers:** Step-up transformers are used for stepping up the voltage level and step-down transformers are used for stepping it down. Transformers permit power to be transmitted at higher efficiency.
- **Line insulators:** to mechanically support the line conductors while electrically isolating them from the support towers.
- **Support towers:** to support the line conductors suspending in the air overhead.
- **Protective devices:** to protect the transmission system and to ensure reliable operation. These include ground wires, lightening arrestors, circuit breakers, relays etc.
- **Voltage regulators:** to keep the voltage within permissible limits at the receiving end.

## Concept of Power Grid

Electricity grid consists of four major components.

**Individual generators**

Variety of facilities generate electricity, including coal and natural gas power plants, hydroelectric dams, nuclear power plants, wind turbines, and solar panels.

**Transmission lines**

Transmission lines are necessary to carry high-voltage electricity over long distances and connect electricity generators with consumers.

## Distribution

The distribution network is simply the system of wires that picks up where the transmission lines leave off. These networks start at the transformers and end with homes, schools, and businesses. The transmission grid comes to an end when electricity finally gets to the consumer.

## Grid

The electricity grid has grown and changed immensely since its origins in the early 1880s, when energy systems were small and localized. During this time, two different types of electricity systems were being developed: the DC, or direct current, system, and the AC, or alternating current, system.

Despite a campaign by Thomas Edison to promote the direct current system, businessman George Westinghouse and inventor Nikola Tesla won the support of electric companies for the alternating current system, which had the distinct advantage of allowing high voltages to be carried long distances and then transformed into lower voltages for customer use.

Distribution grid refers to the final stage of the electrical grid which distributes electricity to homes, industry, and other end users. Distribution both delivers the electric power to every user on the grid and once delivered, it also reduces power to safe customer-usable levels. The transformers used for distribution can be seen on poles for overhead lines, or on the ground for underground lines, called pads.

Distribution stations are either built within buildings or outdoors, but always in an enclosed area. The design of these stations depends on economic, environmental, legal and social factors.

The electricity grid is a dynamic system. It has changed and evolved rapidly over the last century to accommodate new technologies, increases in electricity demand, and a growing need for reliable, diverse sources of electricity.

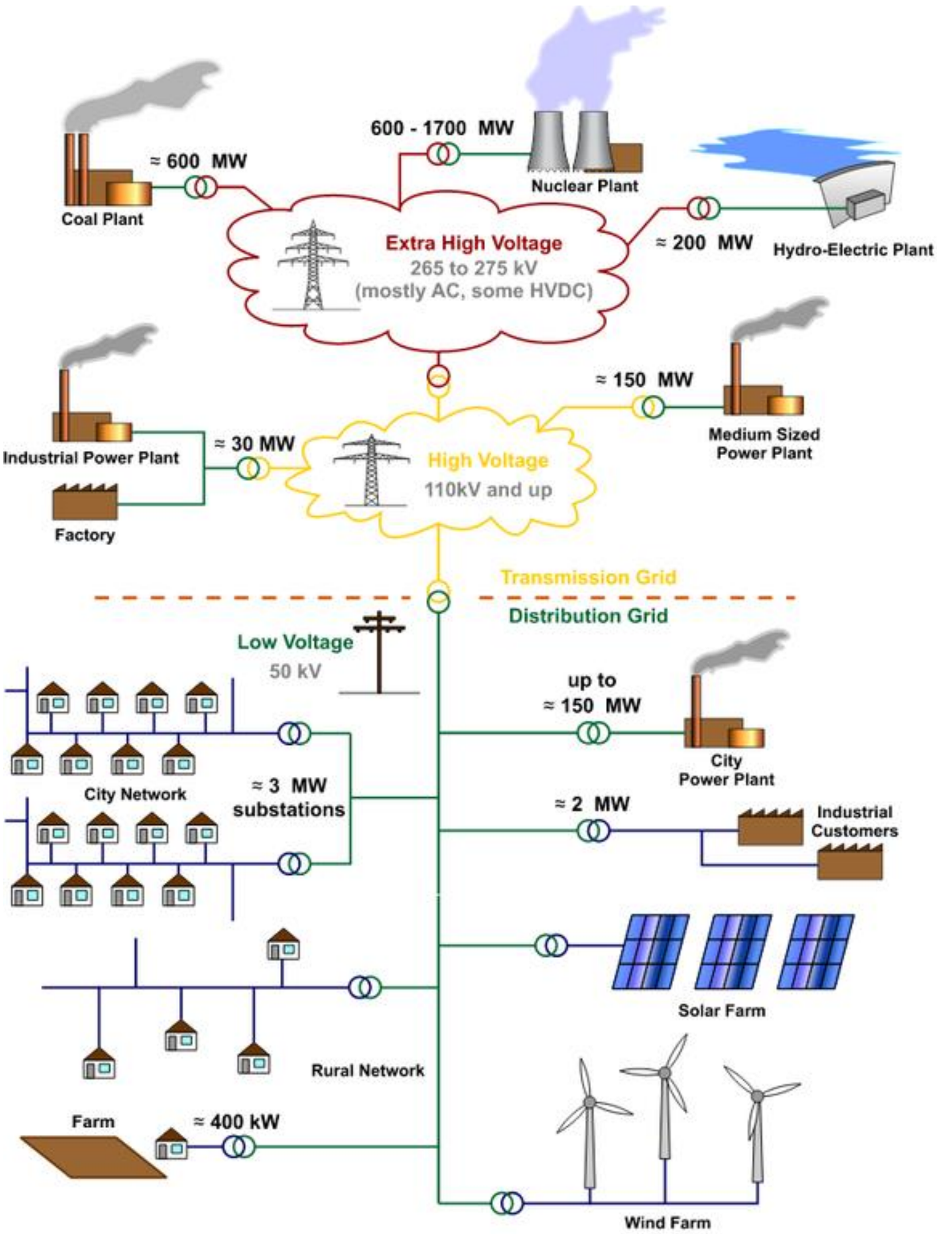
As technology changes and better options become available, significant improvements could be made to the electricity grid.

For example, energy storage technologies could allow electricity to be stored for use when demand for electricity peaks or increases rapidly, increasing efficiency and reliability.

The interconnected and complex nature of the electricity grid delivers several benefits, including:

- **Reliability:** Since the grid is an enormous network, electricity can be deployed to the right places across large regions of the country. The large transmission network allows grid operators to deal with anticipated and unanticipated losses, while still meeting electricity demand.
- **Flexibility:** The electricity grid allows a power system to use a diversity of resources, even if they are located far away from where the power is needed. For example, wind turbines must be built where the wind is the strongest; the grid allows for this electricity to be transmitted to distant cities.
- **Economic competition:** Because the grid allows multiple generators and power plants to provide electricity to consumers, different generators compete with each other to provide electricity at the

cheapest price. The grid also serves as a form of insurance – competition on the grid protects customers against fluctuations in fuel prices.

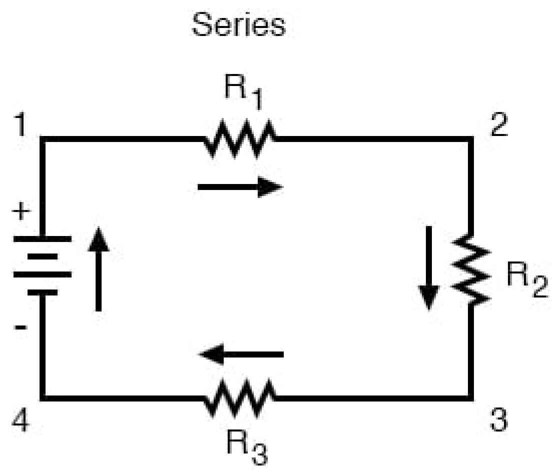



## Series and Parallel Connections

A series circuit is a circuit in which resistors or loads are connected end to end so that the circuit will have only one path through which electric current flows. Thus, when a number of resistors are connected in series, the effective resistance (total resistance in the circuit) is gotten by adding the individual resistance algebraically. That is to say, if we have resistors with resistance R1, R2, R3 …Rn **connected in series**, then;

**$R_{eff} = R_T = R_1 + R_2 + R_3 + \ldots R_n$.**

In series connections, the same current flows across all the branches of the circuits, but different voltage across it thus making the resistors to have different voltage across them. Each resistor or load will experience a voltage drop. The applied voltage is equal to the sum of the voltage drop across the different parts of the circuit. Voltage drop is proportional to the resistance current being the same throughout the circuit. When loads are connected in series, the loads will tend to have a common switch. This kind of connection is employed in school halls, street lights.




With simple parallel circuits, all components are connected between the same two sets of electrically common points, creating multiple paths for the current to flow from one end of the battery to the other:

Series circuit connections are common and greatly employed in electrical equipment. The tube filaments in small radios are usually in series. Current controlling devices are always connected in series with the device that they protect. Fuses are connected in series with the device they protect, Automatic house-heating equipment has a thermostat, electromagnetic coils, and safety cut-outs connected in series with a voltage source etc.

**Rules regarding Series Circuits:**

- Voltage drops add to equal total voltage.
- All components share the same (equal) current.
- Resistances add to equal total resistance.

Advantages of Series Connection

- Less size of wire cable is required in series wiring.
- We use to protect the circuit to connect fuse & circuit breakers in series with other appliances.
- Series circuit don't get overhead easily due to high resistance when more load added in the circuit.
- The lifespan of battery in series circuit is more as compared to parallel.
- It is most simple method of electrical wiring and fault can be easily detect and repair as compared to parallel or series-parallel wiring.

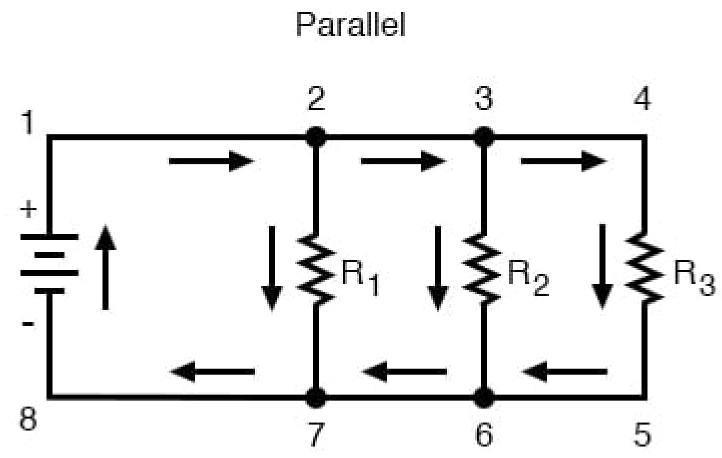
Disadvantages of Series Circuit

- The break in the wire, failure or removal of any single lamp will break the circuit and cause all of the others to stop working as there is only one single path of current to flow in the circuit.

- If more lamps are added in series lighting circuit, they will all be reduced in brightness. because voltage are shared in series circuit. If we add more loads in series circuit, the over voltage drop is increases which is not a good sign for electrical appliances protection.
- Series Wiring is "ALL or NONE" type wiring means all the appliances will work at once or all of them will disconnect if fault occurs at any one of the connected devices in series circuit.
- High supply voltage is needed if we need to add more load (light bulbs, electric heaters, air conditioner etc.) in the series circuit. For example, If five, 220V Lamps are to be connected in Series, then Supply Voltage would have to be: 5 x 220V = 1.1kV.
- The overall series circuit resistance increases (and current decreases) when more load added in the circuit.
- According to future need, only those electrical appliances should be added in the current series circuit if they have the same current rating as current are same at each point in series circuit. However, we know that electrical appliances and devices i.e. light bulbs, fan, heater, air conditioner etc have different current rating, therefore, they cannot be connected in series circuit for smooth and efficient operation.

**Parallel Circuits:**

Resistors, loads are said to be connected in parallel when the end of each of the resistors or loads have a common point or junction and the other ends are also connected to a common point or junction. Such circuits are known as parallel circuits.




Unlike the series circuit connection, when finding the total (effective) resistance in a parallel circuit, the reciprocal of the individual resistance is taken. Thus, when a number of resistances are connected in parallel, the reciprocal of the effective resistance is given by the arithmetic or algebraic sum of the reciprocal of the individual resistance.

**$1/R_{eff}$ or $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 \ldots 1/R_n$.**

Parallel circuit connection have the same voltage flowing across all the branches of the circuits. Different resistors have their individual currents.

**Advantages of Parallel Circuit**

- Each connected electrical device and appliance are independent from others. This way, switching ON / OFF a device won't affect the other appliances and their operation.

- In case of break in the cable or removal of any lamp will not break the all circuits and connected loads, in other words, other lights/lamps and electrical appliances will still work smoothly.
- If more lamps are added in the parallel lighting circuits, they will not be reduced in brightness (as it happens only in series lightning circuits). Because voltage is same at each point in a parallel circuit. In short, they get the same voltage as the source voltage.
- It is possible to add more light fixture and load points in parallel circuits according to future need as far as the circuit is not overloaded.
- Adding additional devices and components wont increase the resistance but will decrease the overall resistance of the circuit especially when high current rating devices are used such as air conditioner and electric heaters.
- parallel wiring is more reliable, safe and simple to use.

**Disadvantages of Parallel Connections**

- More size of cable and wire is used in parallel lighting wiring circuit.
- More current needed when additional light bulb added in the parallel circuit.
- Battery runs out quicker for DC installation.
- The parallel wiring design is more complex as compare to series wiring.

**Rules regarding Parallel Circuits:**

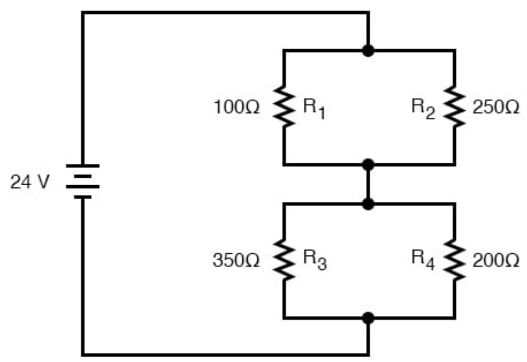
- All components share the same (equal) voltage.
- Branch currents add to equal total current.
- Resistances diminish to equal total resistance.

**Series - Parallel Circuits**

As the circuit is combination of series and parallel, We can not simplify the current, voltage, resistance and power by simple Ohm's Law. We have to apply different theorems like Norton's, Thevenin's, maximum power transfer theorem etc. or will simplify the circuit in basic series and parallel circuits to find all those quantities.

Most common of household wiring installation nowadays using this wiring method.

A series-parallel combination circuit




This circuit is neither simple series nor simple parallel. Rather, it contains elements of both. The current exits the bottom of the battery splits up to travel through $R_3$ and $R_4$, rejoins, then splits up again to travel through $R_1$ and $R_2$, then rejoin again to return to the top of the battery.

Main differences between series and parallel connections

| S No. | Series Circuit | Parallel Circuit |
|---|---|---|
| Current (I) | Currents are same in each point in series circuit: $I_1 = I_2 = I_3 = .... I_n$ | Currents are additive in parallel circuit: $I_1 + I_2 + I_3 + .... I_n$ |
| Voltage (V) | Voltages are additive in series circuit: $V_1 + V_2 + V_3 + .... V_n$ | Voltages are same in each point in parallel circuit: $V_1 = V_2 = V_3 = .... V_n$ |
| Resistance (R) & to Find (R) | Resistances are additive in Series Circuit: $R_1 + R_2 + R_3 + ...R_n = R_{eff} = R_T$ | Resistances are divided when more load added in the circuit. $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 ...1/R_n$ or $I = G_1 + G_2 + G_3 + ... G_n$ |
| To Find Current (I) | $I = V_1/R_1 = V_2/R_2 = V_3/R_3 = V_n/R_n$ | $I = V_1/R_1 + V_2/R_2 + V_3/R_3 + V_n/R_n$ |
| To Find Voltage (V) | $V = I_1R_1 + I_2R_2 + I_3R_3 + ... I_nR_n$ | $V = I_1R_1 = I_2R_2 = I_3R_3 = ... I_nR_n$ |
| To Find Electric Power (P) | $P = I^2R_1 + I^2R_2 + ... I^2R_n$ or $P = V_1^2/R_1 + V_2^2/R_2 + ... V_n^{2/}R_n$ | $P = V^2/R_1 + V^2/R_2 + ... V^{2/}R_n$ or $P = I_1^2R_1 + I_2^2R_2 + ... I_n^2R_n$ |
| Paths of flow of Electric Current | Only one path | Two or more paths |
| Brightness of Bulb | Dimmer if added more bulbs (P = V x I) | Brighter due to same voltages |
| If breaks occur in the circuit | Whole circuit is useless | The rest of the circuit will still work |
| Battery Status | Battery Discharge slowly (Ah Rating of Battery) | Battery Discharge Quickly (Battery Ah Time & Currents) |

| | | |
|---|---|---|
| Applications | Used to protect the circuit while connecting fuses and circuit breakers in series with the connected appliances | Used in most of household electrical wiring installations |

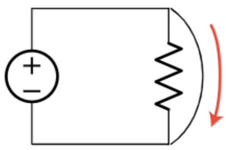
## Technicalities of Junctions and Loops in Circuits

*Circuit* comes from the word *circle*. A circuit is a collection of real components, power sources, and signal sources, all connected so current can flow in a complete circle.

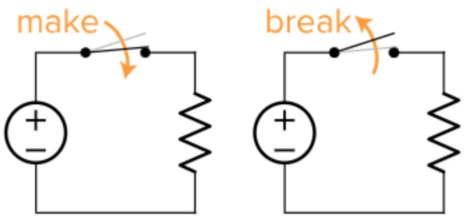
**Closed circuit** – A circuit is *closed* if the circle is complete, if all currents have a path back to where they came from.

**Open circuit** – A circuit is *open* if the circle is not complete, if there is a gap or opening in the path.

**Short circuit** – A *short* happens when a path of low resistance is connected (usually by mistake) to a component. The resistor shown below is the intended path for current, and the curved wire going around it is the short. Current is diverted away from its intended path, sometimes with damaging results. The wire *shorts out* the resistor by providing a low-resistance path for current (probably not what the designer intended).

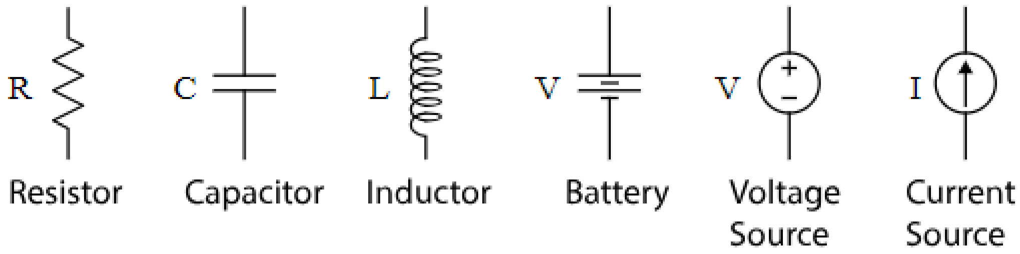


**Make or Break** – You *make* a circuit by closing the current path, such as when you close a switch. *Breaking* a circuit is the opposite. Opening a switch *breaks* the circuit.




**Elements** – The term *elements* means "components and sources."

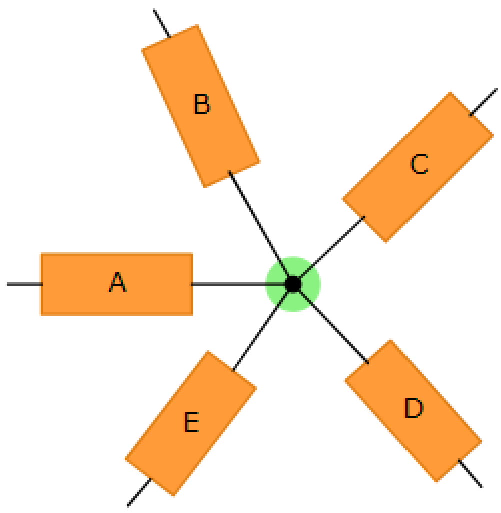
**Symbols** – Elements are represented in schematics by *symbols*.



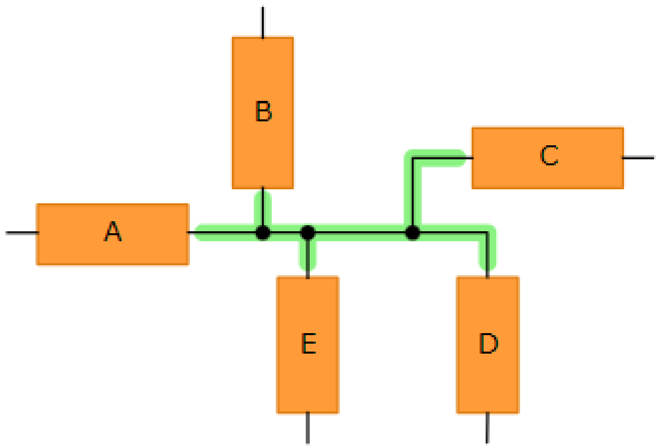

**Lines** – Connections between elements are drawn as lines, which we often think of as "wires". On a schematic, these lines represent perfect conductors with zero resistance. Every component or source terminal touched by a line is at the same voltage.

**Dots** – Connections between lines can be indicated by *dots*. Dots are an unambiguous indication that lines are connected.

**Node** – A junction where  *or more* elements connect is called a *node*.

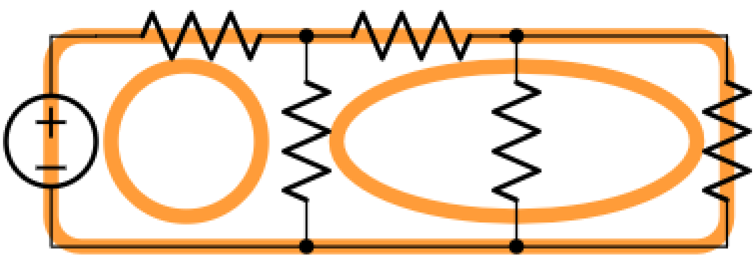


Since lines on a schematic represent perfect zero-resistance conductors, there is no rule that says lines from multiple elements are required to meet in a single point junction. We can draw the same node as a *distributed* node like the one in the schematic below. These two representations of the node mean exactly the same thing.




**Branch** – *Branches* are the connections between nodes.

**Loop** – A *loop* is any closed path going through circuit elements. a loop can visit (pass through) a node only *one time*. It is ok if loops overlap or contain other loops.



**Mesh** – A *mesh* is a loop that has no other loops inside it.

**Ground** – The reference node is often referred to as *ground*.

## Transmission Losses (Qualitative)

When electrical currents travel on a network, some energy is dissipated in the form of heat, and is "lost" due to the electrical resistance in the network. This energy is known as network losses. The transmission network is the high voltage network which carries electricity from generation to the distribution network, or to large electrical users which are directly connected to the transmission network. The places where the transmission and distribution networks connect are called grid supply points1 (GSP). Distribution losses happen between a GSP and a household.

Due to network losses, generators must produce more energy to ensure that demand users receive all the energy they need. Rules are in place to make sure that the cost of transmission losses is recovered from all transmission network users in their transmission network charges.

The three main types of losses in transmission lines are:

1. Resistive
2. Capacitive
3. Inductive

Most conductors, like power lines, are not perfect. This means that when power travels down cables, some of it is lost. Typically, electrical cables carrying higher voltages incur less line losses. This can be understood better by considering the formula for power: Power = current x voltage.

Resistive, capacitive and inductive line losses do not only occur in high-voltage transmission, but also in low and medium voltage scenarios. All three of these types of line losses are caused, in part, by heat loss from power being impeded along power lines. Alternating current (AC) power suffers from all three of these line losses, regardless of voltage, and direct current (DC) power only suffers from some types of resistive power losses.

AC power is compatible with transformers, it's more easy and cost effective to step AC voltages up or down, as well as isolate power for safety. This makes the infrastructure to transmit AC power generally cheaper, and that's why transmission systems are usually high-voltage AC. High-voltage AC is usually what power grids are transmitting, *DC power is more often associated with low-voltage distribution.*

A lower voltage also implies a higher current, and a higher current produces more heat and energy losses. So, if we compare a high-voltage AC transmission system to a low-voltage DC distribution system, the high-voltage AC transmission is more efficient. This is essentially where the misconception that DC power is less efficient came from: because people associate DC power with lower voltages, they might assume DC power is just less efficient.

However, if we were to compare AC and DC distribution at the same voltage level (high or low), AC power would suffer from all three types of line losses, while DC power would only suffer from certain types of resistive power losses, making AC power ultimately less efficient at all voltage levels.

**Resistive Line Losses**

Resistive power loss is when electrical power is lost due to the resistance of a conductor, like a power line. There are no perfect conductors, except for superconductors. Aside from those, all conductors have a bit of electrical resistance.

This is why, when either type of electricity meets any resistance, electrical power is converted into thermal power (or heat). Thus, energy is lost in the form of heat.

**Capacitive Line Losses**

Capacitive losses only occur in AC circuits, not DC circuits, and are a type of reactive power loss. Like resistive power losses, reactive power losses come in the form of heat.

When two conductors run parallel to each other, they create a “capacitance” with each other, especially if they’re close together. So, with this in mind, consider these two conductors: power lines and the earth. Every electrical cable has a “parasitic capacitance” with the earth. “Parasitic”, in this context, means something unwanted, like a parasite.

As for capacitance, capacitance occurs when two conductors are close enough together that they can store energy in an electric field. In the case of power transmission, capacitance occurs between the earth and power lines (our two conductors).

When energy is stored in an electric field, there is some loss of power, which is known as capacitive line loss. Capacitive effects don’t occur in DC circuits because the voltage of a DC circuit is steady.

**Inductive Line Losses**

Inductive line losses are the third type of line loss experienced by AC circuits, including power lines. Inductive losses are essentially power losses that occur when a magnetic field is built and collapsed repeatedly, on a wire.

To explain this further, an inductor is an electrical component that stores energy in a magnetic field. When AC power alternates, it charges up a parasitic inductor (created by the wire), creating a magnetic field that collapses and changes direction repeatedly. When power is stored in these magnetic fields, it doesn't make it to power loads, which makes it a type of line loss. Additionally, each time these parasitic inductors charge up and down, power is lost in the form of heat. The lost power that's stored up in these magnetic fields and lost in the form of heat, is considered an inductive line loss.

Direct current (DC) power doesn't have an alternating frequency, so its voltage is steady. This means it doesn't charge a parasitic inductor up and down repeatedly, like AC power, and so it doesn't incur inductive power losses.

## Roles Of Step-Up and Step-Down Transformers

A transformer is a passive component that transfers electrical energy among AC circuits. There is a part called the core in a transformer in which any fluctuating current gives rise to magnetic flux, thereby inducing an electromotive force around the core. More importantly, the transformers are widely used to change the levels of AC voltage and for this application, they are categorized into two types that are namely step up and step down transformers. Sometimes, there are power losses along many power distribution lines due to fluctuation in wire resistances. To prevent such problems, we put forth a transformer that can control the output voltage thereby overcoming the fluctuations. This is why step up and step-down transformers are used. Let us dive deeper into it.

A step-up transformer is a device which makes long-distance transmission of electrical energy economically efficient; it converts low voltage AC into high voltage AC, which decreases the loss of energy during transmission. In the process of voltage conversion, the output current is decreased so that the input and output power of the system would be equal. Step-up transformers are mostly used in electrical equipment to create a balance between the low input voltage and required high voltage such as microwave ovens, inverters, stabilizers, and so on.

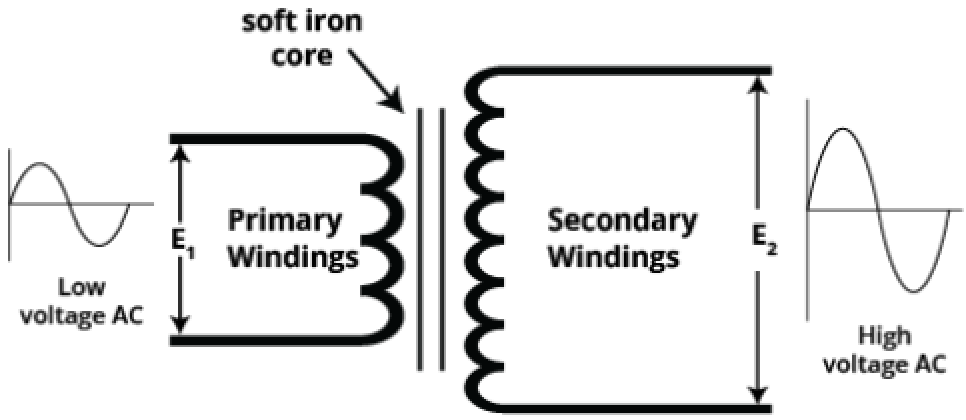
Step-Down Transformer: The type of transformer having output voltage less than the input voltage is called a step-down transformer. It converts high voltage AC into low voltage AC, keeping the input and output power the same. High voltage AC running in the transmission lines is converted into the Low Voltage AC by step down transformer for the successful operation of our home appliances. For example, the doorbell operates at 16V, while our power circuit carries 230V – 110V, so this balance between input and output voltage is managed by a step-down transformer; it reduces the voltage from 220V to 16V.

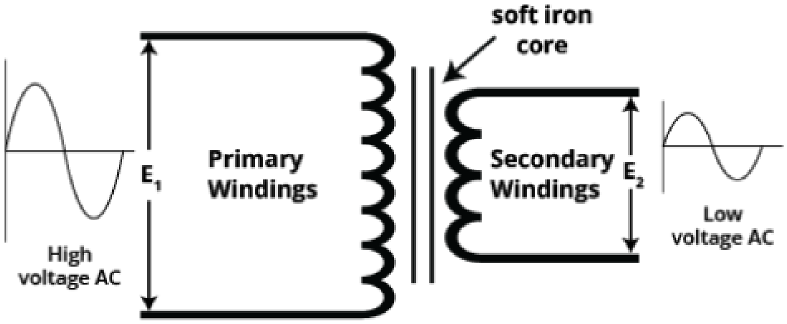
The major construction revolves around the two parts, the core and the windings.

Core: A transformer consists of a soft iron core and two inductive windings. The core is made up of soft iron with a collection of laminated metal sheets to facilitate the windings; laminated metal sheets are used to reduce the eddy current loss.

Windings: It has two windings primary and secondary winding; primary winding is connected to the input and secondary winding is connected to the output. Proper insulation is provided between both the coils and between the coil and core. Here is the image of the primary and secondary winding of a step-up transformer.

In a step-up transformer, the number of turns in secondary windings is greater than in primary windings, therefore it steps up the voltage, i.e., converts a primary voltage into a high secondary voltage. Meanwhile, in step down transformers, the number of turns in the primary winding is greater than in the secondary winding. Therefore, it converts the voltage in a primary coil into a low secondary voltage.






Step up and step-down transformers work on the principle of mutual induction. According to this, the changing current in one coil induces EMF in the other coil. Alternating current flows in one direction, stops reversing its direction, and then again flows in another direction. Alternating current flowing in the primary coil will create a varying magnetic field in the core of the transformer that in turn produces the alternating current in the secondary coil. Depending on the number of turns in the primary and secondary coil, the voltage is either stepped up or down.

In the step-down transformer, the number of turns is greater in the primary coil than in the secondary coil, so the output value will be lesser than the input and it converts high voltage AC into low voltage AC. In the step-up transformer, the number of turns in the secondary coil is greater than the primary coil and it converts low voltage AC into high voltage AC. The number of turns in coils, current and voltage can be related by the equation below

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$$

Where Vs and Vp are the voltages of the secondary and the primary winding of the transformer respectively. Ns and Np are the numbers of turns of the secondary and the primary windings. Is and Ip are the currents induced in the windings.

Step up and step down transformers neither create nor destroy the electrical power. The input and output power remain the same by changing the voltage and current at the primary and secondary coils.

Difference Between Step Up and Step Down Transformers

| Criteria | Step Up Transformer | Step Down Transformer |
|---|---|---|
| Operation | Increases voltage at the output. | Decreases voltage at the output. |
| Construction | The number of turns in the secondary coil is greater than in the primary coil. | The number of turns in the primary coil is greater than in the secondary coil. |
| Voltage | Low input voltage and high output voltage | High input voltage and low output voltage |
| Current | High input current and low output current | Low input current and high output current |

There are applications of step-up and step-down transformers which we can witness in our daily life. A Step-up transformer would be applicable in power transmission, microwave ovens, inverters, and so forth. Whereas a step-down transformer is used in power distribution, electrical devices such as bells, mobile chargers etc.

Step up and step-down transformers are used to create a balance between the supply and required voltage in electrical appliances. Step-up transformers are mainly used to reduce the loss of electrical energy during transmission, while step-down transformers are used to distribute the high supply voltage to the devices using low voltage for their operation. Step up and step-down transformers do not create or destroy the electrical energy, but only convert it.

## Quality of Connecting Wires

Wires come in many forms and are made from many materials. two important points:

-Electricity in long wires used in transmission behaves very differently than in short wires used in design of devices

-The use of wires in AC circuits brings on all sorts of problems like skin effect and proximity effects.

**1.) Behavior of electricity in wires: Resistance and Impedance**

**AC Power:**

In AC power current likes to travel near the surface of a wire (skin effect). AC power in a wire also causes a magnetic field to form around it (inductance). This field effects other nearby wires (such as in a winding) causing proximity effect. All of these properties must be dealt with when designing an AC circuit.

**DC Power:**

In DC power current travels through the whole of a wire.

**Size of the conductor and material (AC and DC power):**

Electricity travels more easily in highly conductive elements like copper, silver or gold, the less conductive the material, the larger the diameter has to be to carry the same current load.

**Quality of Material: Impurities and Crystals:**

Most materials have impurities. In copper the oxygen content and other materials in the copper effect the conductivity, so copper which will be made into an electrical wire is alloyed differently than copper which on it's way to becoming plumbing.

Metals are crystalline. Monocrystalline copper or aluminum has better conductivity than polycrystalline metals, however large crystal copper is very expensive to produce and only used in high performance applications.

**Resistivity:**

Resistance in a wire the describes the excitation of electrons in the wire's conductor material. This excitation results in the creation of heat, and loss of efficiency. Using DC power people couldn't send power for a long distance without using wide-diameter copper wires due to resistance over distance. This made DC power not cost effective and allowed for the growth of AC power.

**Measurement Tools:**

Ohms Law is used to calculate how much resistance a given wire will have. This tells us how much energy we will lose over distance.
**I = V / R** Amps = Volts divided by Resistance

Formulas for Resistance and Conductance:

Resistance = resistivity / cross sectional area

Conductance = 1 / Resistance

Creation of heat in a wire is normally a sign of wasted energy, however in a tungsten or tantalum wire the heat makes the wire glow and produce light which may be desired. Tungsten is used to make filaments because it has a very high melting point. The wire can get very hot and glow brightly without melting. Tungsten would be very bad for power transmission since most of the energy put through is lost in the form of heat and light.

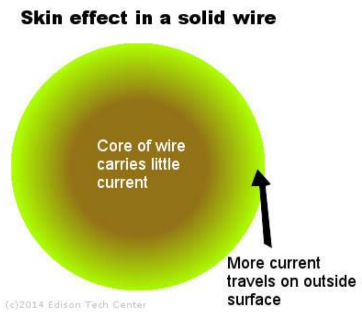
In power transmission we look for the lowest resistivity possible, we want to transmit power over long distances without losing energy through heat. We measure resistance in a wire by ohms per 1000 feet or meters. The longer electricity has to travel, the more energy it loses.

One great solution to power transmission is superconductors. As a metal becomes super cold (approaching absolute zero) it obtains a conductivity of infinity. At a certain point there is no resistivity at all. There have been experimental superconductive high voltage lines which were able to transmit power with almost no losses, however the technology is not developed enough to be cost effective.

**Magnetic Fields (inductance and impedance):**

Every wire used to transmit AC power creates a magnetic field while current flows through it. The magnetic field is visualized by concentric rings around the cross section of the wire, each ring closer to the wire has a stronger magnetic power. Magnetic fields are useful for making very strong magnets (when in a coil) i.e. making motors and generators, however these magnetic fields are unwanted in power transmission lines. While resistivity of a wire can impedes the flow of current and make heat, the inductance of a wire/transmission line can also impede the flow of current but this impedance does not create heat since the energy is 'lost' in creating a magnetic field rather than exciting electrons in the material. This impedance is called Reactive impedance in AC Circuits. We used the word 'lost' however the power is not truly lost, it is used to create the magnetic field and it returns when the magnetic field collapses.

**2.) Skin Effect:**




In AC power electrons like to flow on the outside of a wire. This is because the changing of current back and forth causes eddy currents that result in current crowding toward the surface.

**Skin Depth**

Skin depth is a fixed number for given frequency, resistivity and permittivity. The higher the frequency of AC power in system, the more current is compressed on the outside of the wire, so a wire that is used at 60 Hz at a given voltage will not be ok at 200 MHz.

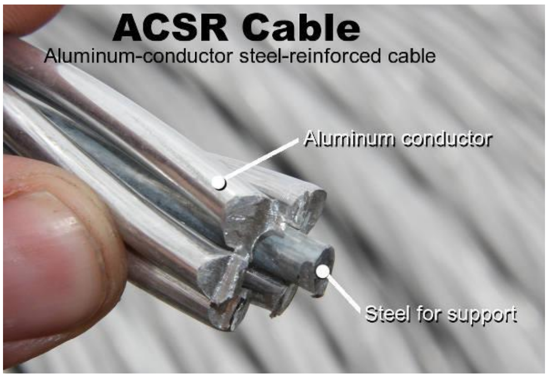
**3.) Types of Wire:**

Here are the factors for determining wire design:
-Durability (ability to flex repeatedly or be subject to crushing weights)
-Voltage and Current level
-Suspension strength (ability to hold its own weight over long spans between support)
-Underground or underwater
-Temperature of operation (like superconducting wire)

-Cost

**4.) Wire Materials:**

The most common material for electrical wire is copper and aluminum, these are not the best conductors however they are abundant and low cost. Gold is also used in applications because it is corrosion resistant. Gold is used in automobile airbag electronics to guarantee that the device will function many years later despite exposure to harmful elements. Gold is usually used in contact areas because this point in the system is more exposed to corrosion and has more potential for oxidization.




Aluminum wrapped around a steel center wire is used in power transmission because the aluminum is cheaper than copper and doesn't corrode. The steel center is used simply for strength, to hold the wire over long spans. Above is a typical ACSR cable used in overhead powerlines around the world.

**4.) WIRE INSULATION:**

Left: To make an efficient motor or generator windings have to be packed tight together, minimizing air spaces. Wire used in motors and generators is generally coated in enamel to allow the windings to be packed tight together. Traditional rubber or polymer insulation would make the wire diameter thicker; this is one reason why old electric motors were bigger and heavier than modern motors of the same horsepower.

## Characteristics of Single and Multicore Wires

**Single-core cable**

A solitary metallic conductor is characteristic of the design of cables that are referred to as having a single core. A protective insulating coating is wrapped over the conductor, which is commonly made of copper or aluminum, so that the level of safety may be increased. When it comes to the effective transmission of high voltage electricity, single-core cables are among the best options available.

These cables can carry substantial current loads without producing an excessive amount of heat, and they have that capability. Because of their low resistance and capacity to endure metal fatigue, single-core cables are renowned for their excellent durability and flexibility. This is due to the fact that these cables can tolerate metal fatigue. Their very low levels of resistance in comparison to those of other people are likely the root cause of this phenomena. Nevertheless, the usage of single-core cables is subject to a number of constraints that must be taken into consideration.

When compared to managing multi-core cables, the management of bigger and heavier conductors involves a greater number of obstacles and results in higher financial expenditures. In addition, the installation of these components as well as their interface with one another calls for the utilization of specific terminals and connections, which presents the possibility of a difficulty.

When it comes to single-core cables is the possibility that they may produce powerful magnetic fields. Magnetic fields like this have the ability to affect the functioning of electrical equipment that are in close proximity to them by causing electromagnetic interference.

**Multi-core cable**

Multi-core cables are known for their capacity to house multiple metal conductors within a single cable structure. The conductors are commonly twisted in a helical pattern, ensuring electrical isolation from each other and the outer layer. The advantages of multi-core cables for low voltage control or communication systems lie in their ability to efficiently transfer multiple signals or data streams simultaneously.

Multi-core cables offer cost-effective and easy handling benefits over single-core cables. This is because they use thinner and lighter conductors, leading to improved efficiency and manageability. One key benefit of utilizing multi-core cables is their capacity to reduce magnetic fields and inductive reactance in the circuit. The cancellation of each conductor's effects is achieved through the twisted topology of the cables, resulting in optimized performance. Multi-core cables have lower reliability and flexibility compared to single-core cables due to their increased resistance. This can increase the risk of short circuits and electrical damage. Elevated stress and temperature can negatively affect the performance and longevity of these cables, making them more vulnerable to these factors. In addition, the challenges of securely attaching all individual strands make the process of soldering or crimping connectors for multi-core cables more complex.

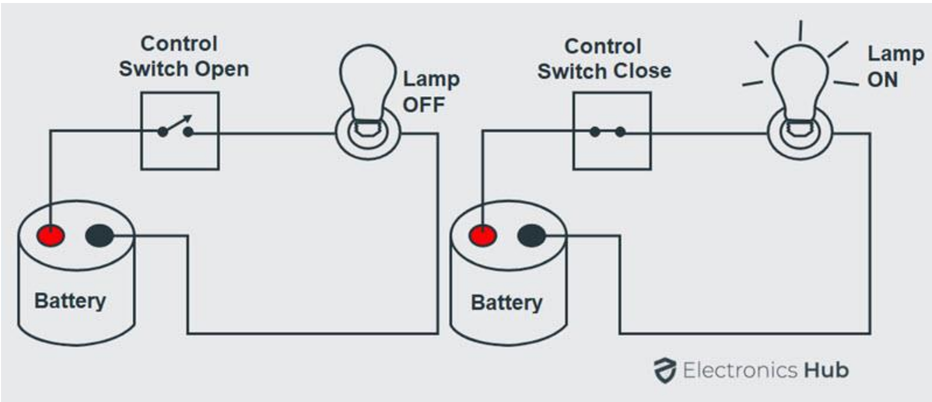
# Unit III

# ELECTRICAL WIRING

## Different types of switches

A Switch is a device which is designed to interrupt the current flow in a circuit. In simple words, a Switch can make or break an electrical circuit. Every electrical and electronics application uses at least one switch to perform ON and OFF operation of the device.

So, switches are a part of the control system and without it, control operation cannot be achieved. A switch can perform two functions, namely fully ON (by closing its contacts) or fully OFF (by opening its contacts).




When the contacts of a switch are closed, the switch creates a closed path for the current to flow and hence load consumes the power from source. When the contacts of a switch are open, no power will be consumed by the load.

Another important function of a Switch is to divert the flow of electric current in a circuit. Consider the following circuit. When the switch is in position A, the lamp 1 turns ON and while it is in position B, lamp 2 turns ON.

There are numerous applications of switch, found in wide variety of fields such as homes, automobiles, industrial, military, aerospace and so on. In home and office applications, we use simple rocker switches to turn ON and OFF appliances like lights, computers, fans etc. In some applications, multi way switching is employed (like building wiring), where two or more switches are connected to control an electrical load from more than one location, like a Two-Way Switch, for example.

**Types of Switches**

Basically, Switches can be of two types. They are:

- Mechanical
- Electronic

Mechanical Switches are physical switches, which must be activated physically, by moving, pressing, releasing, or touching its contacts.

Electronic Switches, on the other hand, do not require any physical contact in order to control a circuit. These are activated by semiconductor action.

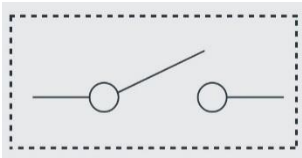
**Mechanical Switches**

Mechanical switches can be classified into different types based on several factors such as method of actuation (manual, limit and process switches), number of contacts (single contact and multi contact switches), number of poles and throws (SPST, DPDT, SPDT, etc.), operation and construction (push button, toggle, rotary, joystick, etc.), based on state (momentary and locked switches), etc.

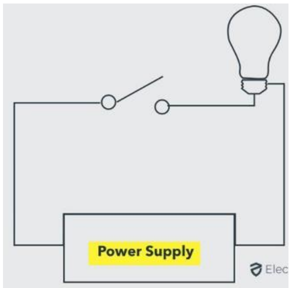
Based on the number of poles and throws, switches are classified into following types. The pole represents the number of individual power circuits that can be switched. Most of the switches are designed have one, two or three poles and are designated as single pole, double pole and triple pole.

The number of throws represents the number of states to which current can pass through the switch. Most of the switches are designed to have either one or two throws, which are designated as single throw and double throw switches.

**Single Pole Single Throw Switch (SPST)**

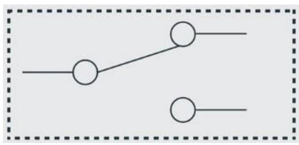


- This is the basic ON and OFF switch consisting of one input contact and one output contact.

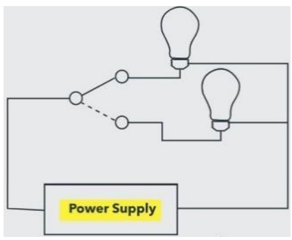



- It switches a single circuit and it can either make (ON) or break (OFF) the load.
- The contacts of SPST can be either normally open or normally closed configurations.

**Single Pole Double Throw Switch (SPDT)**



- This switch has three terminals: one is input contact and remaining two are output contacts.

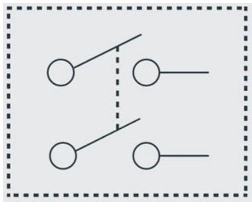



- This means it consist two ON positions and one-OFF position.
- In most of the circuits, these switches are used as changeover to connect the input between two choices of outputs.

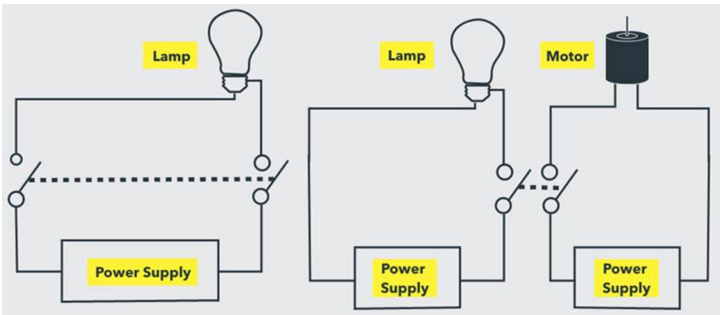
- The contact which is connected to the input by default is referred as normally closed contact and contact which will be connected during ON operation is a normally open contact.

**Double Pole Single Throw Switch (DPST)**

- This switch consists of four terminals: two input contacts and two output contacts.



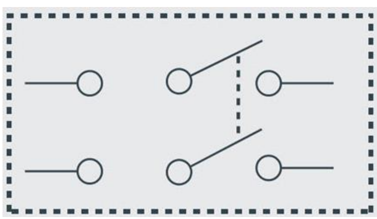
- It behaves like a two separate SPST configurations, operating at the same time.
- It has only one ON position, but it can actuate the two contacts simultaneously, such that each input contact will be connected to its corresponding output contact.




- In OFF position both switches are at open state.
- This type of switches is used for controlling two different circuits at a time.
- Also, the contacts of this switch may be either normally open or normally closed configurations.

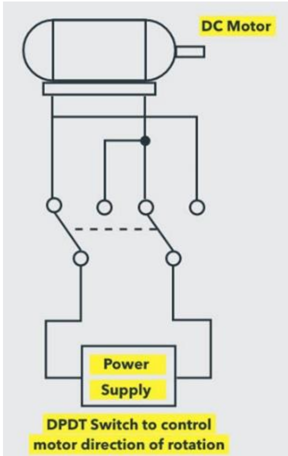
**Double Pole Double Throw Switch (DPDT)**

- This is a dual ON/OFF switch consisting of two ON positions.



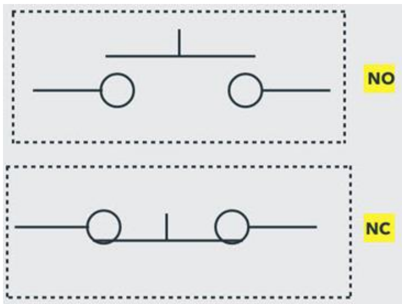
- It has six terminals, two are input contacts and remaining four are the output contacts.

- It behaves like a two separate SPDT configuration, operating at the same time.
- Two input contacts are connected to the one set of output contacts in one position and in another position, input contacts are connected to the other set of output contacts.




**Push Button Switch**

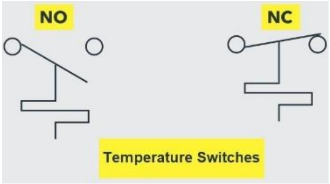
- It is a momentary contact switch that makes or breaks connection as long as pressure is applied (or when the button is pushed).
- Generally, this pressure is supplied by a button pressed by someone's finger.
- This button returns its normal position, once the pressure is removed.




- The internal spring mechanism operates these two states (pressed and released) of a push button.
- It consists of stationary and movable contacts, of which stationary contacts are connected in series with the circuit to be switched while movable contacts are attached with a push button.
- Push buttons are majorly classified into normally open, normally closed and double acting push buttons as shown in the above figure.
- Double acting push buttons are generally used for controlling two electrical circuits.

### Temperature Switches

- The most common heat sensing element is the bimetallic strip that operates on the principle of thermal expansion.

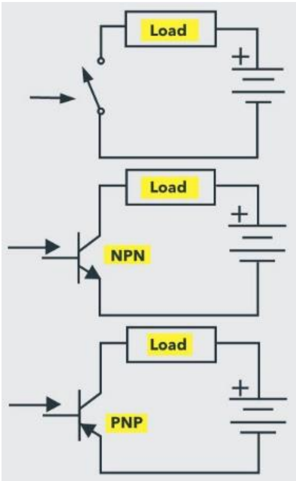



- The bimetallic strips are made with two dissimilar metals (that are having different thermal expansion rates) and are bonded with each other.
- The switch contacts are operated when the temperature causes the strip to bend or wrap. Another method of operating the temperature switch is to use mercury glass tube.
- When the bulb is heated, mercury in the tube will expand and then generates pressure to operate the contacts.

### Electronic Switches

The electronic switches are generally called as Solid State switches because there are no physical moving parts and hence no physical contacts. Most of the appliances are controlled by semiconductor switches such as motor drives and HVAC equipment.

### Bipolar Transistors




A transistor either allows the current to pass or it blocks the current as similar to working of normal switch.

In switching circuits, transistor operates in cut-off mode for OFF or current blocking condition and in saturation mode for ON condition. The active region of the transistor is not used for switching applications.

Both NPN and PNP transistors are operated or switched ON when a sufficient base current is supplied to it. When a small current flows though the base terminal supplied by a driving circuit (connected between the base and emitter), it causes the transistor to turn ON the collector-emitter path.

And it is turned OFF when the base current is removed and base voltage is reduced to a slight negative value. Even though it utilizes small base current, it is capable of carrying much higher currents through the collector- emitter path.

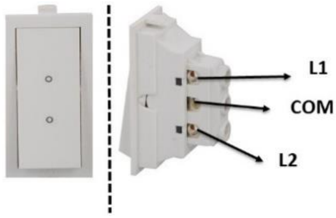
## Installation of two-way switch

2 Way Switch. It is also called as a Staircase Switch, as you can control a single load, a light bulb for example, from two different places, like either ends of a staircase.

It is a standard single pole double throw switch with three terminals.

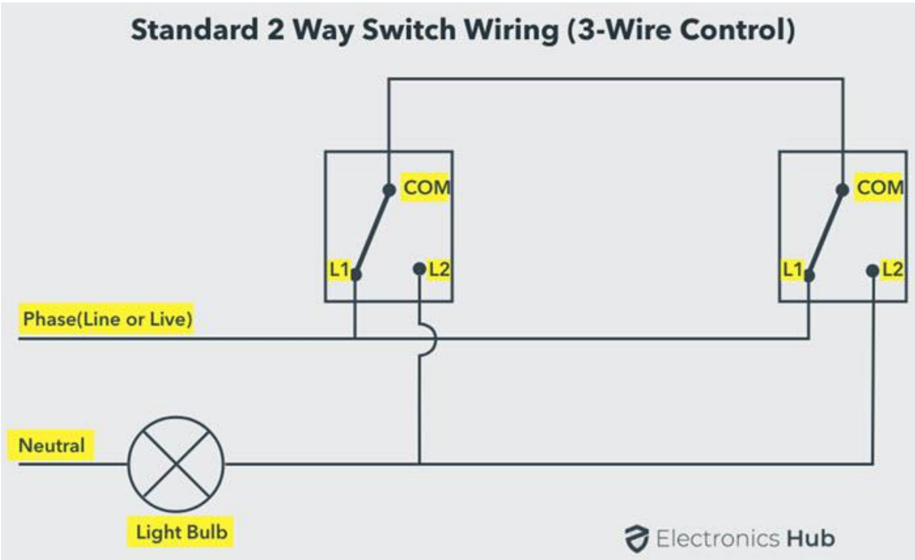
The three terminals are usually named COM, L1 and L2, but sometimes the terms COM, 1 Way and 2 Way are also used. In one position, the COM and L1 terminals are connected, while in the second position, the COM and L2 terminals are connected.

This type of connection is typically called a “Break before make” design, as the first connection has to be broken before making the second connection. This is in contrast to a regular two terminal switch, which is just a make-or-break device.




The following image shows the front and back view of a typical household two-way switch.

wiring uses a couple of Two-Way Light Switches with a three wire control (3 Wire Control). The following is the simple schematic of a three-wire 2-Way Switch wiring.




You can observe in the schematic that both the COM terminals are connected together. The L1 terminals of both the switches are connected to line (or phase or live) of the AC Supply.

The L2 terminals of both the switches are connected to one terminal of the light bulb, while the other terminal of the light bulb is connected to the neutral of the AC power supply.

In the default state shown in the above image, the light is off. If either of the switches is toggled, the light turns on. To turn off the light, you can toggle any switch.

For example, in the above state, the COM terminals of both the switches are connected to respective L1 terminals. Now, if we toggle Switch 1 i.e., COM of Switch 1 is now connected to its L2 terminal, then there is a path to complete the circuit and the light turns on.

To turn off the light, we can toggle either Switch 1 or Switch 2 as any toggling action will break the flow of current to the light. So, considering all the possibilities, the light is on in two cases:

- COM of Switch 1 is connected to L1 and COM of Switch is connected to L2.
- COM of Switch 1 is connected to L2 and COM of Switch is connected to L1.

If we compare this setup with digital electronics, then this is similar to an Ex-OR Gate, where the status of the light (ON or OFF) depends on the status of the COM terminals of both the switches connected to respective L1 and L2 terminals.

The following table shows the truth table for Standard Wiring i.e., 3-Wire Control of Two-Way Switch, where the output (status of the light) depends on what terminal (L1 or L2) is connected to the COM terminal.

| **Switch 1 COM (connected to)** | **Switch 2 COM (connected to)** | **Status of Light** |
|---|---|---|
| **L1** | L1 | OFF |
| **L1** | L2 | ON |
| **L2** | L1 | ON |
| **L2** | L2 | OFF |

This method is recommended as both the line and neutral wires come from the same lighting circuit (or breaker) even though it uses more wire.

## Role of sockets, plugs, sockets

Electrical plugs and socket-outlets differ in voltage and current rating, shape, size and type of connectors. The types used in each country are set by national standards. Generally, the plug is the movable connector attached to an electrically operated device's power cord, and the socket-outlet is fixed on equipment or a building structure. The plug has protruding prongs, or pins that fit into matching slots or holes in the socket-outlet. A socket is also called a receptacle, outlet, or power point. It is enclosed in a cover. Design features of plugs and socket-outlets have gradually developed to reduce the risk of electric shock and fire.


Safety measures may include

• Pin and slot dimensions and layout that permit only proper insertion of plug into socket-outlet

• Earth pins longer than power pins so the device becomes earthed before power is connected.

• Electrical insulation of the pin shanks was added as an additional feature to reduce live contact exposure when a plug is partially inserted in a socket-outlet.

• Shutters that open only for the correct plug prevent foreign objects from coming into contact with live slots.

Commonly used Electrical Plugs: The two pin plug is also called the Euro plug. It has two round pins. It can be inserted in either way into the socket. The three-pin plug is rated at 6A / 250V or 16A/ 250 V. It has three round pins in a triangular pattern. The earth terminal is slightly larger and longer than the live and neutral terminals. Socket Outlets Socket outlets, or electric receptacles, help provide direct access to an electric power source. They are designed to feed power to most electrically-run equipment from a series of small 2 boxes that are wired directly to an electrical panel or other power source. Socket outlets are commonplace in most homes and businesses, as they provide both easy and direct access to electrical power from various points. A socket outlet’s design may vary depending on the electrical current, the country of origin, and the type of equipment or plug it must accept. Due to these variances, not all electrical outlets and electric-run components are mutually compatible.

Damaged plugs, sockets and flexible cables can cause electric shocks, burns and fires.

• Check the plug and socket for burn marks, sounds of ‘arcing’ (buzzing or crackling), fuses blowing, circuit-breakers tripping or whether it feels hot.

• Remove plugs from sockets carefully. Pulling out a plug by the cable puts a strain on it, and could damage the contact between the plug and the socket. This could result in the plug overheating, its wires becoming loose or an electric shock (if the earth wire is disconnected).

• Only use plugs with the ISI mark

- Always replace damaged cables immediately. Touching exposed live wires may give you an electric shock.

One way to avoid this is to install tamper-resistant electrical socket outlets ie., with shutters. Many new homes already come equipped with them, and we can upgrade socket outlets in older homes to these new receptacles.

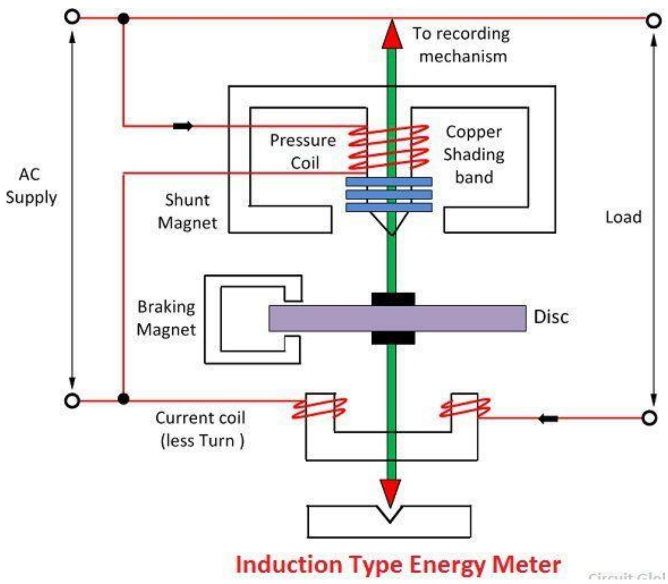
## Installation of meters

An electric meter, or energy meter, is a device that measures the amount of electric energy consumed by a building, tenant space, or electrically powered equipment.

The meter which is used for measuring the energy utilises by the electric load is known as the energy meter. The energy is the total power consumed and utilised by the load at a particular interval of time. It is used in domestic and industrial AC circuit for measuring the power consumption. The meter is less expensive and accurate.

### Construction of Energy Meter

The construction of the single-phase energy meter is shown in the figure.




The energy meter has four main parts. They are the

1. Driving System
2. Moving System
3. Braking System
4. Registering System

**1. Driving System** – The electromagnet is the main component of the driving system. It is the temporary magnet which is excited by the current flow through their coil. The core of the electromagnet is made up of silicon steel lamination. The driving system has two electromagnets. The upper one is called the shunt electromagnet, and the lower one is called series electromagnet.

The series electromagnet is excited by the load current flow through the current coil. The coil of the shunt electromagnet is directly connected with the supply and hence carry the current proportional to the shunt voltage. This coil is called the pressure coil.

The centre limb of the magnet has the copper band. These bands are adjustable. The main function of the copper band is to align the flux produced by the shunt magnet in such a way that it is exactly perpendicular to the supplied voltage.

**2. Moving System** – The moving system is the aluminium disc mounted on the shaft of the alloy. The disc is placed in the air gap of the two electromagnets. The eddy current is induced in the disc because of the change of the magnetic field. This eddy current is cut by the magnetic flux. The interaction of the flux and the disc induces the deflecting torque.

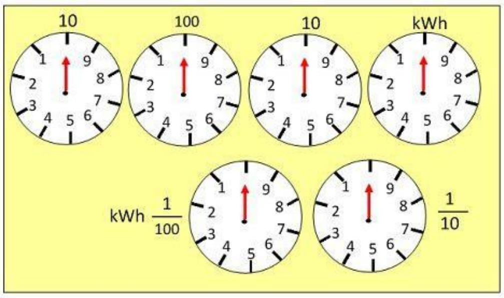
When the devices consume power, the aluminium disc starts rotating, and after some number of rotations, the disc displays the unit used by the load. The number of rotations of the disc is counted at particular interval of time. The disc measured the power consumption in kilowatt hours.

**3. Braking system** – The permanent magnet is used for reducing the rotation of the aluminium disc. The aluminium disc induces the eddy current because of their rotation. The eddy current cut the magnetic flux of the permanent magnet and hence produces the braking torque.

This braking torque opposes the movement of the disc, thus reduces their speed. The permanent magnet is adjustable due to which the braking torque is also adjusted by shifting the magnet to the other radial position.

**4. Registration (Counting Mechanism)** – The main function of the registration or counting mechanism is to record the number of rotations of the aluminium disc. Their rotation is directly proportional to the energy consumed by the loads in the kilowatt hour.

The rotation of the disc is transmitted to the pointers of the different dial for recording the different readings. The reading in kWh is obtained by multiply the number of rotations of the disc with the meter constant.



Pointer Type of Register

**Working of the Energy Meter**

The energy meter has the aluminium disc whose rotation determines the power consumption of the load. The disc is placed between the air gap of the series and shunt electromagnet. The shunt magnet has the pressure coil, and the series magnet has the current coil.

The pressure coil creates the magnetic field because of the supply voltage, and the current coil produces it because of the current.

The field induces by the voltage coil is lagging by 90° on the magnetic field of the current coil because of which eddy current induced in the disc. The interaction of the eddy current and the magnetic field causes torque, which exerts a force on the disc. Thus, the disc starts rotating.

The force on the disc is proportional to the current and voltage of the coil. The permanent magnet controls Their rotation. The permanent magnet opposes the movement of the disc and equalises it on the power consumption. The cyclometer counts the rotation of the disc.

Theory of Energy Meter

The pressure coil has the number of turns which makes it more inductive. The reluctance path of their magnetic circuit is very less because of the small length air gap. The current $I_p$ flows through the pressure coil because of the supply voltage, and it lags by 90°.

The current produces the two flux linkages which is again divided into two. The major portion of the flux $\Phi_{p1}$ passes through the side gap because of low reluctance. The flux $\Phi_{p2}$ goes through the disc and induces the driving torque which rotates the aluminium disc.

The flux $\Phi_p$ is proportional to the applied voltage, and it is lagged by an angle of 90°. The flux is alternating and hence induces an eddy current $I_{ep}$ in the disc.

The load current passes through the current coil induces the flux $\Phi_s$. This flux causes the eddy current $I_{es}$ on the disc. The eddy current $I_{es}$ interacts with the flux $\Phi_p$, and the eddy current $I_{ep}$ interacts with $\Phi_s$ to produce another torque. These torques are opposite in direction, and the net torque is the difference between these two.

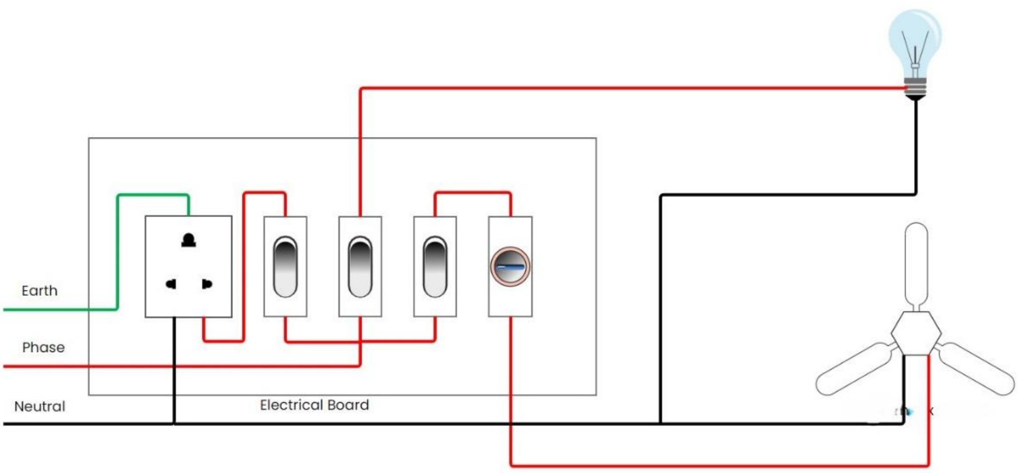
## Basic switch board

A switchboard can consist of a single vertical structure or multiple structures depending on the number and sizes of the loads being powered.

An electric switchboard is a device that directs electricity from one or more sources of power supply. In Switch Board, there are switch available to operate electrical appliances individually.

A main structure will contain the main disconnects or main lugs and will often contain utility and/or customer metering equipment and surge protection.

Cabling can enter directly into the main structure




or through a dedicated pull structure. Pull structures are commonly used in service entrance switchboards. Cables can enter the structure from the floor (bottom entry) or from above (top entry.)

Distribution structures divide and send power to branch circuit protection devices and then to branch circuits to power downstream loads. Power flows from the main structure to the distribution structure via cross bus.

In most installations, switchboards are mounted close to a wall and are front accessible only. If required, the switchboard can be constructed to allow both front and rear access. Rear access switchboards provide easier access for installation and maintenance, but they are typically deeper than front access only switchboards.

The primary components of a switchboard structure are the frame, bus, overcurrent protective devices, instrumentation, enclosures and exterior covers. The switchboard frame is the metal skeleton that houses all the other components. The bus, which is either copper or aluminum, is mounted within this frame. The bus distributes power from the incoming cable conductors to the branch circuit devices. A horizontal bus distributes power to each switchboard section. In contrast, a vertical bus distributes power to the circuit protection devices within an individual section.

Switchboards are used to safely distribute electricity throughout commercial and industrial facilities. A switchboard is a component of an electrical distribution system which divides an electrical power feed into branch circuits while providing a protective circuit breaker or fuse for each circuit in a common enclosure.

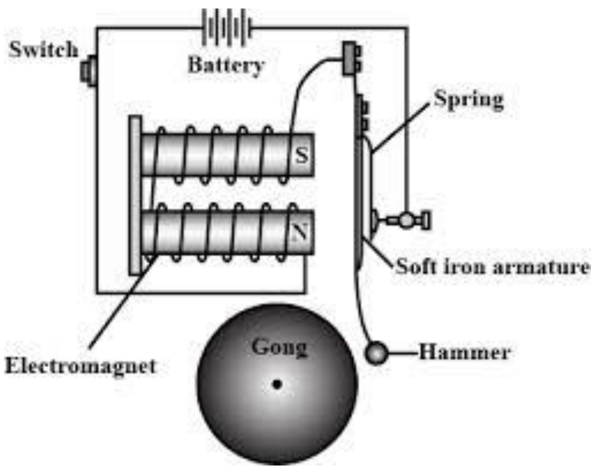
Switchboards typically have a maximum voltage rating of 600 Vac/Vdc and a maximum bus rating of 6000 A.

## Electrical bell

An electric doorbell is a simple circuit that triggers a tone by pressing a button when the circuit is complete. It is this simplicity that makes the doorbell such a wonder. Doorbell's simple device implements the scientific principles of electromagnetism in a meaningful way. To understand how an electric bell works, we first need to know about electromagnet. Electromagnet is a type of magnet where magnetic field is produced using an electric current. When electric current flows through a wire tied around an iron rod the iron rod behave like a magnet. the magnetic effect of electric current has been used in making powerful electromagnet. the iron rod around which the wire is wound is called a solenoid. The wire is wrapped around the iron rod many times electric current is supplied to the wire, the iron Rod behaves like a magnet as long as current is supplied. the more the number of turns in the wire the stronger a magnetic effect. Electromagnet is used in electric bulbs and also in powerful cranes.

**Uses of an Electromagnet**: Electromagnets are commonly used everyday appliances today. They are used in doorbells, hard drives, speakers and much more. Eye specialists use it for taking out foreign particles from the eyes. They are also being used for industrial applications.

**Working of an Electric Bell**



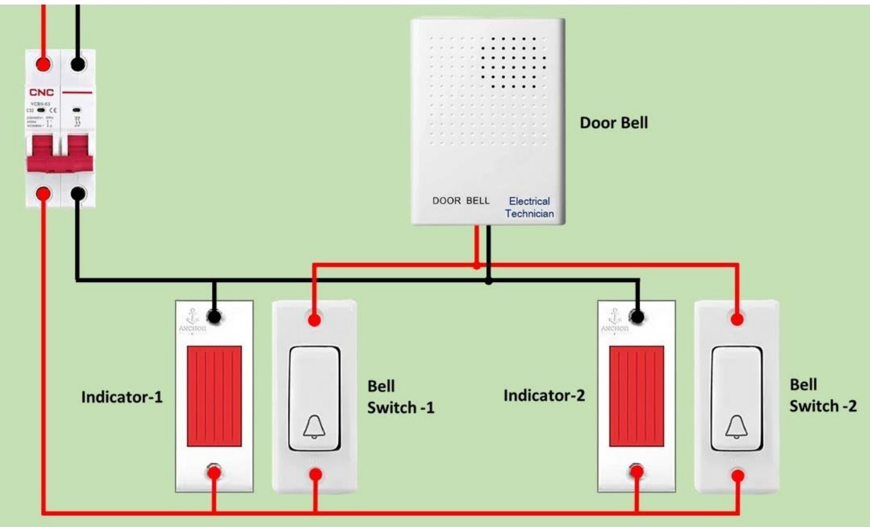

The important things required for construction of an electric bell are a gong , hammer, electrometer switch and soft iron armature or hand.Now that you understand the important things for an electric bell, let's put up with a step-by-step explanation of how the electric bell works. An electric bell has Electromagnet in it. It is made up of two rods of cast iron. The iron rods have a coil wrapped around them. A metallic strip is used and is kept parallel to the coils.  This trip has a Hammer connected to it at one end. The other part of the strip is connected with the circuit. A gong is placed in such a position that it can be hit by a hammer. When electric current is passed through the circuit the cast iron rod becomes charged with electromagnetic energy and attracts the metallic strip. as a result, the metallic hammer hits the ground the circuit breaks when the metallic through peaceful towards Electromagnet and gets disconnected from the point .since there is no magnetism left an Electromagnet the spring pulls back the metallic stripped this cycle is repeated again and again in the electric bell which produces a ringing sound .that is why it is called as making brake circuit.

## Indicator

Bell indicator circuit is used where a bell and buzzers are needed to control from different locations. Bell Indicator circuit is also known as hotelling circuit where an electric bell is controlled from more than one location. In hotel wiring circuit, the bell can be operated from different locations such as rooms by guests. It can be used to find the exact location and room where the guest needs attendant help. When a guest presses the push button, the specified indicator with room number starts to glow with ringing bell at the hotel management and attendant panel. The room attended then attend the exact room specified by indicator lamp where they seek help.

There is one flaw in this circuit as if there in no one in the pantry, They won’t be able to know who need assistance from which room. For this reason, an advanced hotel wiring circuit can be made with the help of 2 nos of NO (normally open) 230 or 120V contact blocks for one push button, 2 nos of NC (normally closed) push / release buttons for 1 room, 230V or 120V relay coil (NO) and 1.5mm 2 wires for phase and neutral.

This way, when a guest press the push button, the indicator bulb and bell will ring until someone in the reception switch off the bell and indicator lamp by pressing the push button installed on the panel board.




This way, it makes sure some one in the pantry is aware and going to attend the guest in the specified room.

The bell indicator circuit used in hotels and restaurants where the bell and different colors bulbs or assigned number to the lamps are configured in a panel installed in reservation and reception. The indicator lamps and bell are controlled from different location by push buttons switches.

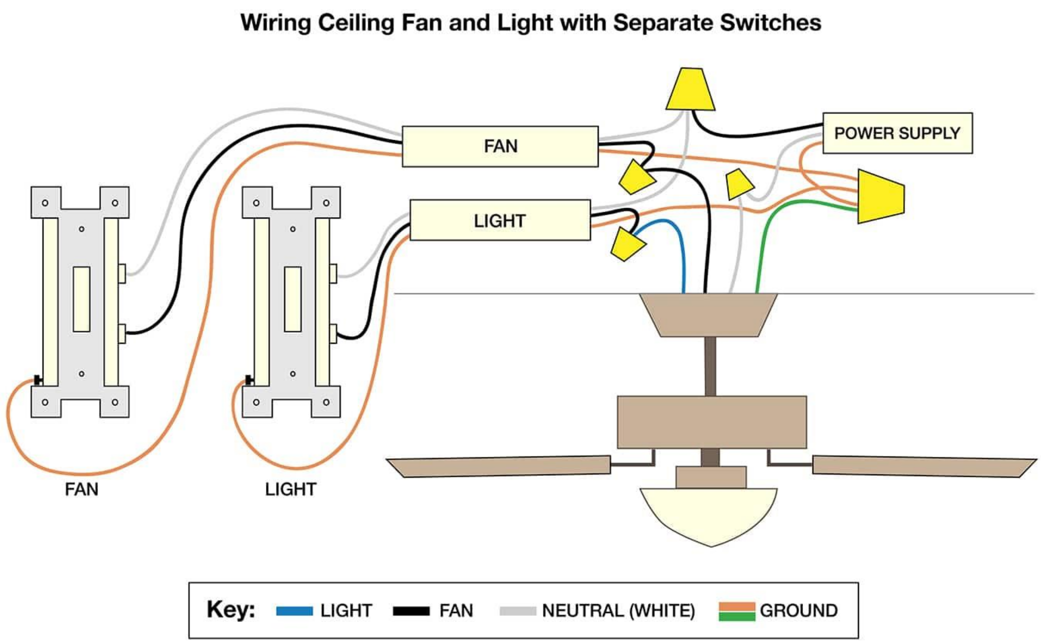
For example, when a guest presses the push button in room 1, the circuit completes which leads to glow the indicator bulb and bell rings. This way, the attendant knows the exact room (specified by assigned number or color to the lamps) and manage him accordingly.

The circuit follow the above sequence for other rooms i.e. pressing any push button will complete the circuit, bell rings and bulbs start to glow.

## Fixing of tube lights and fans

Knowing how to wire a ceiling fan means taking some precautionary steps:

- Make sure all circuit breakers related to the wiring are shut off.
- Make sure to strip the coating on the ends of the wires to expose the copper end.
- Make sure the unused wires have caps or wire connectors at the ends.
- Make sure your fan comes with wire nuts and push connectors. Both of these will be needed when wiring your ceiling fan.
- Some manufacturers may use different color coding, so be sure that you follow the instructions included with your fan.




Separate switches allow the fan and light to operate separately. It also affords the option to install a dimmer for the light. (Don't attach a dimmer to the fan's power. Its speed should only vary by use of its built-in controls.)

The power supply line (the black wire) should feed both switches and those switches power the fan (black) or the light (blue).

To do this, the wire from the wall circuit to your light has to have three wires. If you are replacing an existing fan on a two-switch setup, there may be an existing three-conductor wire, which means a red wire will be in the box. This will supply power for the light kit.

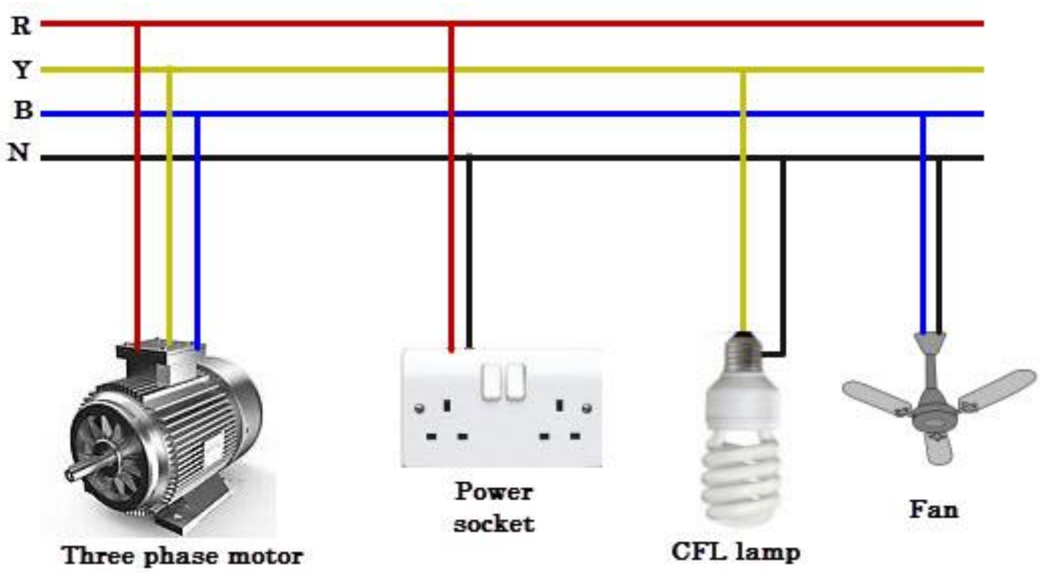
If you are installing a fan for the first time or adding a separate switch for a light kit for the first time, you will need to run a new wire from the switch box to the junction box in the ceiling, where the fan will be. You need to use a new run of three-conductor wire.

- Connect black fan wire to the black ceiling wire.
- Connect the blue wire to the red wire.
- Connect white wires together.
- Connect green/bare copper wires.

In the switch box:

- Split the incoming hot wire into a "Y" and connect it to a terminal on each switch.
- Connect the black wire to the screw located in switch No. 1.
- Connect the red wire to the screw in switch No. 2.
- Connect the white wires together.
- Connect green/bare copper wires together.
- Tuck all wires back in their boxes.
- Turn power on and test.

## Heavy equipment like AC, fridge, washing machine, oven, geyser, jet pumps




3-phase power systems provide three separate currents, each separated by one-third of the time it takes to complete a full cycle. But, as opposed to single-phase, where the two hot legs are always 180 degrees apart, with 3-phase, the currents are separated by 120 degrees.

When any one line is at its peak current, the other two are not. For example, when phase 1 is at its positive peak, phases 2 and 3 are both at -0.5. This means, unlike single-phase current, there's no point at which no power is being delivered to the load. In fact, at six different positions in each phase, one of the lines is at peak positive or negative position.

For practical purposes, this means the collective amount of power supplied by all three currents remains constant; you don't have cyclical peaks and valleys as with single-phase.

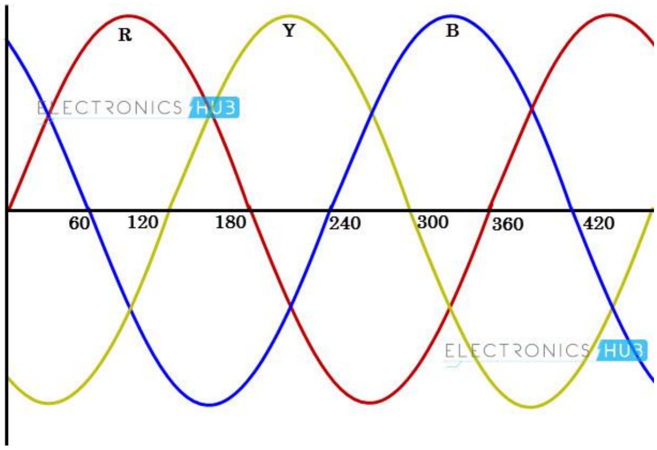
Computers and many motors used in heavy machinery are designed with this in mind. They can draw a steady stream of constant power, rather than having to account for the variation inherent in single-phase AC power. As a result, they use less energy.

Among the benefits that 3-phase power brings is the ability to deliver nearly twice the power of single-phase systems without requiring twice the number of wires. It's not three times as much power, as one might expect, because in practice, you typically take one hot line and connect it to another hot line.

To understand how 3-phase delivers more power, one must do the math. The formula for single-phase power is Power = Voltage (V) x Current (I) x Power Factor (PF). If we assume the load on the circuit is resistive only, power factor is unity (or one) which reduces the formula to P = V x I. If we consider a 120-volt circuit supporting 20 amps, the power is equal to 2,400 watts.

The formula for power of a 3-phase circuit is Power = Voltage (V) x Current (I) x Power Factor (PF) x square root of three. If we assume the load on the circuit is resistive only, power factor is unity (or one) which reduces the formula to P = V x I x square root of three. If we consider a 120-volt, 3-phase circuit and each phase supports 20 amps, the formula works out to 120 Volts x 20 Amps x 1.732 = 4,157 watts. This is how 3-phase can deliver nearly twice the power of single-phase systems. This is a simplified example, but it can be used to investigate the additional power available from circuits supporting higher voltages (e.g. 208 or 480 volts) or currents (e.g. 30 amps or greater).

3 phase power is a common form of electrical power supply for larger installations. To give an example, it is a popular method of electric power transmission throughout the national grid system.




It is typically installed in manufacturing and industrial environments because the equipment being used consumes larger amounts of current.

The following electrical equipment usually requires three phase power:

- Air conditioning
- Plant and heavy machinery
- Heating systems
- Motors and pumps
- UPS systems

In domestic properties, electricity is supplied with one live (phase) wire, which in the UK delivers power at 230 volts and requires a neutral conductor (wire) to work.

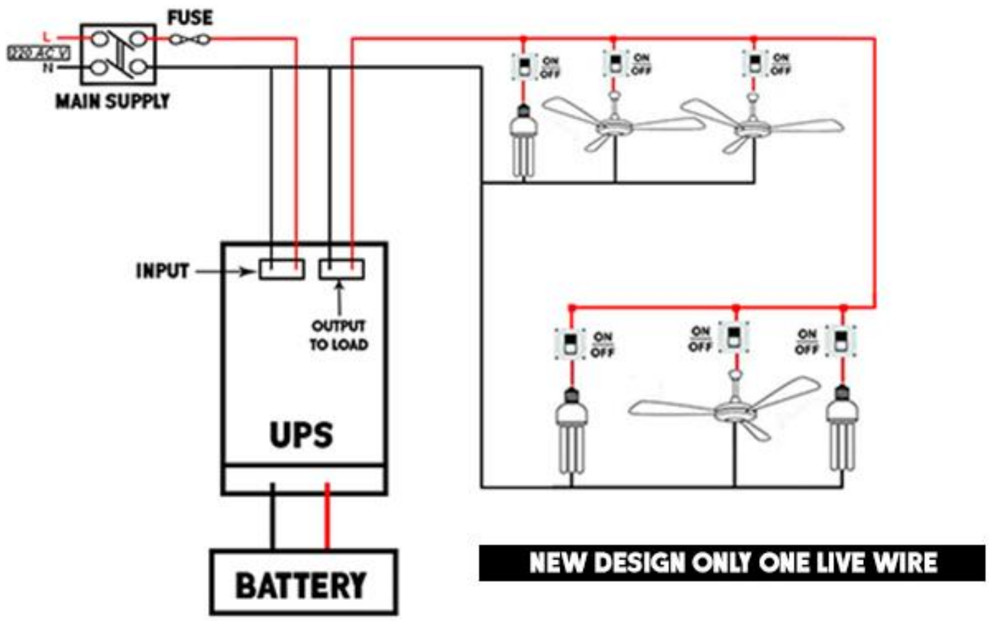
However, a 3 phase supply uses three live wires. The voltage between these live wires is 400 volts, as 3 phase consuming devices typically require more power. Even so, most 3 phase systems still utilize a neutral wire, as some electrical devices in industrial settings are still rated at 230 volts and feature a 13 amp plug socket.

Once a 3-phase system has been installed, the price per unit of electricity is the same as single phase power. However, some 3-phase equipment tends to be more efficient than single phase alternatives anyway.

When installing a 3-phase system, it is important that equal amounts of current flow through each of the conductors. This is called phase balancing.

## Provisions for inverter

An inverter is a piece of standalone equipment that converts a DC voltage to an AC voltage. The inverter performs conversion of direct current to an alternating voltage by converting the energy stored in the dc sources like battery and rectifiers. The batteries in the inverter store energy in the form of direct current and the home appliances we use need alternating current and this is how inverters work. In case of power cuts and such emergencies, the inverter can be used to operate our appliances.



Inverters play a crucial role in converting DC (Direct Current) from the battery into AC (Alternating Current), which is used to power electrical appliances. Ensuring the correct setup is crucial not only for the efficient operation of your equipment but also for the safety and longevity of your batteries and inverter.

Inverter batteries can be connected in series to double the voltage or in parallel to double the capacity. Alternatively, they can be connected in both series and parallel depending on the voltage and capacity requirements of your inverter. Before proceeding with any connections, you must confirm the voltage of your inverter.

For instance, if you have a 12-volt inverter, the battery bank must be wired for 12 volts. You can connect more than one 12-volt battery, but the output voltage must remain 12 volts. The reason for this is simple: over-voltage can damage your inverter and appliances while under-voltage can cause inefficient operation or even system failure.

Essential Steps to Connect an Inverter to a Battery

Step 1: Confirm Your Inverter's Voltage Requirement

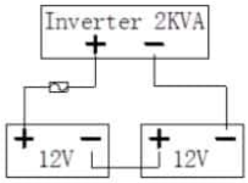
The first step is to understand the voltage requirements of your inverter. Check the manufacturer's specifications to ascertain this information. For instance, a Mercury 2.4 kVA inverter requires a 24-volt connection.

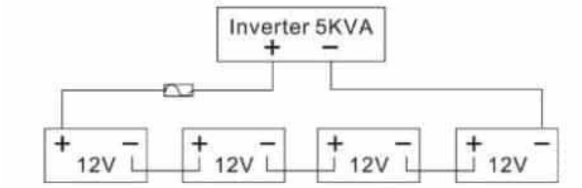
Step 2: Choose the Correct Wiring Method

If you're using more than one battery, decide whether to connect your batteries in series, in parallel, or a combination of both. Remember, connecting in series increases voltage while retaining capacity, while connecting in parallel increases capacity while retaining the same voltage.

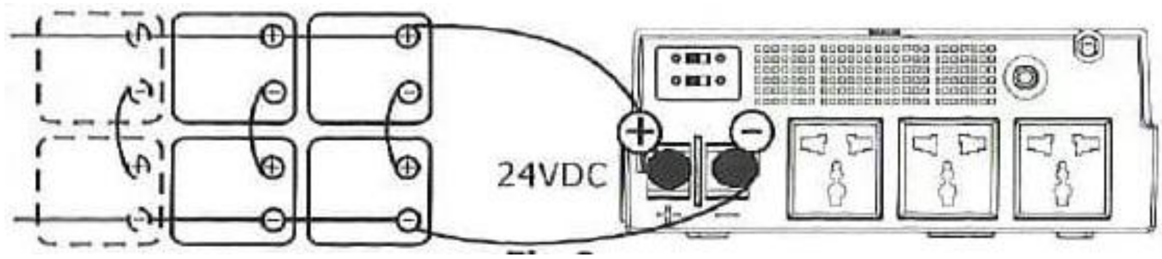
24v & 48 V Battery Connection in Series

For a 24-volt inverter and four 12-volt batteries, you'll need a series-parallel connection. This entails connecting two sets of batteries in series (which doubles the voltage) and then connecting these sets in parallel (which maintains the 24-volt level but doubles the capacity).




24v-Battery-Connection-in-Series-and-Parallel




Step 3: Use the Correct Size Wires

Using the correct size wires is critical for the performance and safety of your inverter connection. The wire size must be capable of carrying the current without overheating. An undersized wire can lead to voltage drop, inefficiency, and can even pose a fire risk

| **Inverter Size (kVA)** | **Wire Size (AWG)** | **Wire Size (mm2)** |
|---|---|---|
| 1 - 2 | 14 | 2.5 |
| 3 - 4 | 12 | 4 |
| 5 - 6 | 10 | 6 |

| Inverter Size (kVA) | Wire Size (AWG) | Wire Size (mm2) |
|---|---|---|
| 7 - 8 | 8 | 10 |
| 9 - 10 | 6 | 16 |

Step 4: Connect Your Inverter to the Battery

Once your batteries are connected correctly, you can connect your inverter to the battery bank. The inverter should be connected to the positive terminal of the first battery and the negative terminal of the last battery in your series-parallel setup.

Always ensure you connect the positive terminal first and the negative terminal last when setting up your inverter connection. This method reduces the risk of a short circuit.

Step 5: Test Your Connection

After connecting your inverter to the battery, it's vital to test the system to ensure everything is working correctly. Check the voltage at the inverter terminals using a multimeter. If it matches the manufacturer's specifications, your connection is successful.

The power consumption is not the same as the inverter's capacity, although it does seem ideal for it to be that way. The incoming power to the inverters is not as efficient, and hence the power factor measured for residential use is 0.8.

Therefore, to calculate the required capacity of the inverter and know how inverter works, you need to divide the total energy consumption (in Watts) by 0.8 to derive an inverter's capacity. This resultant capacity of the inverter is measured in VA. This capacity denotes the maximum amount of power load a respective inverter can handle when all the decided appliances are used simultaneously.

The factors mentioned above will help you find the ideal inverter for your needs, but it is also essential to select the correct battery size. The battery size is measured in Ah.

For calculating the ideal battery size, you will need to know how inverters work and decide on a particular time period for which you will need the inverter to provide backup. You can calculate the battery size by multiplying your inverter's power by the number of hours you want to use the inverter.

Once you are done multiplying, the resultant will be measured in VAh (battery voltage x no. of batteries x capacity of batteries (AH)), but as the vital inverter battery capacity is 12 V, you will have to divide the above-calculated result by 12.

You will find the ideal inverter size based on your power needs and preferences. If the exact battery capacity inverter is not available, you should always opt for a higher capacity.

Some of the other factors you need to mind when opting for an inverter, the battery types are an essential factor.

- **Lead-acid:** These are often used in batteries. The lead-acid batteries are lightweight, easily rechargeable, and they do produce the required amount of current. These batteries last for up to 3 – 4 years with regular maintenance.

- **Tubular:** Tubular battery type is the most popularly used inverter battery. These are known for their high efficiency and long operational life of up to 8 years. The various benefits and properties of Tubular batteries make them expensive, but they are still a popular choice.
- **Maintenance-free:** The maintenance-free batteries are sealed acid batteries that can last up to 4-5 years and do not require frequent check-ups or maintaining the electrolyte levels.

Inverters play a crucial role in converting DC (Direct Current) from the battery into AC (Alternating Current), which is used to power electrical appliances. Ensuring the correct setup is crucial not only for the efficient operation of your equipment but also for the safety and longevity of your batteries and inverter.

## Gauge specifications of wires for various needs

Wire sizes come in their gauges and ampacity. Remember, the higher the gauge, the lower the ampacity. It also means the conductor is thicker with a higher gauge. Here are some gauges to help you familiarize yourself:

- 4-gauge – meant for electric furnaces and heaters at 60 amps
- 60-gauge – meant for cooktops at 40-50 amps
- 10-gauge – meant for dryers, 240-volt air conditioners, water heaters at 30 amps
- 12-gauge – meant for kitchen, bathroom, and outdoor receptacles at 20 amps
- 14-gauge – meant for lighting fixtures, lamps, and circuits at 15 amps

- 16-gauge – meant for extension cords at 13 amps
- 18-gauge – meant for low-voltage lighting and lamps at 10 amps

**Electrical cable measurements**

| CROSS-SECTION in mm2 | (AWG) | CURRENT CONSUMPTION | USED |
|---|---|---|---|
| **25 mm2** | 4 | Very high | Central air conditioning and industrial equipment.. |
| **16 mm2** | 6 | High air | Conditioners, electric stoves and electric power connections. |
| **10 mm2** | 8 | Medium high | Refrigerators and dryers. |
| **6 mm2** | 10 | Medium | Microwave and blenders |
| **4 mm2** | 12 | Medium | Lighting |
| **2.5 mm2** | 14 | Under | Lamps |
| **1.5 mm2** | 16 | Very low | Thermostats, bells or security systems. |

**Color Coding**

Color coding is used on both the outer sheathing of cables and wires. Knowing the coding can help you which wiring is used in a system. For example, a white-sheathed cable is used for 15-amp circuits, while the yellow cable is for 20-amp circuits. Some colors can include blue, gray, and orange.

The coloring does not indicate the exact size and rating. But it does make it a standardization for any circuit. For example, black and red wires are typically used for carrying “hot” connections. White wires, in this case, are for “neutral” conductors.

# Unit IV

# POWER RATING AND POWER DELIVERED

## conversion of electrical energy into different forms

Energy transformations are processes that convert energy from one type (e.g., kinetic, gravitational potential, chemical energy) into another. Any type of energy use must involve some sort of energy transformation.

Conversion of energy is the transformation from one form of energy to another form. It is important to remember that energy can neither be created nor destroyed and the total amount of energy present in the system remains constant.

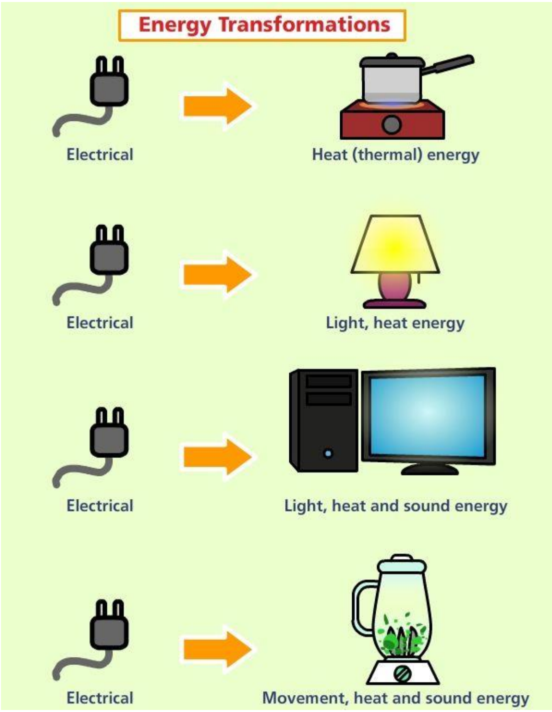
- There are various forms of energy such as thermal energy, electromagnetic energy, mechanical energy, nuclear energy, chemical energy, etc.
- These forms keep changing into one another depending upon the tasks performed in everyday life.

The first law of thermodynamics states that:

"Energy can neither be created nor destroyed, it can only be transformed from one form to another."

Thus, it means the total energy is always constant in the universe. Whenever energy is consumed in some work, it gets converted into another form. For example, when water is boiled, the energy provided in the form of heat gets converted into the kinetic energy of vapor molecules.

Electrical energy is a versatile and easily convertible form of energy. Many devices and appliances are designed to convert electrical energy into other forms of energy to perform various tasks.




Electrical energy is often converted into mechanical energy to generate motion. This is achieved using devices called electric motors. Electric motors use the principle of electromagnetic induction to create rotational or linear motion. The interaction between the magnetic field created by the electric current and the external magnetic field generates a force, which results in motion. Some common applications of electric motors include:

- Fans
- Washing machines
- Electric vehicles
- Industrial machinery

**Thermal Energy**

Electrical energy can also be converted into thermal energy or heat. This conversion occurs when electric current flows through a resistive material, generating heat due to the internal resistance of the material. The heating effect of electric current is called Joule heating. Devices that convert electrical energy into thermal energy include:

- Electric heaters
- Electric stoves
- Water heaters
- Hair dryers

**Light Energy**

Converting electrical energy into light energy is another common application. Various types of light bulbs and lamps are designed to achieve this conversion. The two main types of light bulbs are incandescent and LED (light-emitting diode) bulbs.

Incandescent bulbs work by passing an electric current through a thin filament, which becomes hot and emits light as a result. On the other hand, LED bulbs utilize semiconductor materials to emit light when an electric current flows through them. LEDs are more energy-efficient and longer-lasting than incandescent bulbs.

## Work done by electrical energy

Consider a conductor with endpoints A and B, and assume that current I is flowing through the conductor. Let us denote the potential at ends by $V_{(A)}$ and $V_{(B)}$. Since the current is flowing from A to B, it means that the potential is decreasing from point A to point B.

$V = V_{(A)} - V_{(B)}$

*and*

$V > 0$

*In time "t", the charge Q travels from point A to point B.*

The energy generated by the movement of the electrons from point A to B is called Electrical Energy or Electrical Potential Energy. In general, the energy derived from the kinetic and potential energy of the charged particle is called the electrical potential energy.

the potential energy at point A is denoted by U(A) while the potential energy at point B is denoted by U(B).

$U(A) = Q \times V(A)$ and $U(B) = Q \times V(B)$

Let the change in potential energy be denoted by $U_{net}$

$U_{net}$ = Final Potential Energy – Initial Potential Energy

$U_{net} = U(B) - U(A)$

$U_{net} = \{Q \times V(B) - Q \times V(A)\}$

$U_{net} = -\Delta Q.V$ (Now, $I = \Delta Q/\Delta t$)

$U_{net} = -I \times \Delta t \times V$

If the charges inside the conductor moved freely, this potential energy would have gotten converted into kinetic energy, so that the total energy remains unchanged.

$\Delta K = -\Delta U$

Thus, in case the charges could move freely inside the conductor under the action of the electric field, their velocity would have increased as they move. However due to the collisions between electrons and different ions inside the conductor. The charge carriers due to not move with acceleration but with a steady velocity. During the collisions, energy is transferred from these electrons to the ions which then vibrate more vigorously, and that in turn increases the temperature. Thus the derivation is given above indirectly calculates the energy dissipated in the conductor in form of heat.

***$\Delta W = I \times V \times \Delta t$***

Electrical energy is generally measured in joules or watt-second. When one ampere of current flows through the circuit for a second and the potential difference applied to the conductor is one volt then we say one joule of electrical energy is produced.

- SI unit for measurement of Electrical Energy is Joule. Its dimensional formula is $[ML^2T^{-2}]$
- Another unit for the measurement of Electrical Energy is electron-volt (eV).

It is known that power is the rate of work done. In this case, it can be thought of as the amount of energy dissipated in form of heat when an electric current is passing through the conductor. In all electrical appliances, heat dissipation occurs. This heat dissipation is called power loss or ohmic loss because these losses are due to resistances offered in conductors.

Rewriting the previous equation,

$P = \Delta W / t$

$P = I \times V$

Using ohm's law relation V = IR for substituting the values inside the above equation,

$P = I \times V = I \times I \times R = I^2R$

It can also be written as,

$P = I \times V = (V/R) \times V = V^2/R$

Thus, the power dissipated in a conductor can be written as,

$P = VI = V^2/R = I^2R$

where,

P is the Power

V is the voltage applied

R is the resistance of the material

I is the current supplied

## Power rating of electrical appliances

The energy consumed by an appliance is directly proportional to its power rating, whose unit is expressed in watts (W). For example, an appliance with a power rating of 2000 W will consume 2000 joules per second.

You can find the power rating of most devices and appliances in the manual or on the appliance itself. Find its rated power to calculate its watt-hour usage. However, keep in mind that not all appliances run 24/7. Some operate for only a few minutes a day. For example, you use garage openers for only a tiny fraction of an hour. The power consumed by a 500-

watt lawn mower may seem significant, but running it for only one hour a week translates to 71 Watt-hours per day.

Moreover, some appliances, such as refrigerators, seem to run all day. In reality, they operate for only 12 to 15 hours daily (they turn on and off as needed). The same goes for air conditioning units. Thus, they don't use the maximum amount of energy all the time.

Some devices consume energy when remain plugged in. The current drawn by these appliances or devices is typically small, often less than 1 watt. However, since they're running 24 hours a day, that amount adds up, sometimes by as much as 100 watt-hours in one day. Examples of appliances that consume energy even when not in use include microwaves, printers, and TVs.

The power rating for electrical equipment and devices specifies the required supplied voltage for their smooth operation. It also defines the maximum amount of current that can safely flow through the equipment or appliance. If the current drawn by the equipment exceeds its power rating, it could lead to a breakdown.

| **Appliance/Equipment** | **Watts (Power rating)** |
|---|---|
| **Freezer (Upright – 15 cu. ft.)** | 1240 W (whole day) |
| **Refrigerator (16 cu. ft.)** | 1200 W (whole day) |
| **Air conditioner (room)** | 1000 W (continuous operation) |
| **Air conditioner (central)** | 2000 to 5000 W (continuous operation) |
| **Fan (ceiling)** | 120 W |

| | |
|---|---|
| **Fan (table)** | 10 to 25 W |
| **Laptop computer** | 20 to 75 W |
| **Desktop PC** | 80 to 200 W |
| **Printer** | 100 W |
| **LCD monitor** | 100 W |
| **Heater** | 1000 W |
| **Coffee machine** | 1000 W |
| **Dishwasher** | 1200 to 1500 W |
| **Electric kettle** | 1200 W |
| **Microwave** | 600 to 1500 W |
| **Electric oven** | 1200 W |
| **Toaster** | 800 to 1500 W |
| **Clothes washer** | 800 W |
| **Iron** | 1000 W |
| **TV (LCD)** | 150 W |
| **TV (plasma)** | 200 W |
| **Vacuum cleaner (upright)** | 200 to 700 W |
| **CFL bulb (40 watt equivalent)** | 11 W |
| **CFL bulb (100 watt equivalent)** | 30 W |
| **LED bulb (40 watt equivalent)** | 10 W |

| | |
|---|---|
| **LED bulb (100 watt equivalent)** | 23 W |
| **Drill (½ inch)** | 750 W |
| **Hedge trimmer** | 450 W |

## Energy consumption

**Energy consumption** is the use of power or energy of a system by making use of supply. The consumption is done in Giga Joule per year, kilograms of oil equivalent per year (kg/a), and in Watts.

### Formula of Energy Consumption

The energy consumption formula is articulated as,

$$E = P \times t/1000$$

Where,

- E is energy in kilowatt-hours(kWh),
- P is power in Watts,
- t is hours

### Calculating Annual Electricity Consumption and Costs

Follow these steps for finding the annual energy consumption of a product, as well as the cost to operate it.

Estimate the number of hours per day an appliance runs. There are two ways to do this:

- Rough estimate

- Keep a log

Find the wattage of the product. There are three ways to find the wattage an appliance uses:

- Specified on the appliance
- Multiply the appliance ampere usage by the appliance voltage usage
- Use online sources to find typical wattages or the wattage of specific products you are considering purchasing.

Find the daily energy consumption using the following formula:

(Wattage × Hours Used Per Day) ÷ 1000 = Daily Kilowatt-hour (kWh) consumption

Find the annual energy consumption using the following formula:

Daily kWh consumption × number of days used per year = annual energy consumption

**Energy Consumption Solved Problems**

**Problem 1:** Compute the energy consumption in a system that consumes 190 Watts of power and works for 3 hrs a day.

**Answer**:

Given: Power P = 190 W, total number of hours = 3 hrs

$E = P \times t/1000$

E =(190*3*60*60)/1000

E =2052 kWh

Therefore, the energy consumption is 2052 kWh

**Problem 2:** A toy car consumes energy of 500 Watts of power if it works for 2 hrs a day using it. Calculate the energy consumption a day.

**Answer:**

Given: Power P = 500 W, total number of hours= 2 hrs

$E = P \times t/1000$

E = (500*2*60*60)/1000

E =3600 kWh

There are various factors that directly influence energy consumption such as:

The activity that takes place in the home or business.

The number of people in a household or workers.

The consumption habits of each person.

The energy performance of household appliances.

## Electrical energy unit in kWh

A kilowatt-hour, otherwise known as a kWh, is a way to measure how much energy you're using. It's not the number of kilowatts you're using in an hour, even though that seems to make sense.

A kWh equals the amount of energy you would use by keeping a 1,000 watt appliance running for one hour.

For instance, if you turned on a 100 watt bulb, it would take 10 hours to use one kilowatt-hour of energy. A 2,000 watt appliance, on the other hand, would only take half an hour. It all comes down to dividing the number of watts in an appliance into 1,000.

**What is a Kilowatt-Hour?**

A kilowatt-hour is a unit of measure for energy usage. It's using one kilowatt of power (1000 watts) used for one hour. It's abbreviated as kWh.

Kilowatt-Hour vs. Kilowatt

Difference between a kilowatt hour (kWh) and a kilowatt (KW)

A kilowatt (kW) is 1,000 watts and is a measure of how much power something needs to run. In metric, 1,000 = kilo, so 1,000 watts equals a kilowatt.
A kilowatt hour (kWh) is a measure of the amount of energy something uses over time.

Think of it this way: a kilowatt (kW) is the amount of power something needs just to turn it on. A kilowatt hour (kWh) is the amount of power that device will use over the course of an hour.

**How do I calculate what 1 kWh will power?**

1. Locate the wattage for the device.
2. Convert the wattage from watts (W) to kilowatts (kW). To do that, just divide the number of watts by 1000.
3. Divide the number of kilowatts into 1kWh to see how long it takes for your device to use 1 kWh.

## Calculation of EB bill

In India, electricity tariffs are regulated by the State Electricity Regulatory Commissions.

1. **Meter Reading:-** The first step in calculating your electricity bill is meter reading. A meter reader from your electricity distribution company will come to your house and take a reading of your electricity consumption. The meter measures the amount of

electricity you have used since the last meter reading. The meter reading is typically recorded in units of kilowatt-hour (kWh).

2. **Tariff Rates:-** The next step is to determine the tariff rates. Tariff rates are set by the State Electricity Regulatory Commission and are based on various factors such as the cost of generating and distributing electricity, fuel prices, and other operational expenses. The tariff rates may vary based on the category of consumers, such as residential, commercial, or industrial. The tariff rates are published on the DISCOM's website and can also be obtained by contacting their customer care.

3. **Energy Consumption Calculation:-** The energy consumption is calculated by subtracting the previous meter reading from the current meter reading. The difference is then multiplied by the tariff rate per unit of electricity consumption. For example, if your previous meter reading was 1000 kWh, and the current reading is 1200 kWh, then your energy consumption would be 200 kWh (1200 – 1000). If the tariff rate is Rs. 5 per kWh, then your energy consumption cost would be Rs. 1000 (200 x 5).

4. **Fixed Charges:-** Apart from the energy consumption charges, the DISCOMs also charge a fixed fee, also known as a service connection charge, which is charged every month regardless of the amount of electricity consumed. The fixed charges may vary based on the type of connection, such as single-phase or three-phase, and the category of consumers.

5. **Taxes and Other Charges:-** Finally, taxes and other charges such as meter rent, electricity duty, and others are added to the bill. In India, the GST (Goods and Services Tax) on electricity is levied at a rate of 5%.

Calculating electricity bills involves meter reading, determining tariff rates, calculating energy consumption, adding fixed charges, taxes, and other charges. It is important to note that energy consumption is the primary factor in determining the electricity bill, and reducing energy consumption through energy-efficient practices can significantly reduce the bill amount. Understanding the billing process and taking steps to conserve energy can help consumers save money and contribute to a sustainable future.

To calculate your electricity bill, follow these steps:
Watts = (amps) x (volts)

Kilowatt-hours = (watts) x (usage) / 1000.

Cost = (kilowatt-hours) x (electricity rate)

- Subtract the current meter reading from the previous month's reading to find the energy consumption.
- Multiply the units consumed by the per-unit charges based on the applicable slabs (e.g., Rs. 4.22 for 1-100 units, Rs. 5.02 for 101-200 units).
- Add the fixed charge and energy duty (e.g., Rs. 40 fixed charge and Rs. 0.15 per unit) to the energy charges.

- The sum of the energy charges, fixed charge, and energy duty gives you the total bill amount.
- Example: If you consumed 250 units with the applicable slabs mentioned above, the energy charges would be Rs. 1218. Adding the fixed charge and energy duty, the total bill amount would be Rs. 1296.

Some energy-saving tips to reduce the EB bill in India:

- Use energy-efficient appliances and LED lighting.
- Turn off lights, fans, and electronics when not in use.
- Opt for natural lighting during the day.
- Set air conditioners to moderate temperatures.
- Insulate doors and windows to prevent heat loss.
- Unplug chargers and unused electronics.
- Use power-saving modes on devices.
- Regularly maintain and clean appliances for optimal efficiency.
- Use sunlight for drying clothes instead of using a dryer.
- Educate and encourage family members to practice energy-saving habits.

**Problem:**

We want to heat up 0.5 liter of water with a resistive heater that carries 5 A at 120 V. How long will it take to bring the water from 27$^{o}$C to the boiling point? How much does this cost at Rs. 7/kWh? The specific heat of water is 4.19 kJ/(kgC).

Solution:

The energy required to raise the temperature of the water by $\Delta T$ is $\Delta U = mc\Delta T$, where m is the mass and c is the specific heat of the water.

The power dissipated by the heater is P = IV = energy/time. The time t required to convert an amount of electrical energy $\Delta U$ into thermal energy is $t = \Delta U/P$.

Details of the calculation:

$\Delta U = (10^{-3}\ kg/cm^3)(500\ cm^3)(4.19\ kJ/(kg^oC))(73^oC) = 153\ kJ.$

P = IV = (5 A)(120 V) = 600 W.

The time t required to convert 153 kJ into thermal energy therefore is

$t = \Delta U/P$ = (153000/600) s = 255 s = 4.3 minutes.

The electrical energy converted into heat in units of kWh is

U = (0.6 kW)(255 s)(1 hour/3600 s) = 0.043 kWh.

At Rs. 7/kWh, we spend Rs. 0.30 to heat the water.

2. Calculate the electricity bill amount for a month of 31 days, if the following devices are used as specified:

a) 3 bulbs of 30 watts for 5 hours

b) 4 tube lights of 50 watts for 8 hours

c) 1 fridge of 300 watts for 24 hours

Given the rate of electricity is Rs. 7 per unit.

**Solution**

The energy consumed by the bulbs,

As we know enegry=power×time

3 bulbs × 30 watts × 5 hours × 31 days = 13950 Wh

The energy consumed by the tubes,

4 tubes × 50 watts × 8 hours × 31 days = 49600 Wh

The energy consumed by the fridge,

1 fridge × 300 watts × 12 hours × 31 days = 111600 Wh

Therefore, the total energy consumption is given by,

13950+49600+111600 = 175,150 Wh = 175.15 KWh

We need to convert it into units, where 1 unit = 1 kWh

So, electricity bill = 175.15 units × Rs. 7 = Rs. 1226.05

## Joule's heating

The amount of heat that is produced within an electric wire due to the flow of current is expressed in the unit of Joules. When the current flows through the wire there is a collision between electrons and atoms of the wire which leads to the generation of heat. Joule's Law states that when a current flows in a conductor the amount of heat generated is proportional to current, resistance, and time in the current flowing.

Mathematical Representation of Joule's Law

When in a current conducting wire the time of the flowing of current and the resistance of the wire is constant, the amount of heat produced and the square of the amount of current flowing the wire are proportional to each other.

Equation 1 : $H \alpha i^2$ (Where R and T are Constant) When in a current conducting wire the time of the flowing of current and the current of the wire are constant, the amount of heat produced and the amount of electrical resistance of the wire are proportional to each other.

Equation 2: $H \alpha R$ (Where R and T are Constant) When in a current conducting wire the amount of the electrical resistance and the amount of current are constant, the heat produced and the time of current flowing are proportional to each other.

Equation 3: $H \alpha t$ (Where R and i are Constant)

When equations 1, 2, and 3 are merged, the resulting formula is

$H \alpha i^2.Rt$ (i, R, and t are variables)

$H=(1/J).i^2RT$ (where J is a Joule's Constant)

The joule's constant J is defined as the number of work units that furnishes one unit of heat when converted completely into heat.

Electrical Power: The rate at which the work is done in an electric circuit in order to maintain the steady current is known as the electrical power of that circuit. It can also be stated as the rate at which the electrical energy is converted into other forms of energy. The SI unit of electrical power in watts W.

$P=w/t=I^2Rt/t=I^2R=IV=V^2/R$

**Solved Example**

Calculate the heat energy produced in resistance of 5 Ω when 3 A current flows through it for 2 minutes.

The amount of heat produced by the conductor is given by the formula: $Q = I^2 R T$

Substituting the values in the above equation we get $Q = 3^2 \times 5 \times 2 \times 60 = 5400$ J

## Useful energy and energy loss

When energy is transformed from one form to another, or moved from one place to another, or from one system to another there is energy loss. This means that when energy is converted to a different form, some of the input energy is turned into a highly disordered form of energy, like heat. Functionally, turning all of the input energy into the output energy is nigh impossible, unless one is deliberately turning energy into heat (like in a heater). As well, whenever electrical energy is transported through power lines, the energy into the power lines is always more than the energy that comes out at the other end. Energy losses are what prevent processes from ever being 100% efficient.

**Types of Energy Losses**

Energy undergoes many conversions and takes on many different forms as it moves. Every conversion that it undergoes has some associated "loss" of energy. Although this energy doesn't actually disappear, some amount of the initial energy turns into forms that are not usable or we do not want to use. Some examples of these losses include:

- Heat energy, potentially as a result of air drag or friction. Heat energy is the most easily dissipated form of energy.

- Light energy is frequently energy seen in combustion, and is a type of wave motion.
- Sound energy is another type of wave motion caused by the vibration of molecules in the air. Like heat energy, sound is a type of energy that is generally lost.

Overall, the goal is to reduce the amount of energy lost to increase efficiency. As well, collisions that are inelastic refer to collisions where there is some "loss" of energy during the collision.

Electricity use is a good example that illustrates energy loss in a system. By the time the energy associated with electric power reaches the user, it has taken many forms. Initially, the process begins with the creation of the electricity through some method. For example, the burning of coal in a power plant takes the chemical energy stored in the coal and releases it through combustion, creating heat that produces steam. From here the steam moves turbines and the mechanical energy here turns a generator to produce electricity. A typical coal fired electrical plant is around 38% efficient, so ~1/3 of the initial energy content of the fuel is transformed into a usable form of energy while the rest is lost. Further losses occur during the transport of this electricity. In the transmission and distribution of electricity, about 6% of the electricity is lost in these processes. Finally, the electricity reaches its destination. This electricity could reach an incandescent light bulb wherein a thin wire is heated until it glows, with a significant amount of energy being lost as heat. The resulting light contains only about 2% of the energy content of the coal used to produce it.

Changing to CFL light bulbs can improve this by about 4x, but that only takes it up to 8% of the initial chemical energy in the coal.

There are also significant energy losses within a car's internal combustion engine. The chemical energy from the gasoline (or diesel) - which originates from the Sun as it is a fossil fuel - is then converted into heat energy, which presses on pistons in the engine. The mechanical energy is then transported to the wheels which increases the kinetic energy of the car. Some of this kinetic energy is lost to the sound of the engine, light from combustion, and to heat energy from the friction between the road and the tires. Current vehicles are only able to use around 20% of the energy content of the fuel as power, the rest is lost.

## Single and three phase connections

Single phase power circuits have a single power wire, which is known as the phase wire, and a neutral wire.

In a two-wire alternating power circuit, the current flows between the power wire and neutral wire. The power current or voltage reverses periodically, flowing one way on the hot wire to deliver power to a load, and the other way on the neutral wire.

The voltage reverses 50 to 60 times every second, with a full power cycle taking place with every 360-degree phase change.

Three phase power is vital because it is capable of delivering much more power, in a more efficient way, than single phase power ever could. And while single phase power is perfectly suitable for a huge range of different uses, when it comes to powering vast data centers and other businesses that require vast amounts of electricity, three phase power is essential.

Three phase power works using three separate currents, which are separated by one-third of the time it takes to complete a full cycle.

In single phase power, the two hot legs remain 180 degrees apart at all times. By contrast, in three phase power, currents are separated by a smaller 120 degrees.

Three phase power is a three-wire circuit. It's a widely used method of alternating current power generation, transmission and distribution.

- In a single-phase connection, the flow of electricity is through a single conductor. A three-phase connection, on the other hand, consists of three separate conductors that are needed for transmitting electricity.
- In a single-phase power supply system, the voltage may reach up to 230 Volts. But on a three-phase connection, it can carry a voltage of up to 415 Volts.
- For smooth flow of electricity on a single-phase connection, it requires two separate wires. One represents the neutral wire and another one represents a single phase. These are required to complete the circuit. In a three-phase connection, the system requires one neutral wire and three-phase wires to complete the circuit.
- Maximum power gets transmitted on a three-phase connection compared to a single phase power supply.

- A single-phase connection consists of two wires that make a simple network. But the network is complicated on a three-phase connection because there are four different wires.
- Because a single-phase connection has one phase wire, if anything happens to the network, the complete power supply gets interrupted. However, in a three-phase power supply, if anything happens to a single phase the other phases still work. As such, there is no power interruption.
- Regarding efficiency, a single-phase connection is less compared to a three-phase connection. This is because a three-phase supply needs less conductor compared to a single-phase power supply for the same circuit.

## Measures to save electrical energy – energy audit

As per the Energy Conservation Act, 2001, Energy Audit is defined as "the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption".

The type of Energy Audit to be performed depends on: - Function and type of industry - Depth to which final audit is needed, and - Potential and magnitude of cost reduction desired Thus Energy Audit can be classified into the following two types. i) Preliminary Audit ii) Detailed Audit

The information to be collected during the detailed audit includes: - 1. Energy consumption by type of energy, by department, by major items of process equipment, by end-use 2. Material balance data (raw materials, intermediate and final products, recycled materials, use of scrap or waste products, production of by-products for re-use in other industries, etc.) 3. Energy cost and tariff data 4. Process and material flow diagrams 5. Generation and distribution of site services (e.g. compressed air, steam). 6. Sources of energy supply (e.g. electricity from the grid or self-generation) 7. Potential for fuel substitution, process modifications, and the use of co-generation systems (combined heat and power generation). 8. Energy Management procedures and energy awareness training programs within the establishment.

Energy conservation is the act of reducing the usage and wastage of energy. Switching off the AC, light, etc., when nobody is in the room are a few practices that help in energy conservation.

An energy audit is a tool, which is the start of every activity to improve energy efficiency. Under the concept of an energy audit, many activities actually take place – from simple analyses of energy consumption, which are implemented within expert groups in organizations, to comprehensive energy audits, which enable the creation of a quality mid-term energy strategy. If a comprehensive review of possibilities for energy consumption optimization isn't implemented, some opportunities are lost, which is evident in higher energy costs. When conducting an energy audit, it is important to ensure suitable expertise and independence of the contractor. Based on good cooperation with expert groups within organizations, we can identify and also implement simpler measures that don't require higher investments. Within the energy audit, we create a plan, which proposes possible organizational and investment measures and also enables systematic achievement of savings. With every measure, the level and return of investment and a sensible priority of measure implementation are determined alongside energy and cost savings. Recorded energy cost savings, which fluctuate between 5 and 15 percent of total energy cost in organizations, depend on multiple factors. These factors are mostly energy complexity of organizations, existing energy use control and organizational and expert qualifications of responsible persons. A well implemented energy audit is a foundation for an efficient upgrade of an energy management system, which is a tool for continued increase of energy efficiency and cost reduction.

According to the energy auditors we can easily save between 5 and 10% of their energy consumption (and costs) by changing our behaviour such as switching electrical equipment off at the mains rather than leaving it on standby, turning off lights when they're not being used. Saving Electrical Energy will directly save money so it is very necessary to understand bigger unit or amount which we are paying without using the appliances to that level.

The major appliances in our college are air conditioners, choke bulbs, fans, computers and they account for a big chunk of the college monthly utility bill. And if the air conditioner or computer is more than a decade old, a lot more is spend on energy than you need to. Today's major appliances don't hog energy the way older models do because they must meet minimum federal energy efficiency standards. These standards have been tightened over the years, so any new appliance you buy today has to use less energy than the model you're replacing. For instance, if you buy one of today's most energy-efficient air conditioner, it will use less than half the energy of a model that is 12 years older.

**Lighting**

• Get into the habit of turning lights off when you leave a room. —-Saving Energy 0.5 %

• Use task lighting (table and desktop lamps) instead of room lighting. • Take advantage of daylight

• De-dust lighting fixtures to maintain illumination—–Saving Energy 1 %

• Compact fluorescent bulbs (CFL): 1. CFL use 75% less energy than Normal bulbs. 2. CFL are four times more energy efficient than Normal bulbs. 3. CFL can last up to ten times longer than a normal bulb.

• Use electronic chokes, in place of conventional copper chokes.—-Saving Energy 2 %

• Get into the habit of turning lights off when you leave a room. • Use only one bulb for light fittings with more than one light bulb, or replace additional bulbs with a lower wattage version.

• Use energy-saving light bulbs that can last up to ten times longer than a normal bulb and use significantly less energy. A single 20 to 25 watt energy-saving bulb provides as much light as a 100-watt ordinary bulb.

• Use tungsten halogen bulbs for spotlights—they last longer and are up to 100% more efficient.

• Fit external lights with a motion sensor.

**Air Condition Unit**

• Replace air conditioner filters every month.

• Turn off central air conditioning 30 minutes before leaving your home.

• Consider using ceiling or portable fans to circulate and cool the air.

• Try increasing your air conditioner temperature. Even 1 degree higher could mean significant savings, and you will probably not notice the difference.

• Keep central air conditioner usage to a minimum—or even turn the unit off – if you plan to go away.

• Consider installing a programmable thermostat. Just set the times and temperatures to match your schedule and you will save money and be comfortably cool when you return back.

• Replace air conditioner filters every month.

• Buy the proper size equipment to meet your family's needs – an oversized air conditioner unit will waste energy.

**Computer / Laptop**

• Buy a laptop instead of a desktop, if practical. —-Saving Energy 5 %.

• If you buy a desktop, get an LCD screen instead of an outdated CRT.

• Use sleep-mode when not in use helps cut energy costs by approx 40%.

Turn off the monitor; this device alone uses more than half the system's energy.

• Screen savers save computer screens, not energy.

• Laser printers use more electricity than inkjet printers.

**Fan**

• A ceiling fan in operation throughout night will gobble up 22 units in a month.

• There is a wrong notion that fan at more speed would consume more current.

• Fan running at slow speed would waste energy as heat in the regulator.

• The ordinary regulator would take 20 watts extra at low speed.

• The energy loss can be compensated by using electronic regulator.

Insulate the ceiling/roof: Buy efficient electric appliances:

• They use two to 10 times less electricity for the same functionality, and are mostly higher quality products that last longer than the less efficient ones. In short, efficient appliances save you lots of energy and money.

• In many countries, efficiency rating labels are mandatory on most appliances. Look Energy Star label is used.

• The label gives you information on the annual electricity consumption. In the paragraphs below, we provide some indication of the consumption of the most efficient appliances to use as a rough guide when shopping. Lists of brands and models and where to find them are country-specific and so cannot be listed here.

• Average consumption of electric appliances in different regions in the world, compared with the high efficient models on the market.

• Educate everyone in the home, including children and domestic helpers.

# UNIT V

# SAFETY MEASURES

## Insulation for wires

Electrical insulators are materials with a high resistivity (resistivity is a property of the material) so they can make objects with a high resistance. This allows insulators to prevent electric current from flowing where it's not wanted.

Insulators are useful for coating wires, or acting as dielectrics in capacitors. An insulator (such as plastic, rubber, or glass) can have 1020x the resistivity of a metal like copper. Often times these insulators are colour-coded to make it easy to tell what function the wire inside is serving, see figure 1 for an example.

Air (like in the atmosphere) is actually an excellent electrical insulator. This means that electricity can be sent through a conductor and it won't jump through the air. Air does have an upper limit to the voltage it can handle, which is called the average breakdown voltage (to learn more about average breakdown voltage, please see all about circuits. This breakdown voltage is related to lightning.

A copper wire allows the flow of electricity through them easily and to protect this copper wire from surrounding environment, generally copper wires are coated with insulator materials such as plastic or enamel which prevents the charging of wire and it helps in managing any other environmental effects such as moisture, humidity and temperature and protects the safe flow of electricity through copper wires. These insulated wires are widely used in inductors, transformers, motors, speakers, electromagnets and many other electrical devices wherever necessary. If we don't insulate our copper wires from insulating materials there is a possibility of wires getting damaged easily due to its surrounding humidity, moisture and other environmental factors which can affect copper wires easily.

## Colour specification for mains, return and earth

Types of Wiring Color Codes in India

- Single-phase wiring
- Three-Phase Wiring
- Control Wiring System

### Single-Phase Wiring

Single-phase wiring is mainly used for residential or domestic purposes.

- **Red:** Red wires are used as phase wires and they carry electrical current.
- **Black or Yellow:** These wires are used for neutral wires. These wires complete the circuit and provide a return path.
- **Green or Green with yellow stripes:** These wires are used as grounding conductors. They also reduce the risk of electric shock.

### Three-Phase Wiring

Three-phase wiring is used for industrial purposes.

- **Red, Yellow, Blue:** These wires carry alternating currents with a 120-degree phase difference between them.
- **Black:** It is used for neutral connection and it also provides a return path for unbalanced currents.
- **Green:** It is used for grounding conductors.

**Control Wiring System**

It is used for low-voltage signals to control various electrical devices.

- **Red:** It is used for power supply lines for control circuits.
- **Yellow:** It is used for interlock and safety circuits.
- **Blue:** It is used for control signal lines.
- **Black:** It is used for grounding.

**Wiring Color Codes for AC Power System**

Wiring color codes are used to identify and distinguish between the conductors having different functions.

**Phase conductor (Line or Live)**

- **Single phase:** A single-phase system is common in residential wiring in which Red or Brown color is used. This shows that the wire is connected to the single-phase supply.
- **Three-phase:** Three-phase systems are commonly used for industrial and commercial purposes in which Red, Yellow, or Blue are used for the three-phase system.

### Neutral Conductors

- Light Blue or Black color is used for neutral conductors. It shows a return path of the current to the source.

### Earth Conductor

- Green or Green with a Yellow strip is used for earth conductors. It ensures safety by providing an earth connection.

### Wiring Color Codes for DC Power System

The wiring color codes for the DC power systems are not as standardized as AC power systems. Different appliances and different industries have their different wring color for DC power systems.

However a common wiring color code for DC power systems:-

- **Positive voltage :** Red or orange is used for positive voltage or to indicate the positive terminal of the battery or conductor.
- **Negative voltage :** Black or Blue to indicate the negative terminal of the battery or conductor.
- **Earth conductor :** Green color is used to indicate the earth conductor or safety terminal.

### Properties of Wiring Color Codes

- The major property of wiring color codes is to identify and distinguish between different wires or conductors. The different colors used for color codes specify a unique function which makes the identification very easy.

- Another major property of wiring color codes is that They ensure the safety of the appliances and the person working on them.
- Wiring color code is that it makes requirements and maintenance very easy.
- Standardized color codes make it very easy for a person from one country to work or repair some appliances in another country.

**Standards of Wiring Color Codes**

Some of the common color codes accepted in every country are called Standard wiring color codes.

Some standard Wiring Color Codes for AC Power System are as follows:

**Phase Conductors (Line wire)**

- Black color is used in single-phase systems.
- The red color is used in 3-phase systems.
- The brown color is used in 230V single-phase systems.

**Neutral Conductor**

- White or Gray color is used for the neutral conductor, which carries the return current.

**Earth Conductor**

- The green color is used for the grounding conductor for safety.

**Standard Wiring Color Codes for DC Power System**

- **Positive Voltage –** Red or Orange is used to indicate the positive terminal of the battery or conductor.

- **Negative Voltage –** Black or Blue is used to indicate the negative terminal of the battery or conductor.
- **Earth Conductor –** Green or Green with a Yellow strip is used to indicate ground.

**Benefits of Standard Wiring Color Codes**

The benefits of standard wiring color codes are the same as the wiring color codes. But this has one major advantage as having the standard wiring color code is that it helps everyone from any country working with the appliances safely.

**Advantages of Wiring Color Codes**

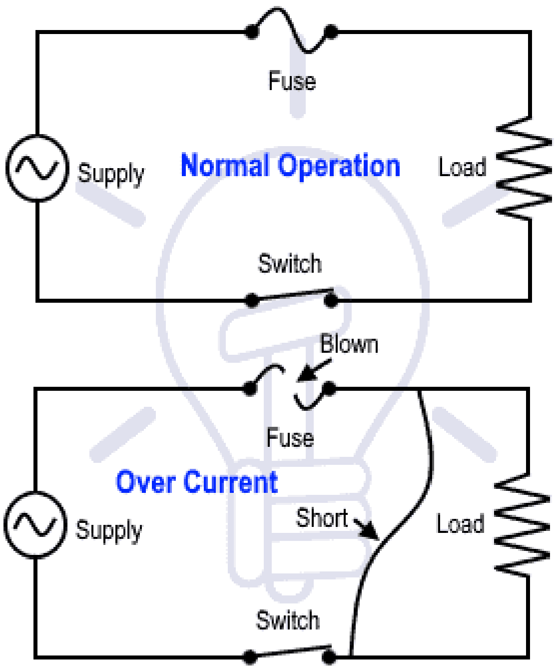
- It helps us to identify specific wires.
- It ensures safety as it provides a visual of the wire's purpose and also provides protection to those working on it.
- It ensures safe and effective electrical installations and maintenance.
- Color codes are the reason for the production of machinery in one country and shipped worldwide.

**Disadvantages of Wiring Color Codes**

Though wiring color seems very important for industry and domestic purposes it still has a few major disadvantages.

- Color codes are very difficult for color-blind people to work on.
- Overheating or dirt accumulation sometimes makes it difficult to distinguish between similar colors like brown and red.
- The use of many colors may sometimes lead to confusion.

## Understanding of fuse and circuit breakers




Working of a Fuse

While selecting the proper fuse and its rated size for electrical appliances is based on different factors and environments.

Fuse Rating = ( Power / Voltage ) x 1.25

For example, you have to find the right size of fuse for 10A two pin socket.

(1000W / 230V ) x 1.25 = 5.4A

In the above example, 1kW is the power rating which can be controlled through the 2 pin socket and the main supply voltage is single phase 230V AC (120V AC in US).

But you should go for the max i.e. 6A fuse rating instead of 5.4A for safe and reliable operation of the circuit.

The electrical circuit or the electric circuit is an interconnection of electrical components to perform a specific function. These circuits use two types of power, one is alternating current and the other is direct current. The AC current is generated by power stations and is used for large devices whereas the DC current is used for batteries, machines, and electrical appliances. When this current is flowing through the devices, the power may increase or decrease suddenly. To protect that circuit breakers or fuses are arranged in series with the components to prevent damage to the whole circuit.

In relation to the electronics, the fuse is an electrical device that provides protection to the electrical circuit from the over current. It is called a sacrificial device because the fuse is a metal strip or a metal wire so whenever there is an overflow of current in the circuit, this strip melts and interrupts the current flow. When the fuse is damaged depending on the type used it must be replaced or rewired. Some of the reasons for fuse operation are short circuits, device failure, mismatched load, or overload. It is used to remove the power automatically from a faulty device. In recent times, the fuses are sometimes replaced by a special device called circuit breakers. But significantly both share different characteristics.

Fuse - Construction: A fuse consists of a wire or metal strip that has a small construction compared to all the electrical conductors. These are arranged in series in order to carry the current flowing through the circuit. Due to the current flow the resistance of the element liberates heat. When there is too much flow of current in the circuit then either the fuse will melt directly or the soldered part in the fuse will melt which makes the circuit open. The fuse elements are made up of desired elements in order to provide stable and predictable characteristics, these elements are copper, zinc, aluminum, silver, or alloys. To increase the heating effect the fuse elements are shaped. The current is divided in between the multiple strips in case of large fuses. To avoid the strain on the fuse these are supported by steel or nichrome wires.

Fuses are used as safety for the electrical circuits. They are less costly. The reliability of the fuses is very good. As the age of the fuse increases, its speed remains the same. There is no necessary to maintain the fuse often. To have a high interrupting capacity it is not necessary to pay for the high premiums.

Circuit breakers are automatically operated switches that are specially designed to protect the circuits from damage. As its basic function is the same as that of the fuse it is not necessary to replace the circuit breaker with a new one, instead, they can reset by themselves or manually to continue performing its operation. The size may vary as they are made to protect the small household appliances from the large switch gears that pass high voltage. The circuit breaker that removes the power from the faulty device is also abbreviated as OPCD - Over Current Protective Device.

The circuit breaker first detects the fault. The detection in the low voltage circuit is done by itself. In the case of high voltage devices, a separate protective relay is been arranged, and hence for the operation of these relays, an extra power supply is required. Once the fault is detected, the circuit must open by removing the connection in between the contacts and this is done by the energy stored in the circuit breaker. The stored energy is such as the battery, or compressed air or the thermal expansion, or magnetic field. Once the contacts are removed, the small or miniature devices are discarded and in the case of high voltage circuit breakers or power circuit breakers, the contacts can be replaceable.

In the case of the power connection, the flow of electricity takes place through the circuit box. The fuse or the circuit breaker performs the same operation, they help the devices to protect the circuit from damage and they act as a switch. These can be operated manually or automatically. Once these are operated on the faulty devices, they can either be replaced or sometimes they can reset themselves to continue the operation.

| Fuse | Circuit Breaker |
|---|---|
| Its working principle is based on the electrical or thermal properties of the conducting materials. | It works on the electromagnetism or switching principle. |
| In case of overload, an indication is not provided. | An indication is provided whenever there is an overload. |
| These are used only once. | It can be used several times. |
| The detection and interruption are done by the fuse itself. | It performs only the interruption operation whereas the detection is done relay system. |
| Perform automatically. | These perform manually or automatically. |
| It has a low breaking capacity. | High breaking capacity. |
| It has a low cost. | It has a high cost. |

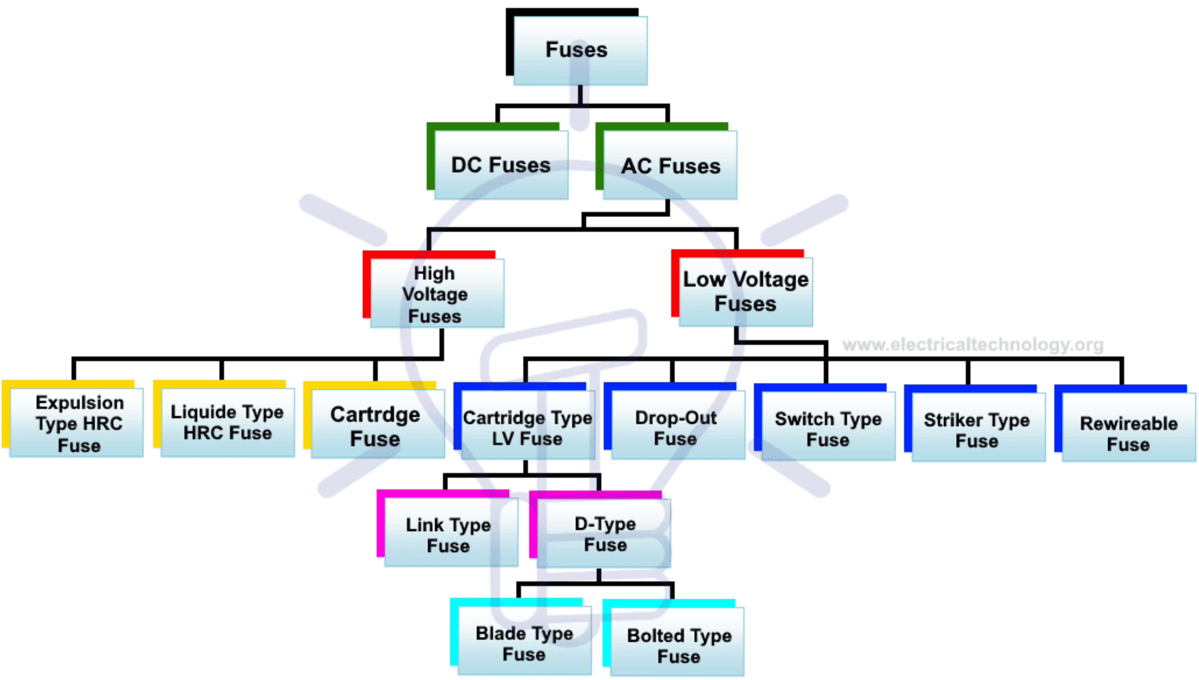
## Types of fuse: kit-kat, HRC, cartridge, MCB, ELCB

Fuses can be classified as "One Time Only Fuse", "Resettable Fuse", "Current limiting and non – current limiting fuses" based on the usage for different applications.

One time use fuses contain a metallic wire, which burns out, when an over current, over load or mismatched load connect event occurs, the user has to manually replace these fuses, switch fuses are cheap and widely used in almost all the electronics and electrical systems.

There are different types of fuses available in the market and they can be categories on the basis of Different aspects.

Fuses are used in AC as well as DC circuits.



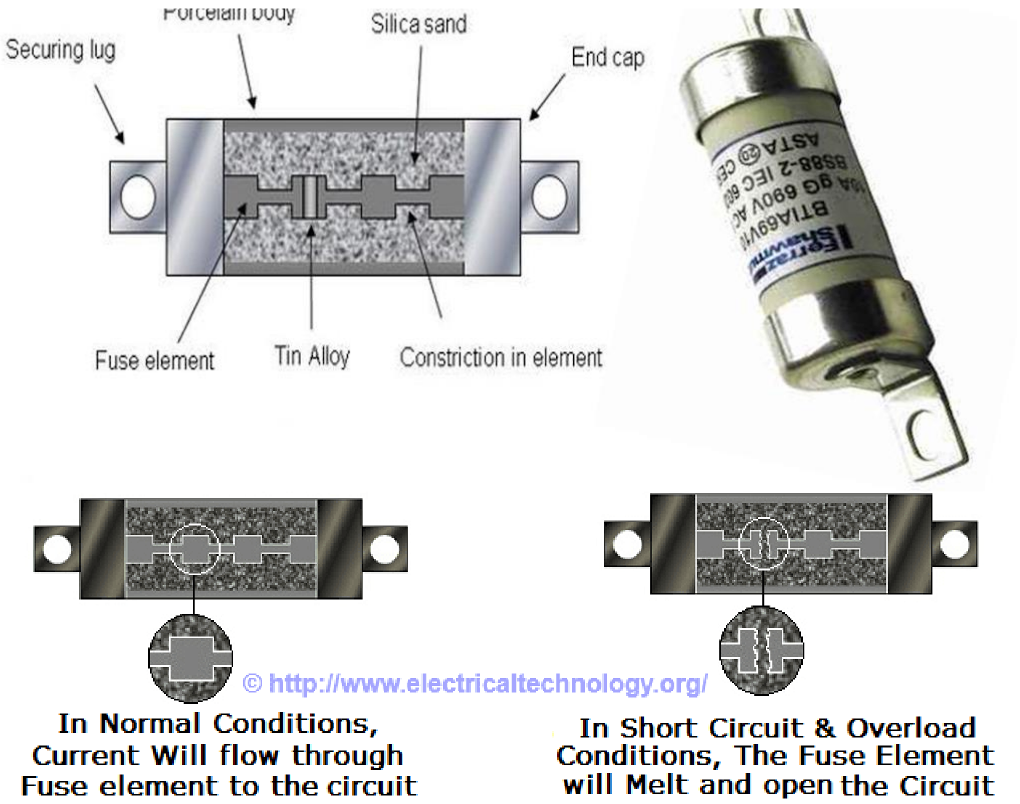

**Cartridge Fuses**

Cartridge fuses are used to protect electrical appliances such as motors, air-conditions, refrigerator, pumps etc, where high voltage rating and currents are required. They are available up to 600A and 600V AC and widely used in industries, commercial as well as home distribution panels.

There are two types of Cartridge fuses. 1. General purpose fuse with no time delay and 2. Heavy-duty cartridge fuses with time delay. Both are available in 250V AC to 600V AC and its rating can be found on the end cap or knife blade.

**HRC fuse**

A high rupturing capacity fuse contains a fuse wire that safely carries the short-circuit current for a given time period. During this period, if the fault is removed, the fuse does not blow off; otherwise, it will melt and disconnect the circuit from the electrical supply, ensuring the circuit remains safe.

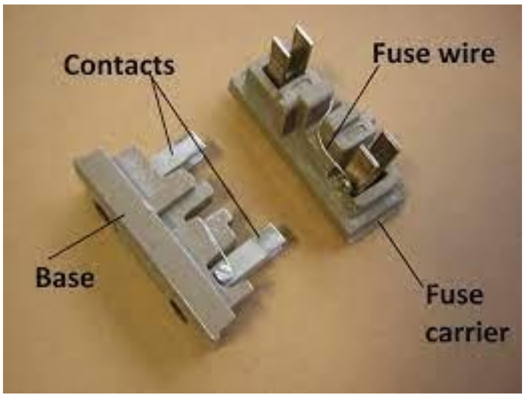



The common material used to make an HRC fuse is glass, but this is not always the case. Other chemical compounds are also employed in the manufacturing and construction of HRC fuses based on different factors. The external enclosure is made fully airtight to prevent the atmosphere's effect on the fuse materials. A major concern with HRC fuses is the low and uncertain breaking capacity of semi-enclosed fuses.

An HRC Fuse consists of a highly heat-resistant material (such as ceramic) body with metal end caps, which are welded to a silver current-carrying element. The internal space of the fuse body is completely filled with a powder. The material used to fill the inner space may include plaster of Paris, quartz, chalk, marble, dust, and cooling mediums, among others. This filling prevents overheating, allowing the fuse to carry normal current.

The heat produced vaporizes the silver element. A chemical reaction occurs between the silver vapor and the filling powder, resulting in a high-resistance substance. This substance helps quench the arc in the fuse.

**Kit-kat fuse**




Kit Kat Fuse is a rewireable, semi-enclosed fuse developed primarily for residential wiring and small-scale applications. The supplied fuse is manufactured at our in-house facility, where we use the proper method and high-grade raw materials in accordance with IS standards. Sentinel Engineers, one of India's leading Kit Kat Fuse Manufacturers, offers a wide range of alternatives. Before it reaches the clients, we make sure it meets all of the quality standards.

Kit Kat Fuse has the following advantages:

1. It is simple and quick to install, and it takes very little time to replace.
2. It is incredibly cost-effective and is the most cost-effective type of fuse.
3. Throughout its service life, the offered Electrical Kit Kat Fuse requires little to no maintenance.

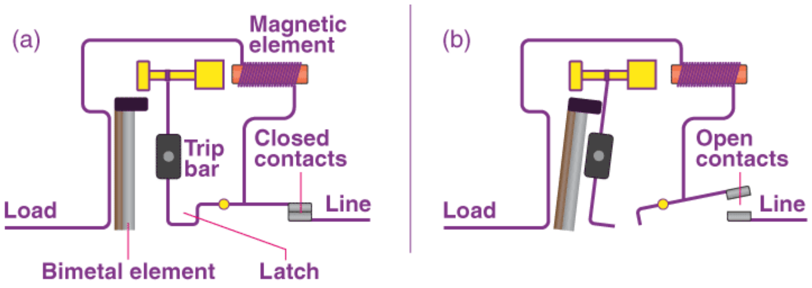
4. With typical handle and lugs options, the range is available from

16A to 500A.

MCBs are time-delay tripping circuit breakers. The operating time of these devices is controlled by the magnitude of the overcurrent passing through them, which means that the device operates whenever an overload exists for long enough to endanger the circuit being protected.

Transients such as motor starting currents or switch surges do not affect MCBs. These devices are typically designed to operate in less than 2.5 milliseconds when there is a short circuit fault and between 2 seconds and 2 minutes when there is an overload.Under normal operating conditions, the MCB acts as a switch (a manual switch) to turn the circuit on or off.

The device automatically trips in the event of a short circuit or overload. This will cause a current interruption in the load circuit, resolving the issue.



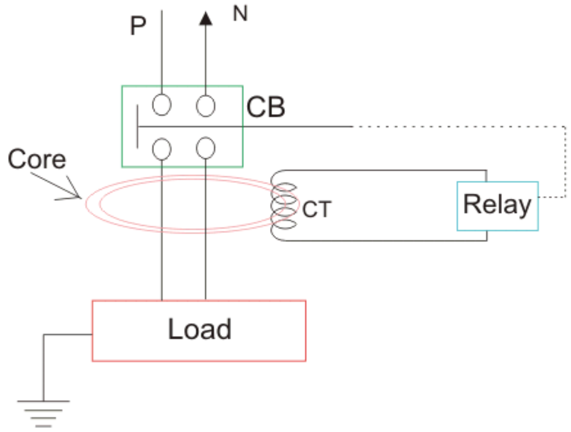

The trip is visually indicated as the operating knob automatically moves to the OFF position. The automatic operation/ tripping MCB can be obtained in two ways; magnetic tripping and thermal tripping.

When there is an excessive flow of electric current in a circuit, the M.C.B. automatically falls and switches off the circuit in a very short time. It is raised after the fault has been corrected. M.C.B.s do not need to be replaced every time a high current pass through them, but fuses must be replaced because they melt and break. Thus, in this way M.C.B is superior to the fuse wire.

**ELCB fuse**

An Earth-leakage circuit breaker (ELCB) is a safety device used in electrical installations with high earth impedance to prevent shock. It detects small stray voltages on the metal enclosures of electrical equipment and interrupts the circuit if the voltage level exceeds danger threshold.

The working principle of voltage ELCB is quite simple. One terminal of the relay coil is connected to the metal body of the equipment to be protected against earth leakage and other terminal is connected to the earth directly.




If any insulation failure occurs or live phase wire touches the metal body, of the equipment, there must be a voltage difference appears across the terminal of the coil connected to the equipment body and earth. This voltage difference produces a current to flow the relay coil.

If the voltage difference crosses, a predetermined limit, the current through the relay becomes sufficient to actuate the relay for tripping the associated circuit breaker to disconnect the power supply to the equipment.

The typicality of this device is, it can detect and protect only that equipment or installation with which it is attached. It cannot detect any leakage of insulation in other parts of the system.

## Purpose of earth line

In every circuit, one wire is connected to the earth, the main function of the earth wire is to protect the sudden damage of the electrical appliances or the electrical instruments due to the sudden voltage increase or the leakage of the current. Earth wire is also used for the safety measures. Accidently if any current is leaked, earth wire helps to ground the leakage of current.

Necessity of the earth wire in metallic electric appliances:

The metallic body of the electrical instruments will be connected to the earth or ground by means of the earth wire or ground wire, if there will be the leakage of the current the current is sent to the ground by means of earth wire. When the earth wire is connected to the metallic body, it gives the low conducting path to the current. Thus, the earth wire keeps the potential of the leaked current to the earth. So, that the user of the metallic electric component may not get the shock.

The main reason for doing this in electrical network is for the safety. When all metallic parts in electrical equipment are grounded then if the equipment fails there are no dangerous voltages present in the equipment's outer case.

Purpose of Earthing

**1. Safety for Human life/Building/Equipment**

To save human life from danger of electrical shock i.e. to provide an alternative path for the fault current to flow so that it will not endanger the user

To protect buildings, machinery & appliances under fault conditions

To ensure that all the exposed conductive parts do not reach a dangerous potential

To provide safe path to dissipate lightning and short circuit currents

To provide stable platform for operation of sensitive electronic equipment

**2. Over voltage protection**

Lightning, line surges or unintentional contact with higher voltage lines can cause dangerously high voltages to the electrical distribution system. Earthing provides an alternative path around the electrical system to minimize damages in the system.

**3. voltage stabilization**

There are many sources of electricity. Every transformer can be considered a separate source. If there were not a common reference point for all these voltage sources, it would be difficult to calculate their relationships to each other.

**Methods of earthing**

1. plate type earthing

Cast iron/ galvanized iron (GI)/copper plate is buried deep into the earth in the vertical position and GI strip is bolted with the plate which is brought up to the ground level. These types of earth pit are generally filled with alternate layer of charcoal & salt.

**2. pipe type earthing**

GI pipe with holes for connecting the earth wires are buried into the earth. pit are also filled with alternate layer of charcoal & salt.

Factors affecting the earth's resistivity

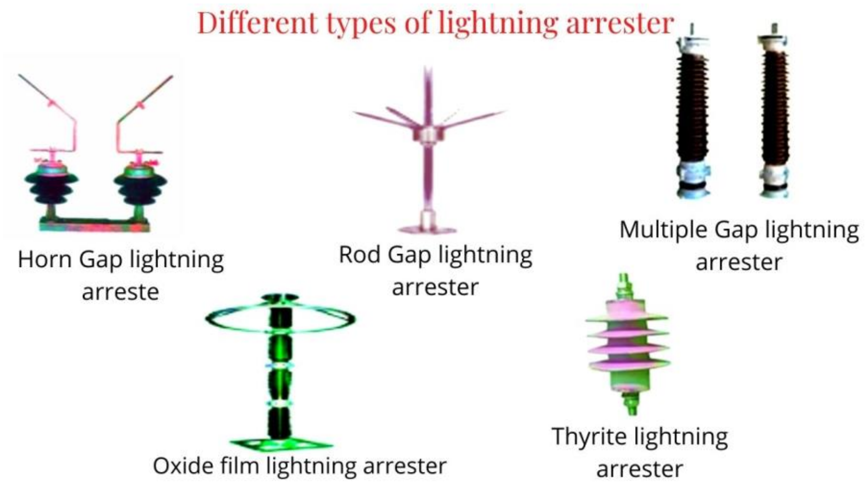
1. Soil condition – different soil conditions give different soil resistivity
2. Moisture – dry soils are poor conductors of electricity, because they have high resistivity
3. Dissolved salts – salt content can improve the conductivity of the soil; but it corrodes metal
4. Physical composition – rocky or gravel soils generally have high resistivity

## Lighting arrestors

Lightning arresters can be made from a variety of components and function similar to a switch, either preventing or allowing electrical flow through them. To do this, a lightning arrester uses semi-conductor materials that act like conductors under some conditions and insulators under other conditions. At normal line voltage the device acts like a high resistance open switch so that electricity cannot flow through it and must stay in the distribution conductors where it normally belongs.

*A lightning arrester on a distribution line*

Once a lightning strike hits the distribution system, however, the higher-than-normal voltage causes the lightning arrestor material to become a conductor and provides an easy, purpose-designed path for the lightning to flow from the distribution system conductors into the earth. Once the energy from the lightning strike leaves the system and the voltage returns to normal levels, the components inside the arrester again act like an open switch thus removing the temporary path to the earth.




Lightning arresters are devices installed to shield power lines, homes, and structures from dangerous power surges. As the name suggests, they're primarily designed to safeguard against damage caused by lightning strikes. However, they can also protect the structure from various other sources.

Lightning arresters are cylindrical objects, one- to two feet long, consisting of a series inductor and a spark gap.

Lightning arresters are typically installed near a critical entry point or appliance, including generators and electrical panels. When a bolt of lightning strikes, the arrester activates and deflects the lightning to the ground, where it disperses harmlessly.

These components don't actually stop lightning strikes, as that would be too dangerous. Instead, they limit the electrical charge and divert it, giving it a safe route to pass through the ground instead of essential electrical devices.

Main features of a fully functional lightning arrester:

The spark-over voltage must exceed the abnormal or normal power frequency occurring in the system. Additionally, it shouldn't draw any electricity in regular operating conditions.

It must break down rapidly due to any abnormal voltage above its breakdown value, providing a safe path to the ground.

When breakdowns take place, the arrester should carry the discharged electricity without sustaining damage. Also, the voltage across the element shouldn't surpass the breakdown threshold.

It must interrupt the current after the breakdown the moment the transient voltage falls below the breakdown threshold.

The lightning arrester should be placed near the equipment it protects. It's generally linked between ground and phase in an AC arrangement and ground and pole in a DC system. Furthermore, AC systems contain a separate arrester in each phase.

Surge diverters are installed in extra-voltage AC arrangements to shield the generator, bus bars, circuit breakers, lines, transformers, and other components. Likewise, HVDC structures include an arrestor to safeguard against filters, reactors, valve converter units, and similar elements.

Moreover, there are various types of lightning arresters that protect different power systems. The choice largely depends on several common factors. The list includes the line frequency, voltage, weather conditions, reliability, and cost.

To determine the perfect arrester for your household, reach out to a seasoned electrician. They can also install the component efficiently without any safety risks.

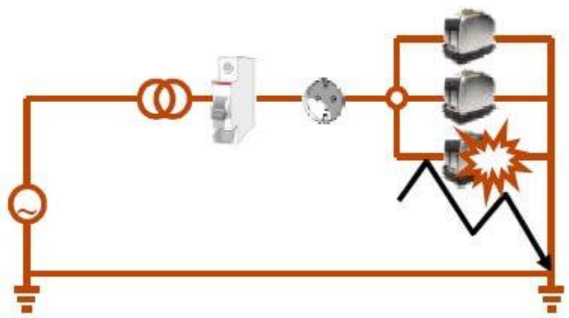
## Short circuiting and over loading

Overload refers to the situation where the current of the electric load exceeds its rated value for a long time. A short circuit refers to an accidental or intentional conductive path between two or more conductive components, forcing the potential difference between these conductive components to be equal to or close to zero.

**Other definitions of short circuit:**

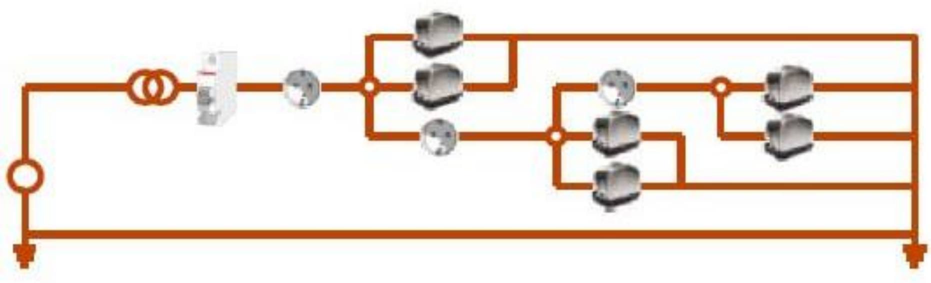
- An unwanted low-resistance connection between two points in the circuit.
- The circuit is abnormal.

- This happens when a circuit path is created between the positive and negative poles of a battery, power supply, or circuit.
- What happens when the hot wire and the neutral wire touch each other.
- An accidental connection between two points in a circuit, such as a tree branch or an animal connecting the gap between two conductors.



**Other definitions of overloading:**

Electrical overload is a kind of overcurrent, the current through the wire or circuit exceeds its capacity, which leads to overheating, and there is a risk of fire or damage to the equipment.



**Voltage level**

For any finite current flowing through a short circuit, the voltage across the short circuit is zero. On the circuit diagram, a short circuit is represented by an ideal wire with zero resistance. In the case of overload, the voltage can be very low, but not zero.

**Current level**

The maximum value of the short-circuit current is directly related to the size and capacity of the power supply, and has nothing to do with the circuit load current protected by the protection device. The greater the capacity of the power supply, the greater the short-circuit current. The overload current is directly related to the capacity of the load. This is why the short-circuit current level is much higher than the overload current. The short circuit is a multiple of the rated current. The overload is close to the rated current.

**Danger**

Short circuit is more dangerous than overload. Because the current level is higher. In high voltage applications, short circuits are extremely dangerous. The energy transfer is fast in a short circuit, and energy transfer is slow in an overload.

**Reason**

Through careful system and equipment design, as well as proper installation and maintenance, the power system should avoid short circuits and overloads as much as possible. However, even if these precautions are taken, short circuits and overloads still occur.

**The reasons for the short circuit are:**

- There are pests and rodents in the equipment.

- Loose connection.
- Voltage surge.
- Deterioration of insulation.
- Accumulation of moisture, dust, concrete sap and contaminants.
- Intrusion of metal or conductive objects, such as fish belts, tools, jackhammers or loaders.

**Some reasons for overloading are:**

1) Excessive consumer load.

2)Malfunctioning electrical appliances.

3)Poor wiring and grounding.

4)Misuse.

**Protective device**

Short circuits and overloads must be quickly eliminated from the power system. This is the job of the circuit protection device. In order to do this, the protection device must have the ability to interrupt the maximum current that can flow at the equipment location.

Fuses and circuit breakers can protect the system from overload and short circuit. Thermal overload relays can only prevent overload. Magnetic circuit breakers can only protect short circuits.

When a short circuit occurs in the power system, several things happen-they are all bad:

- In the short-circuit position, arcing and burning may occur.

- The short-circuit current flows from different power sources to the short-circuit location.
- All components that carry short-circuit current are affected by thermal and mechanical stress.
- The system voltage drop is proportional to the magnitude of the short-circuit current.

**The consequences of overloading are:**

- Residual current caused by line isolation problems increases power consumption.
- Direct contact with damaged wires may cause personal accidents.
- Continuous overload may cause a short circuit.

In industrial and commercial power systems, the calculation of short-circuit current is essential for selecting appropriate rated protection devices and equipment. Nowadays, the power system carries a larger power block and has higher requirements for safety and reliability. There are many parameters to consider when calculating short circuits. Therefore, the short-circuit calculation is not easy and must be performed carefully.

The protection device reacts very quickly to a short circuit. However, the opening time of the overload protection device will be delayed. Fast tripping is essential in short-circuit protection.

An overload will cause a thermal trip, and a short circuit will cause an electromagnetic trip of the protection device.

It should be turned off only when the heat generated by the overload exceeds a predetermined limit. Therefore, the trip time of a smaller overload is correspondingly longer than that of a larger overload. The short-circuit current should be disconnected immediately.

## Electrical safety

We rely on electricity, but sometimes underestimate its capability of causing injury. Even household current (120 volts) can stop your heart. UW personnel need to be aware of the hazards electricity poses, such as shock, fire and explosion, and either eliminate or control those hazards.

**Shock**

Electrical shock happens when current passes through the body. Electricity travels through closed circuits, and people, sometimes tragically, can become part of the circuit. When a person receives a shock, electricity flows between parts of the body or through the body to a ground.

This can happen if someone touches both wires of an energized circuit, touches one wire of the circuit while standing unprotected or touches a metal part that has become energized.

Electrocution refers to the injury or lethal dose of electrical energy. Electricity can also cause forceful muscle contraction or falls. The severity of injury depends on the amount of current flowing through the body, the current's path through the body, the length of time the body remains in the circuit and the current's frequency.

**Fire/Explosion**

Electrical fires may be caused by excessive resistance that generates heat from any of the following:

- Too much current running through wiring where overcurrent protection fails or does not exist
- Faulty electrical outlets resulting in poor contact or arcing
- Poor wiring connections and old wiring that is damaged and cannot support the load

An explosion can occur when electricity ignites a flammable gas or combustible dust mixture in the air. Ignition from a short circuit or static charge is possible.

## Tips to avoid electrical shock

- Don't work with exposed conductors carrying 50 volts or more.
- Make sure electrical equipment is properly connected, grounded and in good working order.
- Extension cords may not be used as permanent wiring and should be removed after temporary use for an activity or event.
- Surge suppressors with built-in circuit breakers may be used long-term and are available with three, six and 15 foot-long cords.
- High amperage equipment such as space heaters, portable air conditioners and other equipment must be plugged directly into permanent wall receptacles.

- Do not access, use or alter any building's electrical service, including circuit breaker panels, unless you are specifically qualified and authorized to do so.
- Wet environments can increase the risk of an electrical shock.
- Inspect portable cord-and-plug connected equipment, extension cords, power bars, and electrical fittings for damage or wear before each use. Repair or replace damaged equipment immediately.
- Always tape extension cords to walls or floors when necessary. Do not use nails and staples because they can damage extension cords and cause fire and shocks.
- Use extension cords or equipment that is rated for the level of amperage or wattage that you are using.
- Always use the correct size fuse. Replacing a fuse with one of a larger size can cause excessive currents in the wiring and possibly start a fire.
- Be aware that unusually warm or hot outlets or cords may be a sign that unsafe wiring conditions exists. Unplug any cords or extension cords from these outlets and do not use until a qualified electrician has checked the wiring.
- Always use ladders made with non-conductive side rails (e.g., fibreglass) when working with or near electricity or power lines.
- Place halogen lights away from combustible materials such as cloths or curtains. Halogen lamps can become very hot and may be a fire hazard.
- Risk of electric shock is greater in areas that are wet or damp. Install Ground Fault Circuit Interrupters (GFCIs) as they will interrupt the

electrical circuit before a current sufficient to cause death or serious injury occurs.

- Use a portable in-line Ground Fault Circuit Interrupter (GFCI) if you are not certain that the receptacle you are plugging your extension cord into is GFCI protected.
- Make sure that exposed receptacle boxes are made of non-conductive materials.
- Know where the panel and circuit breakers are located in case of an emergency.
- Label all circuit breakers and fuse boxes clearly. Each switch should be positively identified as to which outlet or appliance it is for.
- Do not use outlets or cords that have exposed wiring.
- Do not use portable cord-and-plug connected power tools if the guards are removed.
- Do not block access to panels and circuit breakers or fuse boxes.
- Do not touch a person or electrical apparatus in the event of an electrical incident. Always disconnect the power source first.

## First aid for electrical shock

If you think someone is suffering from electric shock, approach with extreme caution.

The first step is to separate the person from the source of electricity as quickly as possible. The best way of doing this is to turn off the supply, for example, by unplugging the appliance or by turning the mains off at the fuse box (consumer unit).

If this isn't possible, then try to remove the source of electricity from the person using a piece of insulating material, such as a length of wood.

**Assess the Situation:** The first and most critical step is to ensure your safety and the safety of others. If the area is still hazardous, such as in the case of exposed live wires, refrain from approaching the victim until you have shut off the power source or have received professional assistance.

**Call for Help:** Dial emergency services immediately to request professional medical assistance.

**Do Not Touch the Victim:** Avoid direct contact with the victim until you are sure the power is off or the electrical source has been isolated. Touching an electrified person without proper precautions could lead to a second victim.

**Cut the Power:** If possible, disconnect the power source or turn off the electricity supply at the main circuit breaker or fuse box. Use a non-conductive material, such as a wooden stick or a dry cloth, to turn off the power if you can't reach the breaker without getting too close to the victim.

**Check for Breathing and Pulse:** Once the power is off and it is safe to approach, check the victim for signs of breathing and a pulse. If the person is unresponsive and not breathing, begin cardiopulmonary resuscitation (CPR) immediately.

**Move with Caution**: If the victim is in immediate danger, such as near a fire or immersed in water, use a non-conductive object to gently move them away from the hazardous area before starting CPR.

**Cover Burns:** If the victim has suffered burns due to the electrical contact, cover the affected areas with a sterile, non-adhesive dressing. Avoid using creams, ointments, or ice, as they can worsen the injury.

**Keep the Victim Warm:** Electric shock victims can experience hypothermia even in warm weather. Cover them with a blanket or clothing to help maintain body temperature while waiting for medical help.

**Support Emotional Well-Being:** Electric accidents can be traumatic for both the victim and witnesses. Offer reassurance and emotional support to those involved.

## Fire safety for electric current

About 60% fires are of electric origin on account of electric short circuit, overheating, overloading, use or non-standard appliances, illegal tapping of electrical wires, improper electrical wiring, carelessness and ignorance etc. It can lead to serious fire and fatal accidents, if proper instructions are not followed. Such incidents can be minimized to a great extent if adequate fire precautions are observed. Electrical fires spread rapidly especially in buildings and cause loss of lives and property. It is, therefore, necessary to act fast. Raise an alarm for help. Switch off power supply to de-energise the equipment. Use dry sand, $CO_2$, dry powder or Halon extinguishers.

1. Use I.S.I. certified appliances.
2. Use good quality fuses of correct rating, miniature circuit breakers and earth leakage circuit breakers.
3. Use one socket for one appliance.

4. Switch off the electric supply of the fire affected areas.
5. Fuses and switches should be mounted on metallic cubicles for greater safety against fire.
6. Replace broken plugs and switches.
7. Keep the electrical wires away from hot and wet surface.
8. Switch off appliance after use and remove the plug from the socket.
9. Switch off he 'Main' switch when leaving home for a long duration.
10. Do not overload outlets.
11. Plug heat generating appliances directly into an outlet, not into a power strip or extension cord.
12. Don't put electrical cords underneath rugs or pinched behind furniture
13. Charge laptops and phones only on hard surfaces, not on beds or sofas.
14. Have a licensed electrician review your home's electrical system every ten years. Small upgrades and safety checks can prevent larger problems.
15. Consider installing tamper resistant (TR) outlets in homes with small children.
16. When charging devices that use lithium-ion batteries, always use the manufacturer's battery, cord, and power adapter made specifically for the device. Disconnect charging equipment when the device is charged. Overcharging and aftermarket/generic accessories have been linked to serious Li-ion battery fires.