GBN GOVERNMENT POLYTECHNIC NILOKHERI

E-Content

Of

Fundamentals of Electrical Engineering

Ist Semester ECE

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Syllabus

UNIT I

Electrical Fundamentals

1.1 Nature of Electricity, Charge, free electrons, Electric current, Electric potential and Potential difference, Electric current, Electrical Energy, Electrical power and their unit.

1.2 Resistance: Definition, Unit, Laws of resistance, conductivity and resistivity, Effect of Temperature on resistance, Temperature coefficient of resistance, Types of resistance & Their applications, Color coding of resistance.

1.3 Inductors and capacitors with their wattage consideration.

1.4 Factors affecting capacitance of a capacitor. Capacitors in series and parallel

UNIT II

DC Circuits & Theorems

2.1 Ohm's law and its verification.

2.2 Kirchhoff's current law and Kirchhoff's voltage law.

2.3 Star – Delta connections.

2.4 Voltage and current source, symbol and graphical representation, characteristics of Ideal and practical sources.

2.5 Mesh and Loop analysis

2.6 Thevenin's theorem, Norton's theorem, Superposition Theorem, Maximum Power Transfer Theorem.

UNIT III

AC Circuits

3.1 AC Fundamentals: Cycle, frequency, time period, amplitude, difference between AC and DC, instantaneous value, average value, r.m.s. value, maximum value, form Factor and peak factor.

3.2 Concept of conductance, susceptance, admittance, impedance and concept of inductive and capacitive reactance

3.3 RL-RC Circuits

3.4 Introduction to series and parallel resonance and its conditions

3.5 Power in pure resistance, inductance and capacitance, power in combined RLC circuits.

3.6 Power factor, active and reactive power: Definition and their significance.

UNIT IV

Electro Magnetic Circuit

4.1 Concept of electro-magnetic field produced by flow of electric current, magnetic

Circuit, concept of magneto-motive force (MMF), flux, reluctance, permeability,

Analogy between electric and magnetic circuit.

4.2 Faraday's laws of electro-magnetic induction, principles of self and mutual induction,

Self and mutually induced emf.

4.3 Energy stored in an inductor, series and parallel combination of inductors.

UNIT V

Batteries

5.1 Basic idea of primary and secondary cells.

5.2 Construction, working principle and applications of Lead-Acid, Nickel-Cadmium, LiIon batteries.

5.3 Series and parallel connections of batteries.

5.4 Introduction to maintenance of free batteries.

5.5 Disposal of batteries

5.6 General idea of solar cells, solar panels and their applications

UNIT I

Electrical Fundamentals

1.1 Nature of Electricity

Electricity is the most common form of energy. Electricity is used for various applications such as lighting, transportation, cooking, communication, production of various goods in factories. The basic nature of electricity is, whenever a negatively charged body is connected to a positively charged body by means of a conductor, the excess electrons of negative body starts flowing towards the positive body to compensate the lack of electrons in that positive body.

There are some materials which have plenty of free electrons at normal room temperature. Very well-known examples of this type of materials are, silver, copper, aluminum, zinc etc. The movement of these free electrons can easily be directed to a particular direction if the electrical potential difference is applied across the piece of these materials. Because of plenty of free electrons these materials have good electrical conductivity. These materials are referred as good conductor. The materials which cannot conduct electricity in other words electrical conductivity of these materials is very poor. Such material are known as non-conductor or electrical insulator. The nature of electricity is to flow through a conductor while an electrical potential difference applied across it, but not to flow through insulator even high electrical potential difference applied across them.

Electric Charge

Electric charge is the basic physical property of matter that causes it to experience a force when kept in an electric or magnetic field.

Types of charges are:

1. Protons are positively charged.
2. Electrons are negatively charged.
3. Neutrons have no charge.

Unit of electric charge is Coulomb

“One coulomb is the quantity of charge transferred in one second.”

Electric potential

The amount of work done needed to move a unit positive charge from infinity to that point is called electric potential

$$V = \frac{W}{q}$$

V= Electric Potential

W= Work done

q= Charge
Unit of electric potential is Volts

Potential difference

Potential difference **is** the difference in potential between two points.

Unit of Potential difference is Volts

Electric Current

Electric current is defined as the rate of flow of electrons in a conductor. The SI Unit of electric current is the Ampere.

Electric current is measured by Ammeter

Electrical Energy

The energy which is caused by the movement of the electrons from one place to another such type of energy is called electrical energy.

The basic unit of the electrical energy is the joule (or watt-second).

The commercial unit of electrical energy is kilowatt hour (kWh). It is also called a unit of electricity.

1 kWh=3.6×10^6 Joule

Electrical power

The rate at which work is done in an electric circuit is called electric power.

P= VI

Unit of power is Watts

1 Watt= 1 Volt×1 Ampere

Power is measured with the help of Wattmeter

1.2 Resistance

Resistance is a measure of the opposition to current flow in an electrical circuit. Resistance is measured in ohms, symbolized by the Greek letter omega (Ω).

Laws of Resistance

The resistance of a material varies depending upon the properties of the material and environmental conditions. Laws of resistance gives the four factors where the material depends.

1. The resistance of the material increases with the increase in the length of the material and decreases with the decrease in the length of the material. .i.e.

$$R \propto L$$

2. The resistance of material increases with the decrease in the cross-sectional area of the conductor and decreases with an increase in the cross-sectional area.

$$R \propto 1/A$$

From the first, second and third law, the resistance of a material can be given as $R \propto L/A$

$$R = \rho\, L/A$$

where ρ is known as the resistivity constant or the coefficient of resistance. It is also known as the specific resistance of the material.

The electrical resistance of a conductor is dependent on the following factors:

1. The cross-sectional area of the conductor
2. Length of the conductor
3. The material of the conductor
4. The temperature of the conducting material.

What Is Resistivity?

Electric resistivity is defined as the electrical resistance offered per unit length and unit cross-sectional area at a specific temperature and is denoted by ρ. Electrical resistance is also known as specific electrical resistance. The SI unit of electrical resistivity is Ω m.

$$\rho = \frac{\mathrm{RA}}{\boldsymbol{L}}$$

Effect of temperature on the resistance of the material

We will see the effect of the temperature on the resistance of the following types of materials.

1. Conductor
2. Insulator
3. Semiconductor

Conductor: The effect of temperature on the resistance of the conductor is an increase in the resistance value with an increase in temperature. The resistance of the conductor is proportional to the temperature. The increase in temperature of the conductor increases its resistance.

Insulator: The resistance of the insulator decreases with an increase in temperature.

Semiconductor: In a semiconductor the resistance decrease with an increase in temperature. The resistance of the semiconductor material decreases non-linearly with an increase in temperature. Thus, the semiconductor devices exhibit non-linear or non-ohmic characteristics.

The temperature coefficient of resistance

The temperature coefficient of resistance measures changes in the electrical resistance of any substance per degree of temperature change.

Let us take a conductor having a resistance of R0 at 0 °C. and Rt at t °C, respectively.

From the equation of resistance variation with temperature, we get

$$\frac{R_t}{R_o} = \frac{t_o + t}{t_o + 0}$$

$$\Rightarrow R_t = R_o + \frac{R_o \cdot t}{t_o}$$

$$\Rightarrow R_t - R_o = \Delta R = \frac{1}{t_o} R_o \cdot t = \alpha_o R_o t$$

$$Where,\ \alpha_o = \frac{1}{t_o}$$

This αo is called the temperature coefficient of resistance of that substance at 0 °C.

From the above equation, it is clear that the change in electrical resistance of any substance due to temperature mainly depends upon three factors:

1. The value of resistance at the initial temperature,
2. The rise of temperature and
3. The temperature coefficient of resistance αo.

Types of resistors

There are two basic types of resistors.

1. Linear Resistors
2. Non Linear Resistors

Linear Resistors:

Those resistors, which values change with the applied voltage and temperature, are called linear resistors. In other words, a resistor, which current value is directly proportional to the applied voltage is known as linear resistors. Generally, there are two types of resistors which have linear properties.

1. Fixed Resistors
2. Variable Resistors

Fixed Resistors

Fixed resistor is a resistor which has a specific value and we can't change the value of fixed resistors.

Types of Fixed resistors.

1. Carbon Composition Resistors
2. Wire Wound Resistors
3. Thin Film Resistors
4. Thick Film Resistors

Carbon Composition Resistors

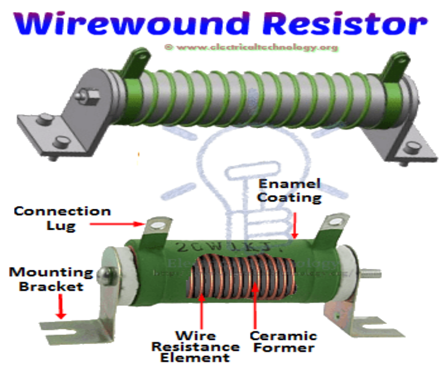
A typical fixed resistor is made from the mixture of granulated or powdered carbon or graphite, insulation filler, or a resin binder. The ratio of the insulation material determines the actual resistance of the resistor. The insulating powder (binder) made in the shape of rods and there are two metal caps on the both ends of the rod.

There are two conductor wires on the both ends of the resistor for easy connectivity in the circuit via soldering. A plastic coat covers the rods with different color codes (printed) which denote the resistance value. They are available in 1 ohm to 25 mega ohms and in power rating from ¼ watt to up to 5 Watts.

Wire wound Resistors

Wire wound resistor is made from the insulating core or rod by wrapping around a resistive wire. The resistance wire is generally Tungsten, manganin, Nichrome or nickel or nickel chromium alloy and the insulating core is made of porcelain, Bakelite, press bond paper or ceramic clay material.

The manganin wire wound resistors are very costly and used with the sensitive test equipment e.g. Wheatstone bridge, etc. They are available in the range of 2 watts up to 100 watt power rating or more. The ohmic value of these types of resistors is 1 ohm up to 200k ohms or more and can be operated safely up to 350°C.

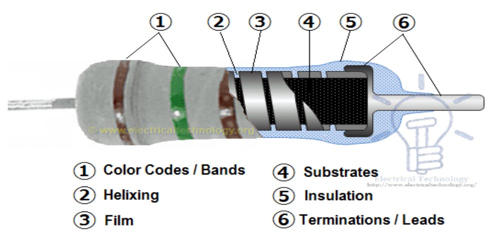


Thin Film Resistors

Basically, all thin film resistors are made of from high grid ceramic rod and a resistive material. A very thin conducting material layer overlaid on insulating rod, plate or tube which is made from high quality ceramic material or glass. There are two further types of thin film resistors.

1. Carbon Film Resistors
2. Metal Film Resistors
3. Carbon Film Resistors

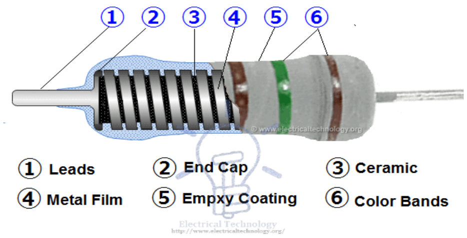
Carbon Film resistors contains on an insulating material rod or core made of high grade ceramic material which is called the substrate. A very thin resistive carbon layer or film overlaid around the rod. These kinds of resistors are widely used in electronic circuits because of negligible noise and wide operating range and the stability as compared to solid carbon resistors



Carbon Film Resistors

Metal Film Resistors

Metal film resistors are same in construction like Carbon film resistors, but the main difference is that there is metal (or a mixture of the metal oxides, Nickel Chromium or mixture of metals and glass which is called metal glaze which is used as resistive film) instead of carbon. Metal film resistors are very tiny, cheap and reliable in operation. Their temperature coefficient is very low (±2 ppm/°C) and used where stability and low noise level is important.



Metal Film Resistors

Thick Film Resistors

The production method of Thick film resistors is same like thin film resistors, but the difference is that there is a thick film instead of a thin film or layer of resistive material around. That's why it is called Thick film resistors. There are two additional types of thick film resistors.

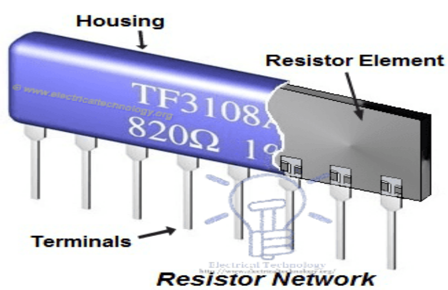
1. Metal Oxide Resistors
2. Cermet Film Resistors
3. Fusible Resistors

Metal Oxide Resistors

By oxidizing a thick film of Tin Chloride on a heated glass rod (substrate) is the simple method to make a Metal oxide Resistor. These resistors are available in a wide range of resistance with high temperature stability. In addition, the level of operating noise is very low and can be used at high voltages.

Cermet Oxide Resistors (Network Resistors)

In the cermet oxide resistors, the internal area contains on ceramic insulation materials. And then a carbon or metal alloy film or layer wrapped around the resistor and then fix it in a ceramic metal (which is known as Cermet). They are made in the square or rectangular shape and leads and pins are under the resistors for easy installation in printed circuit boards. They provide a stable operation in high temperature because their values do not change with change in temperature.



Cermet Film Resistor

Fusible Resistors

These kinds of resistors are same like a wire wound resistor. When a circuit power rating increased than the specified value, then this resistor is fused, i.e. it breaks or open the circuit. That's why it is called Fusible resistors. Fusible restores perform double jobs means they limit the current as well as it can be used as a fuse.

They used widely in TV Sets, Amplifiers, and other expensive electronic circuits. Generally, the ohmic value of fusible resistors is less than 10 Ohms.

Variable Resistors

Variable Resistors consist of a slider which taps onto the main resistor element and a fixed resistor element. Simply we can say that a variable resistor is a potentiometer with only 2 connecting wires instead of 3.

1. Types of Variable Resistors
2. Potentiometer
3. Rheostat
4. Trimmer Resistor

Non-Linear Resistor

Non-linear resistors are those types of resistors where the electric current flowing through it changes with the exchange in applied voltage or temperature and does not change according to Ohm’s law. There are several types of non-linear resistors, but the most commonly used are mentioned below.

Thermistors

Thermistors are a type of variable resistor that notices the change in temperature. In other words, it is a 2 terminal device that is very sensitive to temperature. The resistance of a thermistor is inversely proportional to the temperature.

Photo Resistor or LDR (Light Dependent Resistors)

Photo Resistor or LDR (Light Dependent Resistors) or Photo Conductive Cell is a light-controlled variable resistor. The photo resistor resistance decreases with increase in incident light intensity.

1.3 Inductor

An inductor is a passive component that is used in most power electronic circuits to store energy in the form of magnetic energy when electricity is applied to it.

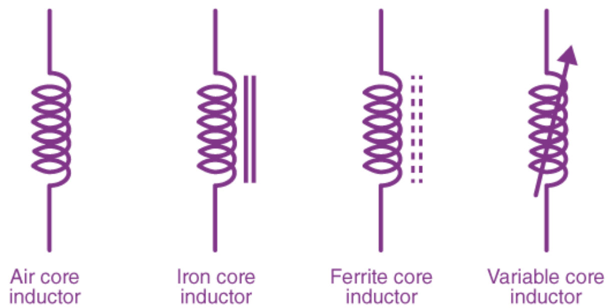
Inductance is the characteristic of an electrical conductor that opposes change in current. The symbol for inductance is L and the basic unit of inductance is the henry (H).

Different Types of Inductors

Depending on the type of material used inductors can be classified as follows:

1. Iron Core Inductor

2. Air Core Inductor
3. Iron Powder Inductor
4. Ferrite Core Inductor which is divided into,
   a. Soft Ferrite
   b. Hard Ferrite



Capacitor

A capacitor is a two-terminal electrical device that can store energy in the form of an electric charge.

The capacitance C of a capacitor is defined as the ratio of the maximum charge Q that can be stored in a capacitor to the applied voltage V across its plates.

$$C = \frac{Q}{V}$$

The SI unit of capacitance is the farad

The parallel-plate capacitor has two identical conducting plates, each having a surface area A, separated by a distance d. When a voltage V is applied to the capacitor, it stores a charge Q

the capacitance of a parallel-plate capacitor is given as

$$C = A\frac{\varepsilon_0}{d}$$

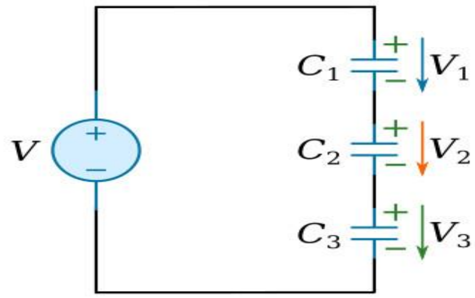
where the constant ε_0 is the permittivity of free space

1.4 Capacitors in Series and Parallel

Capacitors may be connected in series or in parallel to obtain a resultant value which may be either the sum of the individual values (in parallel) or a value less than that of the smallest capacitance (in series).

Capacitors in Series

A circuit consisting of a number of capacitors in series is similar in some respects to one containing several resistors in series. In a series capacitive circuit the same displacement current flows through each part of the circuit and the applied voltage will divide across the individual capacitors. The figure below shows a circuit containing a source and three series capacitors.



Capacitors in series.

The sum of the capacitor voltages must equal the source voltage (Kirchhoff's voltage law)

$$V = V_1 + V_2 + V_3$$

The charges on all capacitors must be the same, since the capacitors are connected in series and any charge movement in one part of the circuit must take place in all parts of the series circuit. Solving the equation $C=Q/V$ for voltage in terms of capacitance and charge ($V=Q/C$), the following results are obtained for each of the series capacitors and the total capacitance (C_t)

$$V = \frac{Q}{C_t} \quad V_1 = \frac{Q}{C_1} \quad V_2 = \frac{Q}{C_2} \quad V_3 = \frac{Q}{C_3}$$

Substituting these results into the above Kirchhoff's voltage law equation

$$\frac{Q}{C_t} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

Dividing both sides of the above equation by the common factor Q

$$\frac{1}{C_t} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Taking the reciprocal of both sides and assuming any number of capacitors

$$C_t = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots + \frac{1}{C_n}}$$

This equation is the general equation used to compute the total capacitance of capacitors connected in series. Notice the similarity between this equation and the one used to find equivalent resistance of parallel resistors. If the circuit contains only two capacitors the product over the sum formula can be used

$$C_t = \frac{C_1 C_2}{C_1 + C_2}$$

It should be evident from the above formulas that the total capacitance of capacitors in series is less than the capacitance of any of the individual capacitors.

Example:

Determine the total capacitance of a series circuit containing three capacitors whose values are 10 nF, 0.25 μF, and 50 nF, respectively.

Solution:

$$C_t = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

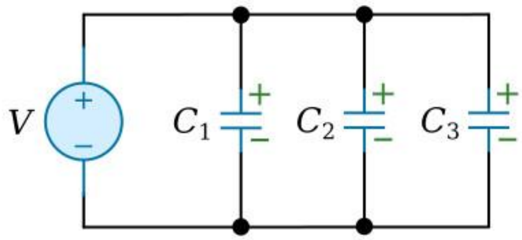
$$C_t = \frac{1}{\frac{1}{10 \times 10^{-9}} + \frac{1}{0.25 \times 10^{-6}} + \frac{1}{50 \times 10^{-9}}}$$

$$C_t = 8\,\text{nF}$$

The total capacitance of 8 nF is slightly smaller than the smallest capacitor (10 nF).

Capacitors in Parallel

When capacitors are connected in parallel (see the figure below), one plate of each capacitor is connected directly to one terminal of the source, while the other plate of each capacitor is connected to the other terminal of the source. In the figure below, all the negative plates of the capacitors are connected together, and all the positive plates are connected together. The total (equivalent) capacitance C_t, therefore, appears as a capacitance with a plate area equal to the sum of all the individual plate areas. As previously mentioned, capacitance is a direct function of plate area. Connecting capacitors in parallel effectively increases plate area and thereby increases total capacitance.



Capacitors in parallel.

The total capacitance can be calculated mathematically. By applying the equation *C*=*Q*/*V* to each capacitor and to the total capacitance

$$C_t = \frac{Q_t}{V} \quad C_1 = \frac{Q_1}{V} \quad C_2 = \frac{Q_2}{V} \quad C_3 = \frac{Q_3}{V}$$

The total charge Q_t is the sum of the charges on each capacitor

$$Q_t = Q_1 + Q_2 + Q_3$$

From the equation *C*=*Q*/*V*, it follows that *Q*=*CV*, and if the charge is written in this form and substituted into the above equation, this equation results

$$C_t V = C_1 V + C_2 V + C_3 V$$

Dividing both sides of the above equation by the common factor *V* and assuming any number of capacitors

$$C_t = C_1 + C_2 + C_3 + \ldots + C_n$$

This equation states mathematically that the total capacitance of a number of capacitors in parallel is the sum of the individual capacitances.

Example:

Determine the total capacitance in a parallel capacitive circuit containing three capacitors whose values are 30 nF, 2 µF, and 0.25 µF, respectively.

Solution:

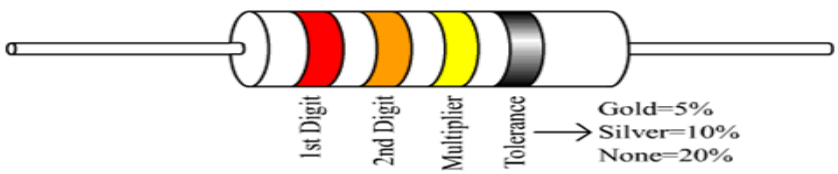
$$C_t = C_1 + C_2 + C_3$$

$$C_t = 0.03\ \mu F + 2\ \mu F + 0.25\ \mu F$$

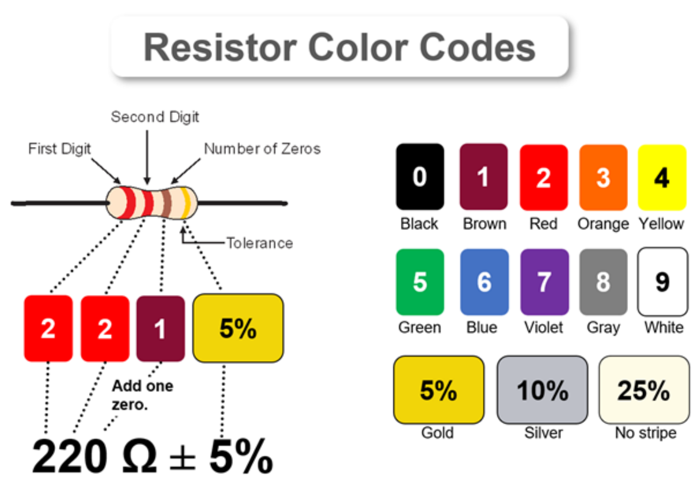
$$C_t = 2.28\ \mu F$$

Color coding of Resistance

Resistor Color Coding uses colored bands to quickly identify a resistors resistive value and its percentage of tolerance with the physical size of the resistor indicating its wattage rating.



Color	Digit	Multiplier	Tolerance (%)
Black	0	10^0 (1)	
Brown	1	10^1	1
Red	2	10^2	2
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	0.5
Blue	6	10^6	0.25
Violet	7	10^7	0.1
Grey	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
Silver		10^{-2}	10
(none)			20



UNIT II

DC Circuits & Theorems

2.1 Ohm's Law

Ohm's law states the relationship between electric current and potential difference.

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.

$$V = IR$$

In the equation, the constant of proportionality, R, is called Resistance and has units of ohms, with the symbol Ω.

The same formula can be rewritten in order to calculate the current and resistance respectively as follows:

$$I = \frac{V}{R}$$

$$R = \frac{V}{I}$$

An example of this is the filament of a light bulb, in which the temperature rises as the current is increased. In this case, Ohm's law cannot be applied. The lightbulb filament violates Ohm's Law.

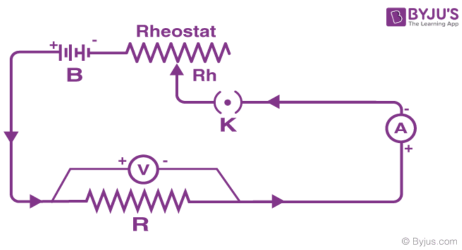
Experimental Verification of Ohm's Law

Ohm's Law can be easily verified by the following experiment:

Apparatus Required:

3. Resistor
4. Ammeter
5. Voltmeter
6. Battery
7. Plug Key
8. Rheostat

Circuit Diagram:



Procedure:

- Initially, the key K is closed and the rheostat is adjusted to get the minimum reading in ammeter A and voltmeter V.
- The current in the circuit is increased gradually by moving the sliding terminal of the rheostat. During the process, the current flowing in the circuit and the corresponding value of potential difference across the resistance wire R are recorded.
- This way different sets of values of voltage and current are obtained.
- For each set of values of V and I, the ratio of V/I is calculated.
- When you calculate the ratio V/I for each case, you will come to notice that it is almost the same. So V/I = R, which is a constant.
- Plot a graph of the current against the potential difference, it will be a straight line. This shows that the current is proportional to the potential difference.

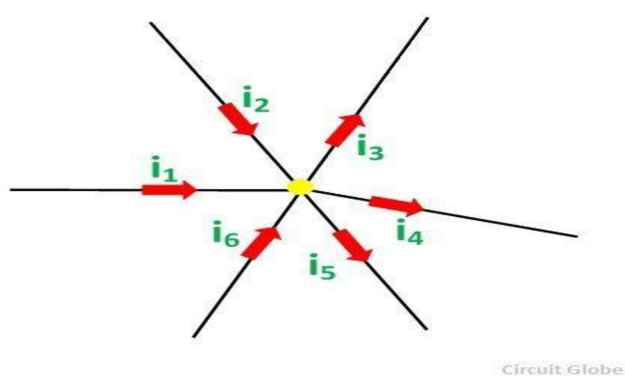
2.2 KIRCHHOFF'S LAWS

The most common and useful set of laws for solving electric circuits are the Kirchhoff's voltage and current laws. Several other useful relationships can be derived based on these laws. These laws are formally known as Kirchhoff's current law (KCL) and Kirchhoff's voltage law (KVL).

Kirchhoff's Current Law (KCL)/ Point Law/ First Law

This is also called as Kirchhoff's first law or Kirchhoff's nodal law.

Statement: Algebraic sum of the currents meeting at any junction or node is zero.



From the given diagram

$I_1 + I_2 + I_6 – I_3 – I_4 – I_5 = 0$

$I_1 + I_2 + I_6 = I_3 + I_4 + I_5$

Incoming currents = Outgoing currents

KIRCHHOFF'S VOLTAGE LAW (KVL)

This is also called as Kirchhoff's second law or Kirchhoff's loop or mesh law. Kirchhoff's second law is based on the principle of conservation of energy.

Statement: Algebraic sum of all the voltages around a closed path or closed loop at any instant is Zero.

Kirchhoff's voltage law can be written as an equation, as shown below:

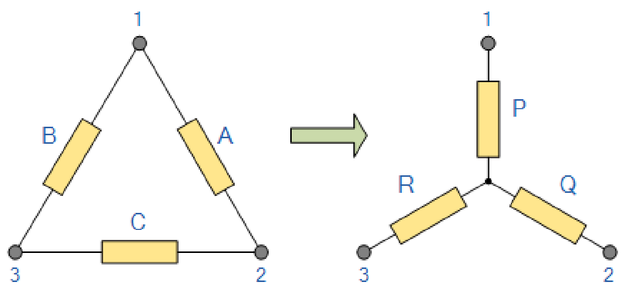
$$V_1 + V_2 + \ldots + V_n = 0$$

where V_1, V_2, etc., are the voltages around any closed circuit loop.

2.3 Delta Star Transformation

To convert a delta network to an equivalent star network we need to derive a transformation formula for equating the various resistors to each other between the various terminals. Consider the circuit below.

Delta to Star Network



Compare the resistances between terminals 1 and 2.

$$P + Q = A \text{ in parallel with } (B + C)$$

$$P + Q = \frac{A(B + C)}{A + B + C} \quad \ldots EQ1$$

Resistance between the terminals 2 and 3.

$$Q + R = C \text{ in parallel with } (A + B)$$

$$Q + R = \frac{C(A + B)}{A + B + C} \quad \text{...EQ2}$$

Resistance between the terminals 1 and 3.

$$P + R = B \text{ in parallel with } (A + C)$$

$$P + R = \frac{B(A + C)}{A + B + C} \quad \text{...EQ3}$$

This now gives us three equations and taking equation 3 from equation 2 gives:

$$EQ3 - EQ2 = (P + R) - (Q + R)$$

$$P + R = \frac{B(A + C)}{A + B + C} - Q + R = \frac{C(A + B)}{A + B + C}$$

$$\therefore P - Q = \frac{BA + CB}{A + B + C} - \frac{CA + CB}{A + B + C}$$

$$\therefore P - Q = \frac{BA - CA}{A + B + C}$$

Then, re-writing Equation 1 will give us:

$$P + Q = \frac{AB + AC}{A + B + C}$$

Adding together equation 1 and the result above of equation 3 minus equation 2 gives:

$$(P - Q) + (P + Q)$$

$$= \frac{BA - CA}{A + B + C} + \frac{AB + AC}{A + B + C}$$

$$= 2P = \frac{2AB}{A + B + C}$$

From which gives us the final equation for resistor P as:

$$P = \frac{AB}{A + B + C}$$

Then to summarize a little about the above maths, we can now say that resistor P in a Star network can be found as Equation 1 plus (Equation 3 minus Equation 2) or Eq1 + (Eq3 – Eq2).

Similarly, to find resistor Q in a star network, is equation 2 plus the result of equation 1 minus equation 3 or Eq2 + (Eq1 – Eq3) and this gives us the transformation of Q as:

$$Q = \frac{AC}{A+B+C}$$

and again, to find resistor R in a Star network, is equation 3 plus the result of equation 2 minus equation 1 or Eq3 + (Eq2 – Eq1) and this gives us the transformation of R as:

$$R = \frac{BC}{A+B+C}$$

When converting a delta network into a star network the denominators of all of the transformation formulas are the same: A + B + C, and which is the sum of ALL the delta resistances. Then to convert any delta connected network to an equivalent star network we can summarized the above transformation equations as:

Delta to Star Transformations Equations

$$P = \frac{AB}{A+B+C} \quad Q = \frac{AC}{A+B+C} \quad R = \frac{BC}{A+B+C}$$

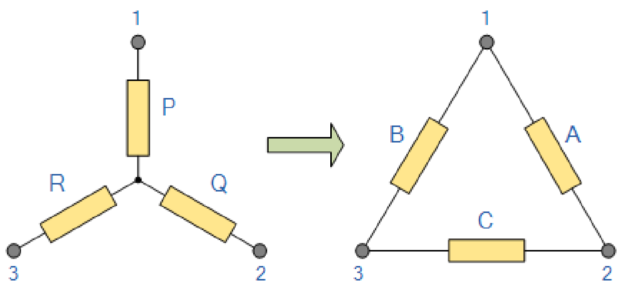
If the three resistors in the delta network are all equal in value then the resultant resistors in the equivalent star network will be equal to one third the value of the delta resistors. This gives each resistive branch in the star network a value of: $R_{STAR} = 1/3*R_{DELTA}$ which is the same as saying: $(R_{DELTA})/3$

Star Delta Transformation

The transformation from a Star network to a Delta network is simply the reverse of above. We have seen that when converting from a delta network to an equivalent star network that the resistor connected to one terminal is the product of the two delta resistances connected to the same terminal, for example resistor P is the product of resistors A and B connected to terminal 1.

By rewriting the previous formulas a little we can also find the transformation formulas for converting a resistive star connected network to an equivalent delta network giving us a way of producing the required transformation as shown below.

Star to Delta Transformation



The value of the resistor on any one side of the delta, Δ network is the sum of all the two-product combinations of resistors in the star network divide by the star resistor located "directly opposite" the delta resistor being found. For example, resistor A is given as:

$$A = \frac{PQ + QR + RP}{R}$$

with respect to terminal 3 and resistor B is given as:

$$B = \frac{PQ + QR + RP}{Q}$$

with respect to terminal 2 with resistor C given as:

$$C = \frac{PQ + QR + RP}{P}$$

with respect to terminal 1.

By dividing out each equation by the value of the denominator we end up with three separate transformation formulas that can be used to convert any delta resistive network into an equivalent star network as given below.

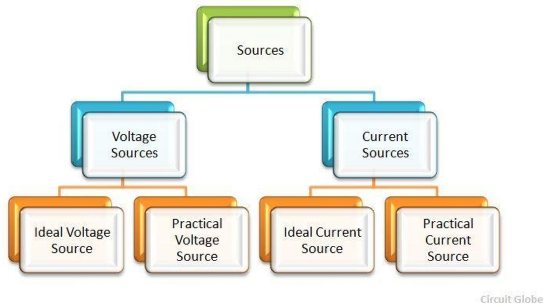
Star Delta Transformation Equations

$$A = \frac{PQ}{R} + Q + P \quad B = \frac{RP}{Q} + P + R \quad C = \frac{QR}{P} + Q + R$$

One final point about converting a star connected resistive network into an equivalent delta connected network. If all the resistors in the star network are all equal in value then the resultant resistors in the equivalent delta network will be three times the value of the star resistors and equal, giving: $R_{DELTA} = 3*R_{STAR}$

Both Star Delta Transformation and Delta Star Transformation allows us to convert one type of circuit connection into another type in order for us to easily analyse the circuit. These transformation techniques can be used to good effect for either star or delta circuits containing resistances or impedances.

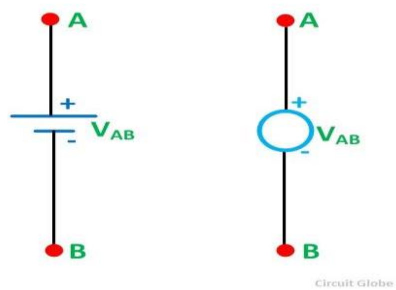
2.4 Voltage and current sources



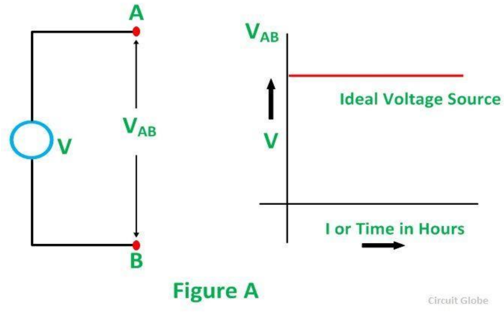
Ideal voltage source: A voltage source is a two-terminal device whose voltage at any instant of time is constant and is independent of the current drawn from it. Such a voltage source is called an Ideal Voltage Source and have **zero internal resistance**.

Sources having some amount of internal resistances are known as **Practical Voltage Source**. Due to this internal resistance; voltage drop takes place, and it causes the terminal voltage to reduce.

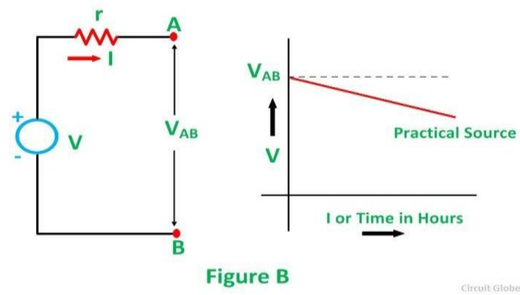
The example of voltage sources is batteries and alternators.



Symbol of voltage source



Ideal voltage source characterstics

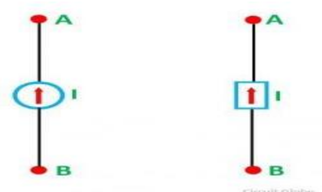


Practical voltage source characterstics

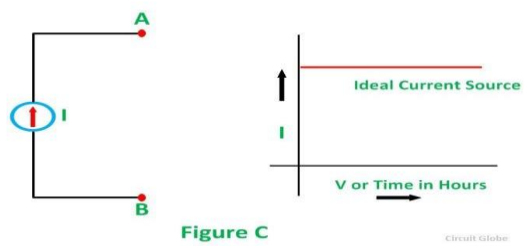
Current Source

An ideal current source is a two-terminal circuit element which supplies the same current to any load resistance connected across its terminals. It is important to keep in mind that the current supplied by the current source is independent of the voltage of source terminals. It has **infinite** resistance.

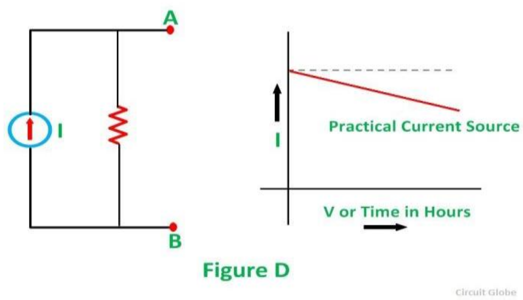
A practical current source is represented as an ideal current source connected with the resistance in parallel. The symbolic representation is shown below:



Symbol of current source



Ideal current source characterstics



Practical current source characterstics

2.6 Thevenin's theorem

Thevenin's theorem is a process by which a complex circuit is reduced to an equivalent circuit consisting of a single voltage source (VTH) in series with a single resistance (RTH) and a load resistance (RL)

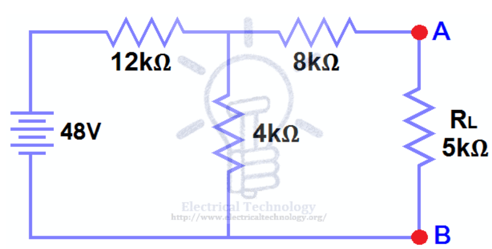
VTH = Thevenin's Voltage

RTH = Thevenin's Resistance

Steps to Analyze an Electric Circuit using Thevenin's Theorem

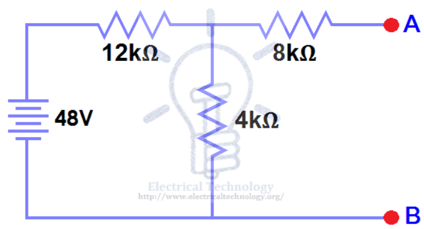
1. Open the load resistor.
2. Calculate / measure the open circuit voltage. This is the Thevenin Voltage (V_{TH}).
3. Open current sources and short voltage sources.
4. Calculate /measure the Open Circuit Resistance. This is the Thevenin Resistance (R_{TH}).
5. Now, redraw the circuit with measured open circuit Voltage (V_{TH}) in Step (2) as voltage source and measured open circuit resistance (R_{TH}) in step (4) as a series resistance and connect the load resistor which we had removed in Step (1). This is the equivalent Thevenin circuit of that linear electric network or complex circuit which had to be simplified and analyzed by Thevenin's Theorem. You have done it.
6. Now find the Total current flowing through the load resistor by using the Ohm's Law: $I_T = V_{TH} / (R_{TH} + R_L)$.

Example:
Find V_{TH}, R_{TH} and the load current I_L flowing through and load voltage across the load resistor by using Thevenin's Theorem.

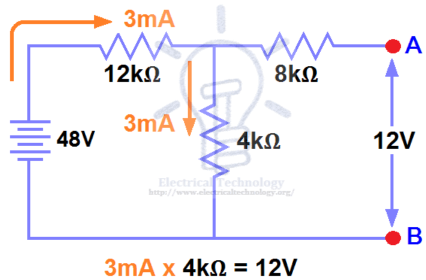


Thevenin's Theorem. Easy Step by Step Procedure with Example (Pictorial Views)

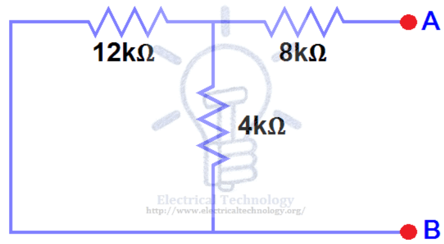
- Open the 5kΩ load resistor



- Calculate / measure the open circuit voltage. This is the Thevenin Voltage (V_{TH}). Now we have to calculate the Thevenin's Voltage. Since 3mA current flows in both 12kΩ and 4kΩ resistors as this is a series circuit and current will not flow in the 8kΩ resistor as it is open.



- Open current sources and short voltage sources



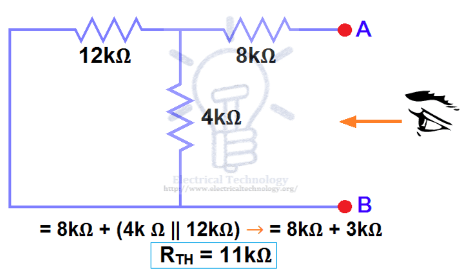
- Calculate / measure the open circuit resistance. This is the Thevenin Resistance (R_{TH})
- We have removed the 48V DC source to zero as equivalent i.e. 48V DC source has been replaced with a short in step 3. We can see that 8kΩ resistor is in series with a parallel connection of 4kΩ resistor and 12k Ω resistor. i.e.:

  8kΩ + (4k Ω || 12kΩ) ….. (|| = in parallel with)

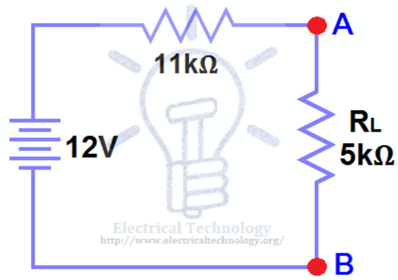
  R_{TH} = 8kΩ + [(4kΩ x 12kΩ) / (4kΩ + 12kΩ)]

  R_{TH} = 8kΩ + 3kΩ

  R_{TH} = 11kΩ



- Connect the R_{TH} in series with Voltage Source V_{TH} and re-connect the load resistor. i.e. Thevenin circuit with load resistor. This the Thevenin's equivalent circuit.



Now apply the last step i.e Ohm's law . Calculate the total load current and load voltage

$I_L = V_{TH} / (R_{TH} + R_L)$

$I_L = 12V / (11k\Omega + 5k\Omega) \rightarrow = 12/16k\Omega$

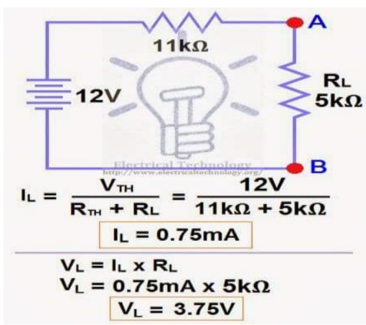
$I_L = 0.75mA$

And

$V_L = I_L \times R_L$

$V_L = 0.75mA \times 5k\Omega$

$V_L = 3.75V$



Norton's theorem

Norton's Theorem states that "Any linear circuit containing several energy sources and resistances can be replaced by a single Constant Current generator in parallel with a Single Resistor"

Steps to Analyze an Electric Circuit using Norton's Theorem

1. Short the load resistor.
2. Calculate / measure the Short Circuit Current. This is the Norton Current (I_N).
3. Open Current Sources, Short Voltage Sources and Open Load Resistor.
4. Calculate /measure the Open Circuit Resistance. This is the Norton Resistance (R_N).
5. Now, Redraw the circuit with measured short circuit Current (I_N) in Step (2) as Current Source and measured open circuit resistance (R_N) in step (4) as a parallel resistance and connect the load resistor which we had removed in Step (3). This is the Equivalent Norton Circuit of that

Linear Electric Network or Complex circuit which had to be simplified and analyzed. You have done it.

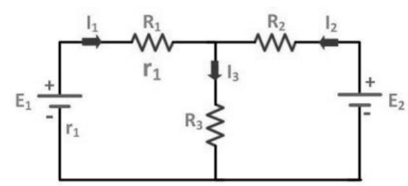
6. Now find the Load current flowing through and Load Voltage across Load Resistor by using the Current divider rule. $I_L = I_N / (R_N / (R_N + R_L))$

Superposition Theorem

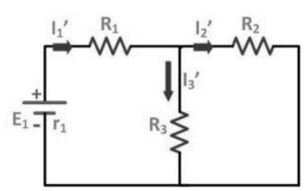
Superposition theorem states that in any linear, active, bilateral network having more than one source, the response across any element is the sum of the responses obtained from each source considered separately and all other sources are replaced by their internal resistance. The superposition theorem is used to solve the network where two or more sources are present and connected.

Steps for Solving network by Superposition Theorem

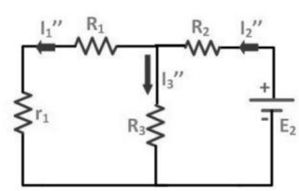
Considering the circuit diagram A, let us see the various steps to solve the superposition theorem:



Circuit Diagram A



Circuit Diagram B



Circuit Diagram C

Step 1 – Take only one independent source of voltage or current and deactivate the other sources.

Step 2 – In the circuit diagram B shown above, consider the source E_1 and replace the other source E_2 by its internal resistance. If its internal resistance is not given, then it is taken as zero and the source is short-circuited.

Step 3 – If there is a voltage source than short circuit it and if there is a current source then just open circuit it.

Step 4 – Thus, by activating one source and deactivating the other source find the current in each branch of the network. Taking the above example find the current I_1', I_2'and I_3'.

Step 5 – Now consider the other source E_2 and replace the source E_1 by its internal resistance r_1 as shown in the circuit diagram C.

Step 6 – Determine the current in various sections, I_1'', I_2'' and I_3''.

Step 7 – Now to determine the net branch current utilizing the superposition theorem, add the currents obtained from each individual source for each branch.

Step 8 – If the current obtained by each branch is in the same direction then add them and if it is in the opposite direction, subtract them to obtain the net current in each branch.

The actual flow of current in the circuit C will be given by the equations shown below:

$$I_1 = I_1' - I_1''$$

$$I_2 = I_2' - I_2''$$

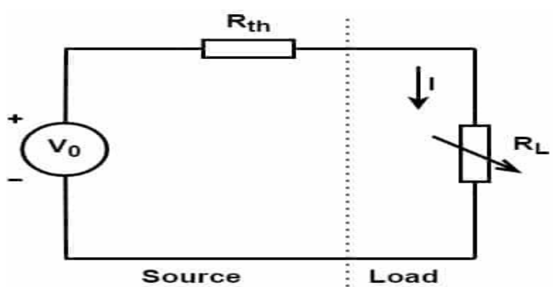
$$I_3 = I_3' - I_3''$$

Maximum Power Transfer Theorem

Maximum power transfer theorem states that the DC voltage source will deliver maximum power to the variable load resistor only when the load resistance is equal to the source resistance.

Maximum Power Transfer Theorem Proof

Consider the circuit in which a DC source network is connected to the load resistance as shown in figure A below. We have to find the Thevenin voltage and Thevenin source of the source and the circuit is transformed to another circuit



The DC source supply current to the load. The power dissipation in the load resistor R_L is $P = I^2R$. The current I flowing through the circuit is:

$$I = \frac{V_0}{R_L + R_{Th}} \quad ----(1)$$

The power dissipation in the resistor RL is:

$$P = I^2 R_L \quad ------(2)$$

Putting the value of I from equation (1) in equation (2),we get:

$$P = \left(\frac{V_0}{R_L + R_{Th}}\right)^2 R_L \;------ (3)$$

The maximum power delivery is possible if;

$$\frac{dP}{dR_L} = 0$$

Equation(3) can be solved as follows.

$$\frac{dP}{dR_L} = 0$$
$$= \frac{d}{dR_L}\left(\frac{V_0}{R_L + R_{Th}}\right)^2 R_L = 0$$
$$= \frac{d}{dR_L}\frac{V_0^2 R_L}{(R_L + R_{Th})^2} = 0$$
$$= \frac{(R_L + R_{Th})^2 \frac{d}{dR_L}(V_0^2 R_L) - V_0^2 R_L \frac{d}{dR_L}((R_L + R_{Th})^2)}{(R_L + R_{Th})^4} = 0$$
$$= \frac{(R_L + R_{Th})^2 V_0^2 - V_0^2 R_L \; X \; 2(R_L + R_{Th})}{(R_L + R_{Th})^4} = 0$$
$$= \frac{V_0^2 (R_L + R_{Th})(R_L + R_{Th} - 2R_L)}{(R_L + R_{Th})^4} = 0$$
$$= \frac{V_0^2 (R_L + R_{Th})(R_{Th} - R_L)}{(R_L + R_{Th})^4} = 0$$
$$R_{Th} - R_L = 0$$
$$R_{Th} = R_L$$

Thus, the condition for Maximum Power Transfer is the source delivers maximum power to load, if the source resistance is equal to the load resistance. Now, we will calculate the system efficiency under maximum power transfer condition.

Efficiency of Maximum Power Transfer

To calculate the efficiency, we first calculate the maximum power transfer when the load resistance is equal to the source resistance.

Maximum Power Delivered to the Load

$$P_{max} = I^2 R_L \quad ------(4)$$

Load Resistance Value for Maximum Power Transfer

$$P_{L,Max} = I^2 \text{ X } R_L$$

$$P_{L,Max} = \left(\frac{V_{th}}{R_{th} + R_L}\right)^2 \text{ X } R_L$$

For max. Power Transfer $R_{th} = R_L$

$$P_{L,Max} = \left(\frac{V_{th}}{R_L + R_L}\right)^2 \text{ X } R_L$$

$$P_{L,Max} = \frac{V_{th}^2}{4R_L^2} \text{ X } R_L$$

$$P_{L,Max} = \frac{V_{th}^2}{4R_L}$$

UNIT III

AC Circuits

3.1 AC Fundamentals

Cycle: It is defined as one complete set of positive, negative and zero values of an alternating Quantity.

Frequency: The number of cycles completed by an alternating quantity per second is known as its frequency. It is denoted by 'f' and measured in cycles/second i.e. Hertz (Hz).

$$f = \frac{1}{T} \quad \text{Hz}$$

Time Period: The time taken by an alternating quantity to complete its one cycle is known as it time period denoted as T seconds

Amplitude/ Maximum Value/ Peak Value: The maximum value attained by an alternating quantity during positive or negative half cycle is called its amplitude.

Instantaneous Value: The value of an alternating quantity at a particular instant is called its instantaneous value

Average Value: It is defined as the average of all instantaneous value of alternating quantities over a half cycle.

e.g. V_{avg} = Average value of voltage

I_{avg} = Average value of current

R.M.S. Value : It is the equivalent dc current which when flowing through a given circuit for a given time produces same amount of heat as produced by an alternating current when flowing through the same circuit for the same time.

e.g. V_{rms} =Root Mean Square value of voltage I_{rms} = Root Mean Square value of current

Form Factor: It is defined as the ratio of r.m.s value to average value of an alternating quantity. Form factor = 1.11 for sine wave.

Peak factor = $\frac{I_{rms}}{I_{av}}$ or $\frac{E_{rms}}{E_{av}}$

Peak Factor: It is defined as the ratio of peak value (crest value or maximum value) to rms value of an alternating quantity.

Peak factor = $\frac{I_m}{I_{rms}}$ or $\frac{E_m}{E_{rms}}$

Peak factor = 1.4142 for sine wave

Difference between AC and DC

Difference between dc current and ac current

===DC current	===AC current
≥ IN DC current, electric charge flow only in one direction.	≥ IN ac current, electric charge changes its direction periodicly.
≥ DC current can not transfer at long distance because of very large energy loss.	≥ Ac current safe travel at long distance.
≥ The frequencies of dc current is zero.	≥ The generating frequencies is 50 hz to 60 hz in ac current.
≥ The current of magnitude verying with time is constant.	≥ The current of magnitude verying with time.
≥ The source of availability is battery or cell.	≥ The source of availability is generator or mains.
≥ IN dc circuit have only resistance.	≥ IN Ac circuit have resistance with capacitor and inductor.
≥ Power factor is always 1.	≥ IN ac power factor laies between o to 1.
≥ Its wave form are pure and pulsating.	≥ Its wave are sinusoidal, tringular, square, quasi square wave.

3.2 Important terms

Admittance: “Admittance is the inverse of impedance”. It is denoted by Y

$$Y = \frac{1}{Z}$$

Its unit is (Siemens) or (Mho)

Conductance: It is the ability of an element to conduct electric current.”

OR

“It is the inverse of resistance”

It is denoted by G.

$$G=1/R$$

Its unit is (Siemens) or (Mho)

Susceptance: Susceptance is an expression of the readiness with which an electronic component, circuit, or system releases stored energy as the current and voltage fluctuate”

OR

"It is a reciprocal of reactance"

It is denoted by B.

$$B=1/X$$

Inductive Reactance: When AC (alternating current) passes through a component that contains reactance, energy might be stored and released in the form of a magnetic field which is known as inductive reactance.

It is denoted by X_L.

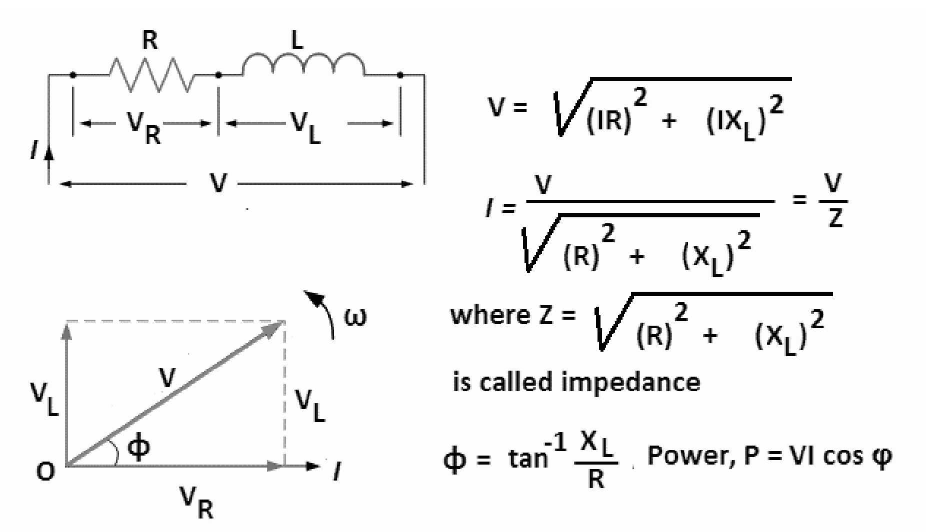
Capacitive Reactance: When AC (alternating current) passes through a component that contains reactance, energy might be stored and released in the form of an electric field which is known as capacitive reactance.

It is denoted by X_C.

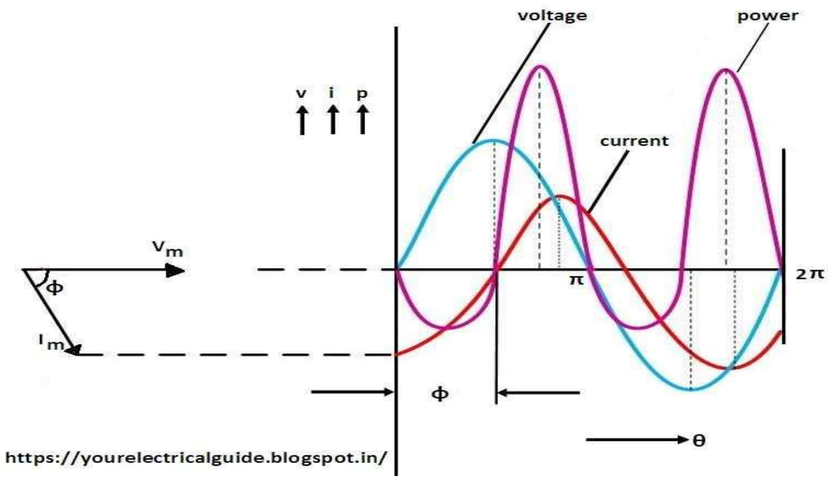
3.3 Series Resistance-Inductance (R-L) Circuit

In an RL series circuit, a pure resistance (R) is connected in series with a coil having the pure inductance (L).

Voltage drop V_R is in phase with current vector, whereas, the voltage drop in inductive reactance V_L leads the current vector by 90^0 since current lags behind the voltage by 90^0 in the purely inductive circuit.



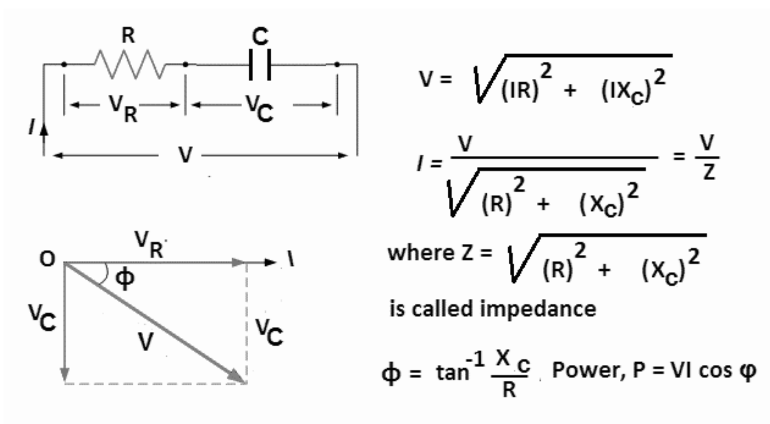
Circuit Diagram & Phasor Diagram



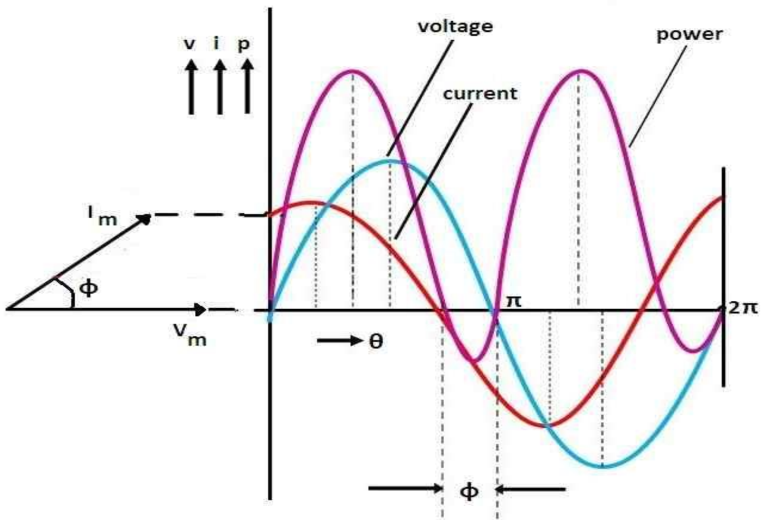
Wave Diagram

RC Series Circuit

In an RC series circuit, a pure resistance (R) is connected in series with a pure capacitor (C). Voltage drop V_R is in phase with current vector, whereas, the voltage drop in capacitive reactance V_C lags behind the current vector by 90^0, since current leads the voltage by 90^0 in the pure capacitive circuit.



Circuit Diagram & Phasor Diagram



Wave Diagram

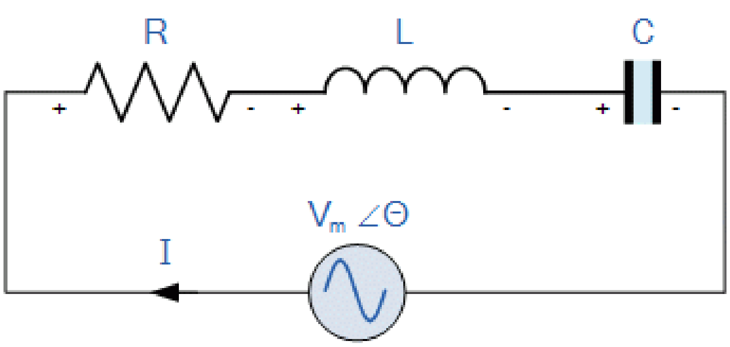
3.4 Resonance

Resonance is a condition in an RLC circuit in which the capacitive and inductive reactance are equal in magnitude.

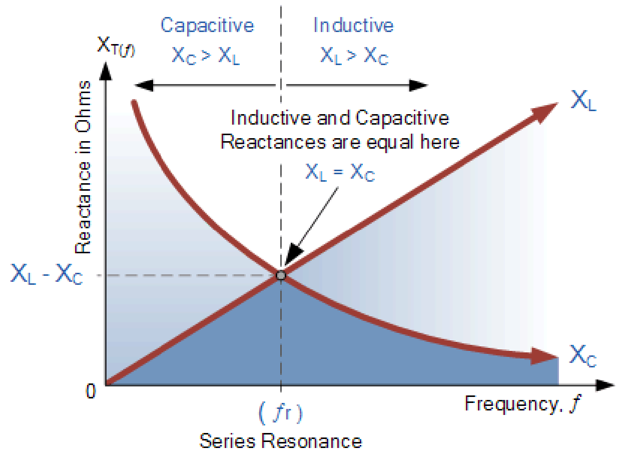
$X_L = X_C$

Series Resonance

When resistor (R), inductor (L) and capacitor (C) are connected in series, and at some frequency of supply voltage, the effect of inductor and capacitor cancel each other so that the circuit behaves like a pure resistive circuit, then this condition of the series circuit is known as series resonance. this type of circuit is also known as an Acceptor Circuit because at resonance, the impedance of the circuit is at its minimum



Circuit Diagram



Series Resonance curve

In a series resonant circuit, the resonant frequency, f_r point can be calculated as follows.

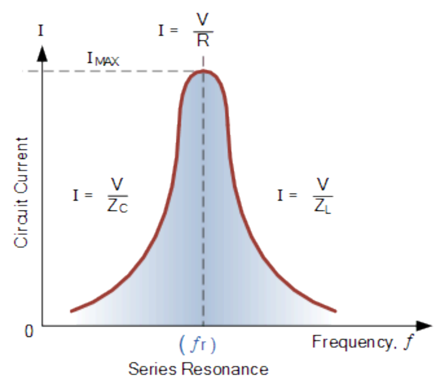
At resonance

$$X_L = X_C \quad \Rightarrow \quad 2\pi f L = \frac{1}{2\pi f C}$$

$$f^2 = \frac{1}{2\pi L \times 2\pi C} = \frac{1}{4\pi^2 LC}$$

$$f = \sqrt{\frac{1}{4\pi^2\ LC}}$$

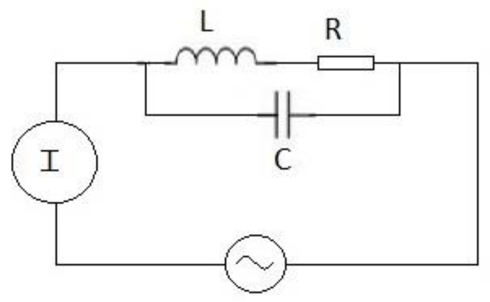
$$\therefore \quad f_r = \frac{1}{2\pi\sqrt{LC}}\ (\mathrm{Hz}) \quad \text{or} \quad \omega_r = \frac{1}{\sqrt{LC}}\ (\mathrm{rads})$$



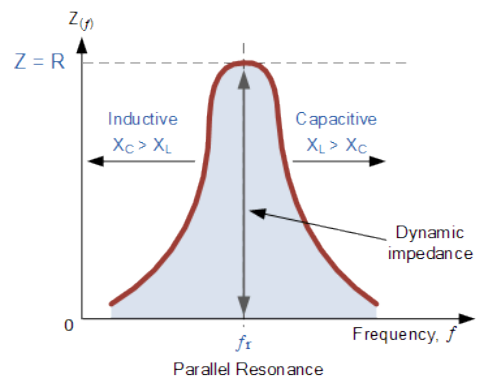
Frequency response curve

Parallel Resonance

A parallel circuit containing a resistance, R, an inductance, L and a capacitance, C will produce a parallel resonance. A parallel resonant circuit stores the circuit energy in the magnetic field of the inductor and the electric field of the capacitor.



Parallel Resonance Circuit



Frequency response curve

Current in parallel resonance is

$$I_R = \frac{V}{R}$$

$$I_L = \frac{V}{X_L} = \frac{V}{2\pi f L}$$

$$I_C = \frac{V}{X_C} = V.2\pi f C$$

Therefore, I_T = vector sum of $(I_R + I_L + I_C)$

$$I_T = \sqrt{I_R^2 + (I_L + I_C)^2}$$

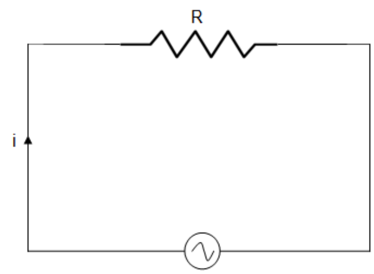
At resonance, currents IL and IC are equal and cancelling giving a net reactive current equal to zero. Then at resonance the above equation becomes.

$$I_T = \sqrt{I_R^2 + 0^2} = I_R$$

Since the current flowing through a parallel resonance circuit is the product of voltage divided by impedance, at resonance the impedance, Z is at its maximum value, (=R). Therefore, the circuit current at this frequency will be at its minimum value of V/R.

Power in Pure Resistance

In a purely resistive circuit, the applied voltage and current are in phase with each other.



Let current at any instant is given as

$$i = I_m \ Sin\omega t$$

The instantaneous value of alternating voltage is given by

$$V = V_m \ Sin\omega t$$

In an a.c. circuit having resistance as any element, the phase difference between voltage and current is zero. In other words it can be said that current is in phase with the voltage power.

We know instantaneous power $p = V\times I$

$$p = (V_m Sin\ \omega t)(I_m Sin\ \omega t)$$

$$= V_m I_m Sin^2 \omega t$$

$$= \frac{V_m I_m (1 - Cos\ 2\ \omega t)}{2}$$

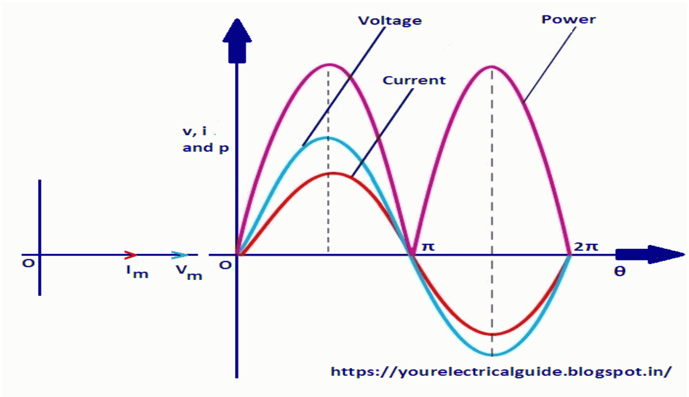
$$= \frac{V_m I_m}{2} - \frac{V_m I_m Cos\ 2\ \omega t}{2}$$

Considering average power

[Average value of $\frac{V_m I_m\ Cos\ 2\ \omega t}{2} = 0$]

$$P = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}$$

V = r.m.s voltage, I = r.m.s current

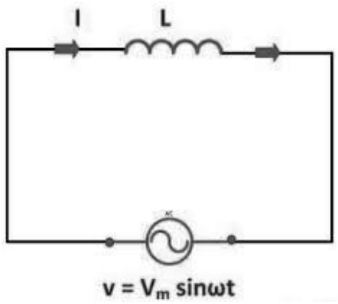


Power Curve

Power in Pure Inductance

The sinusoidal voltage can be given as

$$v = V_m Sin\ \omega t$$



Instantaneous power p = v i

$$= V_m Sin\ \omega t \times I_m Sin(\omega t - \tfrac{\pi}{2})$$

$$= V_m I_m Sin\omega t . Cos\omega t$$

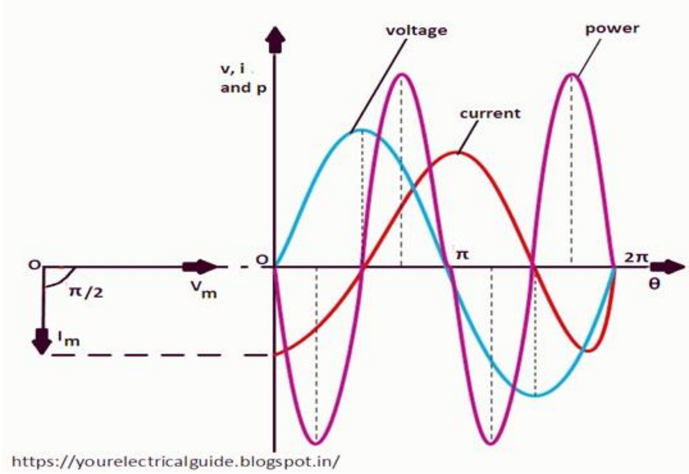
$$p = \frac{V_m I_m}{2} \text{Sin } 2\ \omega t$$

Average power consumed over one cycle

$$p = average\ of\ \tfrac{V_m I_m}{2} \sin 2\ \omega t$$

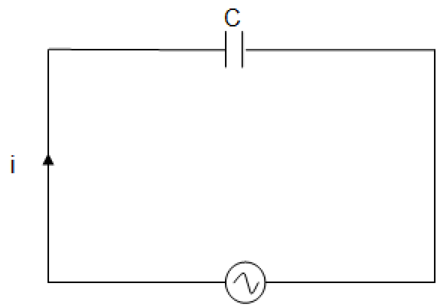
$$p = 0$$

This shows that power absorbed in a circuit having only inductance element is zero



Power Curve

Power in Pure Capacitance



The value of alternating voltage is given as

$$v = V_m Sin\ \omega t$$

Instantaneous power is given by

$$p = v\ i$$

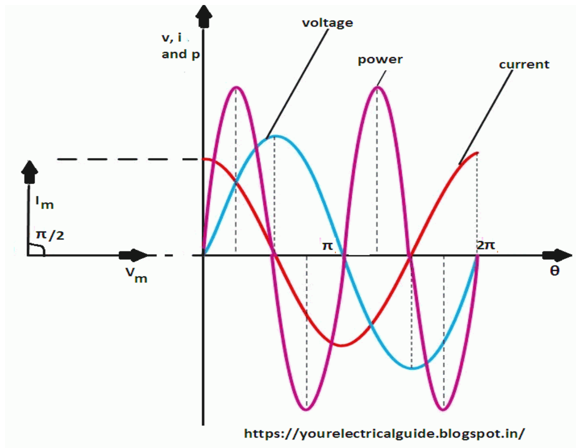
$$= V_m Sin\ \omega t \times I_m Sin\left(\omega t + \frac{\pi}{2}\right)$$

$$= V_m I_m Sin\omega t . Cos\omega t$$

$$p = \frac{V_m I_m}{2}\ Sin\ 2\ \omega t$$

The average power over one complete cycle is p = Zero

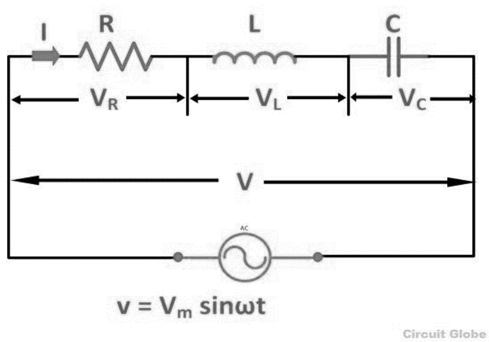
The power absorbed in a circuit with pure capacitance is zero.



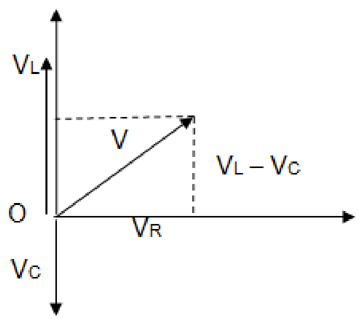
Power Curve

Power in RLC Circuit

When a pure resistance R ohms, pure inductance L Henry and pure capacitor of capacitance C farad are connected in series it is known as R-L-C Series Circuit.



A.C. series circuit for resistance, inductance and capacitance



Phasor diagram for resistance, inductance and capacitance series circuit

The voltage drop across each element is given as:

a) Resistance (R) = V_R = IR (in phase with current I)

b) Inductance (L) = V_L = IX_L (leads current by 90^o)

c) Capacitance (C) = $V_C = I X_C$ (lags current by 90°)

Power in RLC Series Circuit

$$P = VI\cos\varphi = I^2R$$

The product of voltage and current is defined as power. Where cosϕ is the power factor of the circuit and is expressed as:

$$\cos\varphi = \frac{V_R}{V} = \frac{R}{Z}$$

The three cases of RLC Series Circuit

- When XL > XC, the phase angle ϕ is positive. The circuit behaves as RL series circuit in which the current lags behind the applied voltage and the power factor is lagging.
- When XL < XC, the phase angle ϕ is negative, and the circuit acts as a series RC circuit in which the current leads the voltage by 90 degrees.
- When XL = XC, the phase angle ϕ is zero, as a result, the circuit behaves like a purely resistive circuit. In this type of circuit, the current and voltage are in phase with each other. The value of the power factor is unity.

3.6 Power factor

It is defined as the cosine of angle between voltage and current. Power Factor = pf = cosϕ,

where ϕ is the angle between voltage and current.

Active power

It is the actual power consumed in any circuit. It is given by product of rms voltage and rms current and cosine angle between voltage and current. (VI cosϕ).

Active Power= P= $I^2 R$ = VI cosϕ.

Unit is Watt (W) or kW.

Reactive power

The power drawn by the circuit due to reactive component of current is called as reactive power. It is given by product of rms voltage and rms current and sine angle between voltage and current (VI $\sin\phi$).

Reactive Power = Q= I^2 X = VI $\sin\phi$.

Unit is VAR or kVAR.

Apparent power

It is the product of rms value of voltage and rms value of current. It is total power supplied to the circuit.

Apparent Power = S = VI.

Unit is VA or kVA.

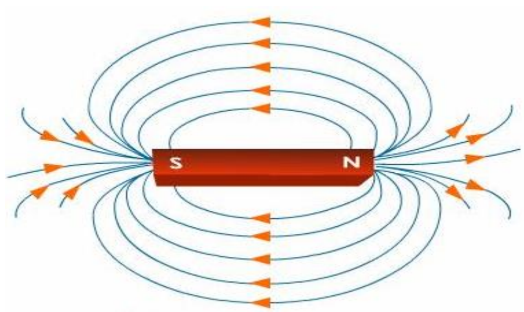
UNIT IV

Electro Magnetic Circuit

4.1 Concept of electro-magnetic field produced by flow of electric current

Magnetic fields

The region around a magnet where its magnetic influence can be experienced is called a magnetic field



Magnetic Field Lines

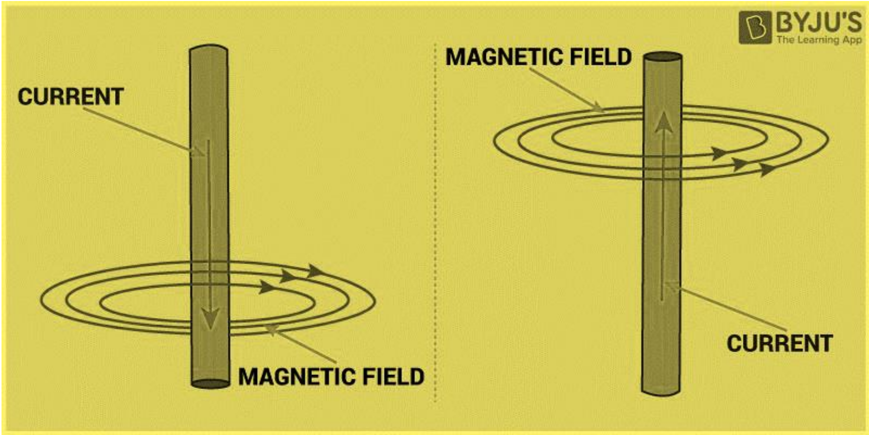
A magnetic field line or lines of forces shows the strength of a magnet and the direction of a magnet's force.

Strength of Magnetic Field Lines

- A straight current-carrying conductor has a magnetic field in the shape of concentric circles around it. Magnetic field lines can visualize the magnetic field of a straight current-carrying conductor.
- Direction of Field Line: Outside the magnet, the direction of magnetic field line is taken from North Pole to South Pole. Inside the magnet, the direction of magnetic field line is taken from South Pole to North Pole.
- The direction of the magnetic field gets reversed if the direction of electric current changes.
- The direction of the magnetic field in electric current through a straight conductor can be represented by using the Right-Hand Thumb Rule.

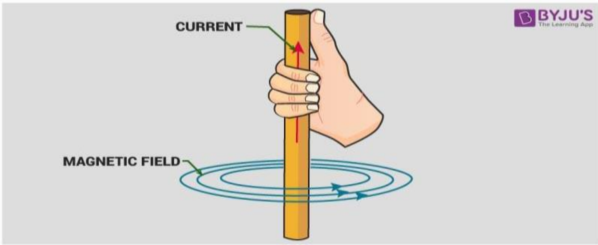
Magnetic field due to a straight current carrying conductor

When current is passed through a straight current-carrying conductor, a magnetic field is produced around it. Magnetic Lines of force are in the form of concentric circles around the conductor.



Right-Hand Thumb Rule

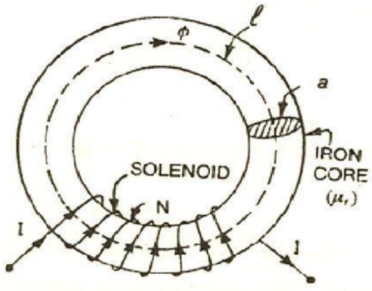
Assume that you are holding a straight current-carrying conductor in your right hand such that the thumb points towards the direction of the current. Then your fingers will wrap around the conductor in the direction of the magnetic field lines.



Magnetic Circuit

A closed path followed by the magnetic flux is called magnetic circuit.

A magnetic circuit is made up of magnetic materials having high permeability such as iron, soft steel, etc.



Magneto-Motive Force (MMF)

The magnetic pressure, which sets up the magnetic flux in a magnetic circuit is called Magneto motive Force (MMF). Its unit is Ampere turn (AT).

Magneto motive Force (MMF) = NI.

Magnetic Flux

Magnetic flux is defined as the number of magnetic field lines passing through a given closed surface.

Magnetic flux symbol: Φ

The SI unit of magnetic flux is Weber (Wb)

Reluctance

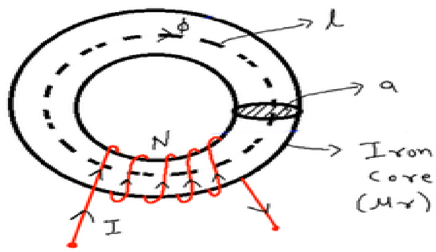
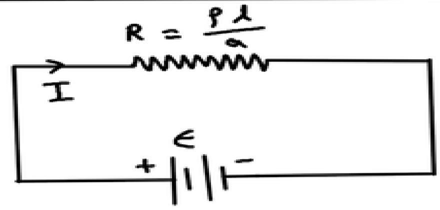
It is defined as the ratio of magneto motive force (mmf) to magnetic flux. Its unit is Ampere turns/Weber. It is denoted by S.

Permeability

The ability of a material to conduct magnetic flux through it is known as Permeability. It is denoted by Greek letter (µ).

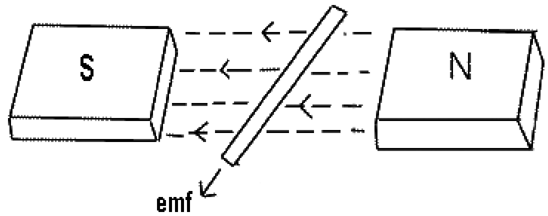
The permeability of nonmagnetic material including air is μ_0. It is equal to $4\pi \times 10^{-7}\, H/m$

Analogy between electric and magnetic circuit

Magnetic circuit	Electric circuit
 Magnetic Circuit	 Electric circuit
The closed path for magnetic flux is called magnetic circuit.	The closed path for electric current is called electric circuit.
$\text{Flux} = \dfrac{\text{mmf}}{\text{Reluctance}}$	$\text{Current} = \dfrac{\text{emf}}{\text{Resistance}}$
flux ϕ in Wb	current I in ampere
mmf in AT	emf in V
Reluctance, $S = \dfrac{l}{a\mu_0\mu_r}$ AT/Wb	$\text{Resistance} = \dfrac{\rho l}{a}$ Ω
$\text{Permeance} = \dfrac{1}{\text{Reluctance}}$	$\text{Conductance} = \dfrac{1}{\text{Resistance}}$
Permeability, μ	Conductivity, $\sigma = \dfrac{1}{\rho}$
Reluctivity	Resistivity
flux density, $B = \dfrac{\phi}{a}$ $\dfrac{Wb}{m^2}$ or T	current density, $J = \dfrac{I}{A}$ A/m^2
Magnetic intensity, $H = \dfrac{NI}{l}$	Electric intensity, $E = \dfrac{V}{d}$ (V → P.D., d → distance)

4.2 Faraday’s laws of electro-magnetic induction

Faraday’s law of electromagnetic induction, also known as Faraday’s law, is the basic law of electromagnetism. Faraday's laws of of electromagnetic induction explains the relationship between electric circuit and magnetic field. This law is the basic working principle of the most of the electrical motors, generators, transformers, inductors etc.



Faraday's First Law:

Whenever a conductor is placed in a varying magnetic field an EMF gets induced across the conductor (called as induced emf), and if the conductor is a closed circuit then induced current flows through it.

Magnetic field can be varied by various methods -

1. By moving magnet

2. By moving the coil

3. By rotating the coil relative to magnetic field

Faraday's Second Law:

Faraday's second law of electromagnetic induction states that, the magnitude of induced emf is equal to the rate of change of flux linkages with the coil. The flux linkages is the product of number of turns and the flux associated with the coil.

Consider the conductor is moving in magnetic field, then

flux linkage with the coil at initial position of the conductor = $N\Phi 1$

flux linkage with the coil at final position of the conductor = $N\Phi 2$

change in the flux linkage from initial to final = $N(\Phi 1 - \Phi 2)$

let $\Phi 1 - \Phi 2 = \Phi$

therefore, change in the flux linkage = $N\Phi$

and, rate of change in the flux linkage = $N\Phi/t$

taking the derivative of RHS

rate of change of flux linkages = N (dΦ/dt)

According to Faraday's law of electromagnetic induction, rate of change of flux linkages is equal to the induced emf

So, E = N (dΦ/dt)   (volts)

Lenz's law of electromagnetic induction states that, when an emf is induced according to Faraday's law, the polarity (direction) of that induced emf is such that it opposes the cause of its production.

E = -N (dΦ/dt)   (volts)

The negative sign shows that, the direction of the induced emf and the direction of change in magnetic fields have opposite signs.

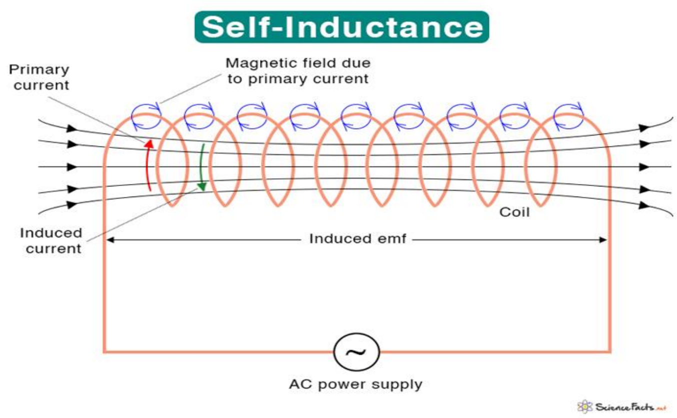
Principles of Self and Mutual Induction

Self-inductance:

Self-inductance is defined as the property of the coil due to which it opposes the change of current flowing through it. Inductance is attained by a coil due to the self-induced emf produced in the coil itself by changing the current flowing through it. It's given by the following:

$$e = L\,\frac{di}{dt}$$

Where e is self-induced emf, L is self-inductance, I is current and t is time passed. The unit of self-inductance, L is Henry.



Self-Induced EMF

Self-induced emf is the emf induced in the coil due to the change of flux produced by linking it with its own turns.

When the current I flows through the coil, it produces flux (φ) linking with its own turns. If the current flowing through the coil is changed by changing the value of variable resistance (R), the flux linking with it, changes and hence emf is induced in the coil. This induced emf is called Self Induced emf.

The direction of this induced emf is such that it opposes its very own cause which produces it, that means it opposes the change of current in the coil. This effect is because of Lenz's Law.

Since the rate of change of flux linking with the coil depends upon the rate of current in the coil.

$$e \propto \frac{dI}{dt}$$

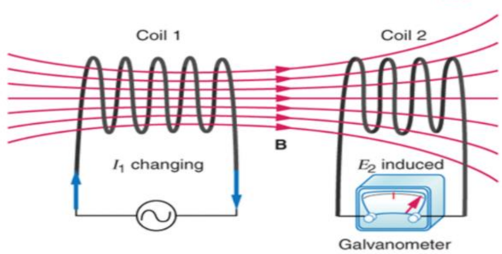
OR

$$e = L\frac{dI}{dt}$$

The magnitude of self-induced emf is directly proportional to the rate of change of current in the coil. L is constant of proportionality and called as Self Inductance or the Coefficient of Self Inductance or Inductance of the coil.

Mutual Induction

When two coils are brought near to each other the magnetic field in one of the coils tend to link with the other. This further leads to the generation of voltage in the second coil. This property of a coil which affects or changes the current and voltage in a secondary coil is called mutual inductance.



Mutually Induced EMF

Let N_1 = Number of turns of coil A

N_2 = Number of turns of coil B

I_1 = Current flowing through coil A

ϕ_1 = Flux produced due to current I_1 in webers.

ϕ_2 = Flux linking with coil B

According to Faraday's law, the induced e.m.f. in coil B is,

$$e_2 = -N_2 \frac{d\phi_2}{dt}$$

Negative sign indicates that this e.m.f. will set up a current which will oppose the change of flux linking with it.

Now $$\phi_2 = \frac{\phi_2}{I_1} \times I_1$$

If permeability of the surroundings is assumed constant then $\phi_2 \propto I_1$ and hence ϕ_2 / I_1 is constant.

$\therefore$ Rate of change of $\phi_2 = \frac{\phi_2}{I_1} \times$ Rate of change of current I_1

$$\therefore \quad \frac{d\phi_2}{dt} = \frac{\phi_2}{I_1} \cdot \frac{dI_1}{dt}$$

$$\therefore \quad e_2 = -N_2 \cdot \frac{\phi_2}{I_1} \cdot \frac{dI_1}{dt}$$

$$\therefore \quad e_2 = -\left(\frac{N_2 \phi_2}{I_1}\right) \frac{dI_1}{dt}$$

Here $\left(\frac{N_2 \phi_2}{I_1}\right)$ is called coefficient of mutual inductance denoted by M.

$$\therefore \quad \boxed{e_2 = -M\frac{dI_1}{dt} \quad \text{volts}}$$

Coefficient of mutual inductance is defined as the property by which e.m.f. gets induced in the second coil because of change in current through first coil.

Coefficient of mutual inductance is also called mutual inductance. It is measured in henries.

4.3 Energy stored in an inductor

Suppose that an inductor of inductance L is connected to a variable DC voltage supply. The supply is adjusted so as to increase the current i flowing through the inductor from zero to some final value I. As the current through the inductor is increased, an emf is generated,

$$\mathcal{E} = -L\, di/dt$$

Work must be done against this emf by the voltage source in order to establish the current in the inductor. The work done by the voltage source during a time interval dt is

$$dW = P\,dt = -\mathcal{E}\,i\,dt = i\,L\,\frac{di}{dt}\,dt = L\,i\,di.$$

To find the total work W done in establishing the final current I in the inductor, we must integrate the above expression. Thus,

$$W = L\int_0^I i\,di,$$

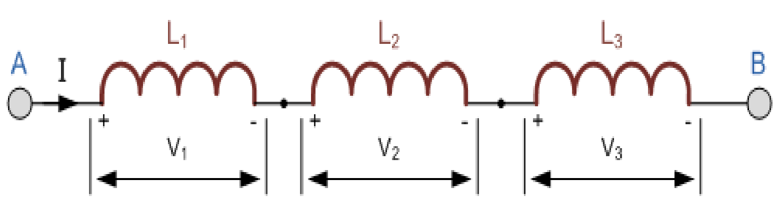
$$W = \frac{1}{2}\,L\,I^2.$$

This energy is actually stored in the magnetic field generated by the current flowing through the inductor.

4.4 Series and Parallel Combination of Inductors

Series Combination of Inductors

When inductors are connected in series, the total inductance is the sum of the individual inductors' inductances.



Series Inductances

$$\mathbf{L_{total} = L_1 + L_2 + \ldots\ L_n}$$

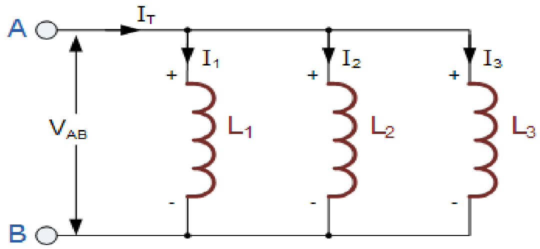
If flux is additive

$L = L_1 + L_2 + 2M$

If flux is Subtractive

$L = L_1 + L_2 - 2M$

Parallel Combination of Inductors



Inductors are said to be connected in parallel when two terminals of an inductor respectively connected to each terminal of other inductor. Similar to the parallel connection of resistors, the total inductance in parallel connection of inductors is somewhat lesser than smallest inductance of an inductor in that connection.

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} \ldots\ldots + \frac{1}{L_N}$$

Or

$$L = \frac{L_1 L_2 - M^2}{L_1 + L_2 + 2M}$$

UNIT V

Batteries

A Battery is a device consisting of one or more electrical cells that convert chemical energy into electrical energy.

5.1 Basic Idea of Primary and Secondary Cells

Primary Cell

Primary cell or battery is the one that cannot easily be recharged after one use, and are discarded following discharge. These cell are not chargeable because the electrode reaction occurs only once and after the use over a period of time the batteries become dead and cannot be reused.

Example: Simple voltaic cell, dry cell

Secondary Cells

A secondary cell or battery is one that can be electrically recharged after its complete discharge. It is recharged by passing current through the circuit in the opposite direction to the current during discharge.

Example: lead-acid cells, Nickle-iron cells.

Difference between Primary and Secondary Cell

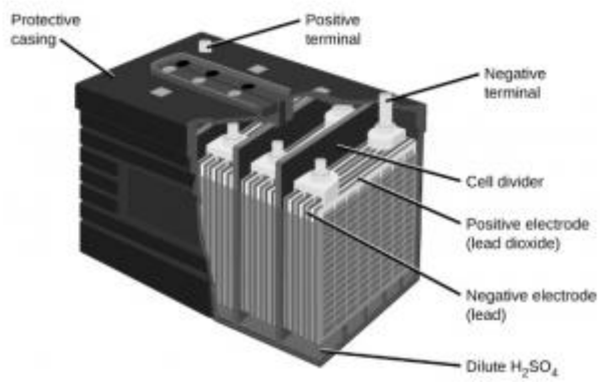
Primary cell	Secondary cell
Primary cells are irreversible i.e., once they get discharged, they cannot be charged again.	Secondary cells are reversible and can be easily charged by electrical supply.
Their internal resistance is very high.	They possess low internal resistance.
They are cheaper.	They are comparably expensive.
They can be easily used.	In comparison to primary cells, they are difficult to handle.
They have a short lifetime.	They are durable.
They are smaller in size.	They are larger.
They are used in small devices like a torch and, other portable appliances.	In large devices like inverters and automobiles, secondary cells are used.
They are made up of dry cells.	They are made of wet cells and molten salts.
They cause an irreversible chemical reaction.	They cause a reversible chemical reaction.

5.2 Lead Acid Batteries

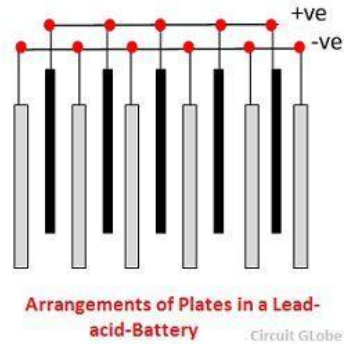
The battery which uses sponge lead and lead peroxide for the conversion of the chemical energy into electrical power, such type of battery is called a lead acid battery. The lead acid battery is most commonly used in the power stations and substations because it has higher cell voltage and lower cost.

Construction of Lead Acid Battery

1. Container – The container of the lead acid battery is made of glass, lead lined wood, ebonite, the hard rubber of bituminous compound, ceramic materials or moulded plastics and are seated at the top to avoid the discharge of electrolyte. At the bottom of the container, there are four ribs, on two of them rest the positive plate and the others support the negative plates.



2. Plate – The plate of the lead-acid cell is of diverse design and they all consist some form of a grid which is made up of lead and the active material. The grid is essential for conducting the electric current and for distributing the current equally on the active material.

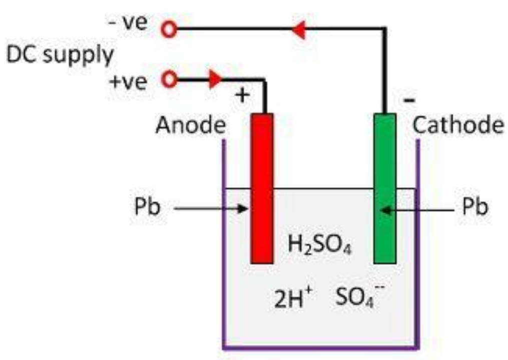


3. Active Material – The material in a cell which takes active participation in a chemical reaction (absorption or evolution of electrical energy) during charging or discharging is called the active material of the cell. The active elements of the lead acid are
   - Lead peroxide (PbO2) – It forms the positive active material. The PbO2 are dark chocolate broom in colour.
   - Sponge lead – Its form the negative active material. It is grey in colour.
   - Dilute Sulfuric Acid (H2SO4) – It is used as an electrolyte. It contains 31% of sulfuric acid.
4. Separators – The separators are thin sheets of non-conducting material made up of chemically treated Leadwood, porous rubbers, or mats of glass fibre and are placed between the positive and negative to insulate them from each other.

5. Battery Terminals – A battery has two terminals the positive and the negative. The positive terminal with a diameter of 17.5 mm at the top is slightly larger than the negative terminal which is 16 mm in diameter.

Working Principle of Lead Acid Battery

When the sulfuric acid dissolves, its molecules break up into positive hydrogen ions (2H+) and sulphate negative ions (SO4—) and move freely. If the two electrodes are immersed in solutions and connected to DC supply then the hydrogen ions being positively charged and moved towards the electrodes and connected to the negative terminal of the supply. The SO4— ions being negatively charged moved towards the electrodes connected to the positive terminal of the supply main (i.e., anode).



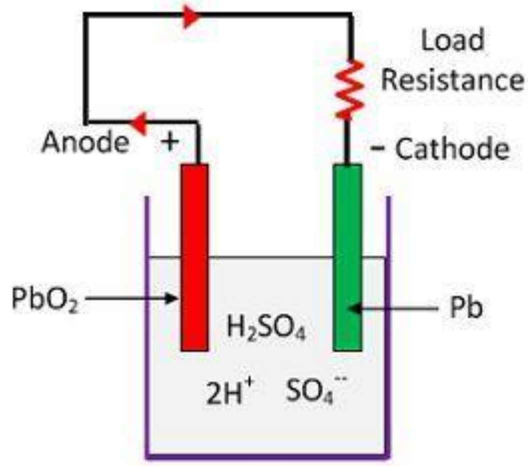
Charging of Lead Acid Cells

Each hydrogen ion takes one electron from the cathode, and each sulphate ions takes the two negative ions from the anodes and react with water and form sulfuric and hydrogen acid.

If the DC source of supply is disconnected and if the voltmeter connects between the electrodes, it will show the potential difference between them. If wire connects the electrodes, then current will flow from the positive plate to the negative plate through external circuit i.e. the cell is capable

Chemical Action during discharging supplying electrical energy

When the cell is full discharge, then the anode is of lead peroxide (PbO2) and a cathode is of metallic sponge lead (Pb). When the electrodes are connected through a resistance, the cell discharge and electrons flow in a direction opposite to that during charging.



Discharging of Lead Acid Cells

$$PbSO_4 + 2H = PbO + H_2O$$

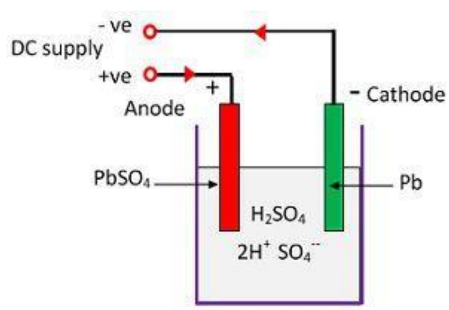
$$PbO + H_2SO_4 = PbSO_4 + 2H_2O$$

$$\overline{PbO_2 + H_2SO_4 + 2H = PbSO_4 + 2H_2O}$$

Chemical Action during Recharging

For recharging, the anode and cathode are connected to the positive and the negative terminal of the DC supply mains. The molecules of the sulfuric acid break up into ions of 2H+ and SO4—. The hydrogen ions being positively charged moved towards the cathodes and receive two electrons from there and form a hydrogen atom. The hydrogen atom reacts with lead sulphate cathode forming lead and sulfuric acid according to the chemical equation.

$$PbSO_4 \ + 2H_2O + 2H = PbSO_4 + 2H_2SO_4$$

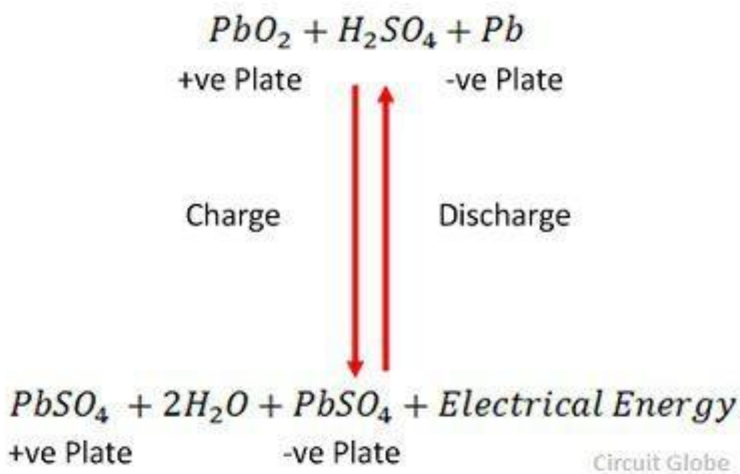


Recharging of Lead Acid Cell

SO4— ion moves to the anode, gives up its two additional electrons becomes radical SO4, react with the lead sulphate anode and form leads peroxide and lead sulphuric acid according to the chemical equation.

$$PbSO_4 + 2H = H_2SO_4 + Pb$$

The charging and discharging are represented by a single reversible equation given below.



Applications

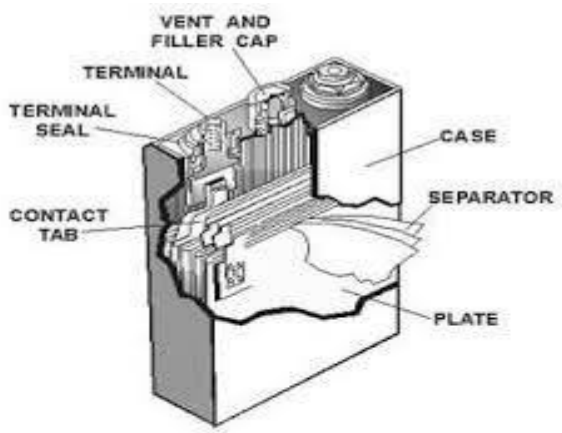
- These are employed in emergency lightening to provide power for sump pumps.
- Used in electric motors
- Submarines
- Nuclear submarines

Nickel-Cadmium Batteries

Nickel-cadmium battery is a source for DC voltage. In a nickel-cadmium battery, the redox material is used as a base, and around it, the layer of nickel and a separator are used. The nickel-cadmium cell voltage is around 1.2 V. When connected in series generally 3 to 4 cells are packed together to get an output of 3.6 to 4.8 V.

Construction

The operation of a nickel-cadmium battery is similar to that of other batteries. Nickel and cadmium are used to increase performance. Since a battery is a DC voltage source, it must have two potential points: positive and negative, commonly known as anode and cathode. A coating of nickel oxide NiO2 is held around the redox in a nickel-cadmium battery. This nickel oxide coating serves as a cathode. A coating of KaOH is held above the nickel oxide layer to serve as a separator. It should be remembered that this separator layer must be wet or damp. Its aim is to provide the chemical reaction with the required OH negative ions. Cadmium is mounted above the separator plate. In a nickel-cadmium battery, the cadmium coating serves as the anode.



The nickel layer acts as a positive electrode collector, while the cadmium layer acts as a negative electrode collector. KOH or NaOH is used as a separator layer between the two layers. Its role is to supply OH ions. A safety valve, sealing pad, insulation ring, insulation gasket, and an exterior case round out the package. The nickel-cadmium battery is constructed similarly to lead-acid batteries. It is made up of three basic layers. The nickel layer is first, followed by the separator layer, and then the cadmium layer. The nickel layer functions as a positive electrode collector, while the cadmium layer functions as a negative electrode collector. KOH or NaOH is used as a separator layer between the two layers.

Working

The chemical equations representing the chemical reaction can be given as

$$2NiOOH + 2H_2O + 2e^- \Rightarrow 2\,Ni\,(OH)_2 + 2\,OH^-$$

$$Cd + 2\,OH^- \Rightarrow 2\,Cd\,(OH)_2 + 2e^-$$

$$2NiOOH + Cd + 2H_2O \Leftrightarrow 2\,Ni\,(OH)_2 + Cd\,(OH)_2$$

The first equation represents the reaction between the cathode layer nickel and the separator. It gives an output of Nickel oxide OH ions. The need for the separator layer as mentioned before is the provide the OH ions required for the chemical reaction.

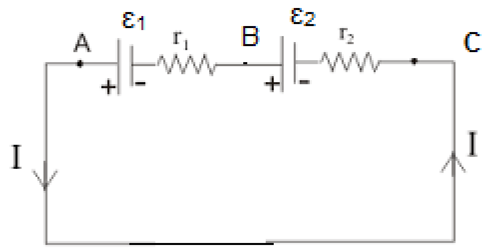
On the anode side, the cadmium layer is also combined with OH ions which are obtained from the separators layer. This results in cadmium oxide and electrons. It may be noted that the electrons in both the equations get canceled. Also, OH ions get canceled. The reminder equation is given by the third equation, where nickel is combined with cadmium and water. It results in nickel oxide and cadmium oxide.

Applications

- Battery
- Toys
- Calculators
- Small Dc Motors

5.3 Series connection of batteries

Consider two cells which is connected in series. The positive terminal of one cell is connected to negative terminal of the next cell. Here one terminal of two cells are free and the other terminal of two cells are joined together. ε1 and ε2 are the emfs of the cells and r1 and r2 are the internal resistance of the cells respectively. Let I be the current flowing through the cells.



n is the number of cells in series

r is the internal resistance

E is the emf of each cell

Total emf is n.E

Total Internal resistance = n.r

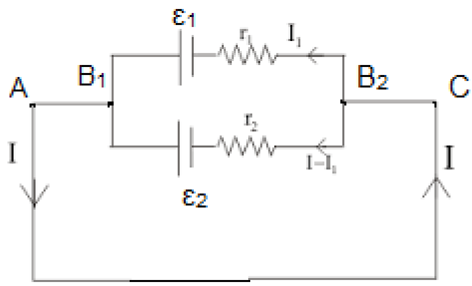
Load Current $I = \frac{n.E}{R+n.r}$

Or

$$I = \frac{n.E}{R}$$

Parallel connection of batteries

Consider two cells which is connected in parallel. Here the positive terminals of all cells are connected together and negative terminals of all cells are connected together.



n is the number of cells in parallel

r is the internal resistance

E is the emf of each cell

Total Internal resistance = $\frac{r}{n}$

Load Current $I = \frac{E}{R+\frac{r}{n}}$

Or

$$I = \frac{n.E}{R.n + r}$$

If R is small then

$$I = \frac{n.E}{r}$$

5.4 Introduction to Maintenance of Free Batteries

1. Check the battery's state of charge. Most batteries have a State of Charge Indicator on top of the battery that will give you an on the spot diagnosis of the battery condition. However, a more reliable way to check is with a voltmeter to determine the stabilized voltage or if the vent caps are removable a hydrometer to determine the specific gravity (SG) of the electrolyte. A charged Century battery will have a stabilized voltage above 12.5 volts and an SG reading above 1.240.

2. Ensure the battery top is clean, dry, free of dirt and grime. A dirty battery can discharge across the grime on top of the battery casing.

3. Inspect the terminals, screws, clamps, and cables for breakage, damage or loose connections. These should be clean, tight and free of corrosion.

4. Apply a thin coating of high-temperature grease to posts and cable connections for added protection.

5. Inspect the battery case for obvious signs of physical damage or warpage. This usually indicates the battery has been overheated or has been overcharged.

6. If you have a maintainable battery, it is important to check if the battery has sufficient electrolyte covering the battery plates. If topping up is required, do not overfill as the fluid levels will rise when the battery is fully charged and may overflow. Top up using distilled or demineralized water and never fill with sulphuric acid.

7. When servicing a sealed maintenance free (SMF) battery, check the State of Charge Indicator. This gives you a snapshot of the battery's condition and whether the battery needs to be charged or replaced. The vehicle may still start the engine although the indicator outlines to replace the battery. If the State of Charge Indicator advises 'Replace Battery' it is important that the battery is replaced as the electrolyte levels may be below the plates which can lead to an internal explosion.

8. For batteries used in seasonal applications and stored long term, fully recharge the battery prior to storing. Check the state of charge or voltage regularly. Should the voltage drop below 12.5V, recharge the battery. It is important to check the battery completely before reconnecting to electrical devices.

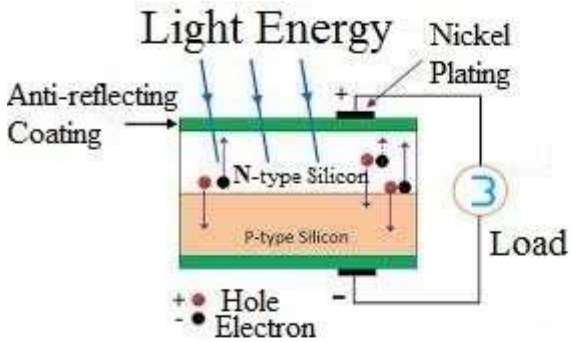
5.5 Steps of Disposal of Batteries

1. Drain Electrolyte
2. Break battery into component parts
3. Plastic components burnt or dumped
4. Lead containing components broken down
5. Broken battery parts are fed to smelter
6. Smelting and refining

5.6 Solar Cells

- Solar Cell is an energy conversion device which are used to convert sunlight to electricity by the use of the photovoltaic effect. This is also known as photovoltaic cell (PV Cell).
- Solar Cells are often coated with transparent thin film of silicon monoxide (SiO) to minimize the reflective losses from the surface.
- In a solar cell, the pinnacle layer is present which includes an anti -reflective cover glass.
- This glass guards the semiconductor materials against the sunlight.
- In a solar cell, small grid patterns with slight metallic strips are available under the glass.
- So, that the top layer of cell can be formed by using the glass, metallic strips & anti-reflective coat.
- It is a semiconductor device and sensitive to photovoltaic effect.
- Solar cells normally consists of single crystal silicon P-n junction.

- When photons of light energy from the sun fall on semiconductor junction, the electron-hole pairs are created.
- Holes pass to the P– region and electrons pass to the N– region.
- The displacement of free charge creates an electric current when the load is connect across the terminals.
- This is the basic principle on which the solar cells work and generates power.



Construction of Solar Cell

Applications

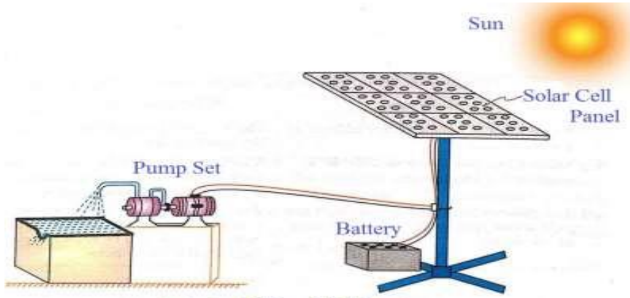
- It is mostly use in the field of toys, watches, etc.
- They also use in the field of electric fence.
- It is also use in the field of Remote lighting systems area.
- This may be use in the field of portable power supplies
- They mostly use in the field of satellites.
- They also use in the field of water treatment & pumping.
- It is may be use in the field of emergency power.

Solar Panel

The solar panel convert solar energy of sun into electricity.

Working

The photons hitting the solar cell lose the electrons from their atoms and with a proper attachment of conductors on the positive and negative sides of a cell, the whole can be transformed into an electrical circuit. Electrons flowing through the circuit help in generating electricity. Many solar cells make up a solar panel and multiple panels can be paired to form a solar array. In this session, let us learn about the uses of solar panels and their practical application in real life.



A typical Solar Cell Panel

Applications

Dairy: Solar panels can be used to generate power which can be used in the dairy industry for the process of sterilization, pressurization, concentration, drying, and boiler feed water.

Tinned Food: Here, the solar panels can provide temperature which can prove useful for processes like sterilization, pasteurization, bleaching, and cooking.

Textile: Textile industry depends on the extensive use of solar panels for efficient use of solar energy. These are used for the process like bleaching, dyeing, drying, degreasing, pressing, etc.

Paper: In this industry, the use of heat is required for various processes and uses solar panels to provide heat for the process like drying, boiler feed water, bleaching, etc.

Chemical: These industries use solar panels for generating heat which is used for the production of soaps, synthetic rubber, processing heat, preheating water, etc.

Beverages: We can see major uses of solar panels in beverage industries for the processes such as washing sterilization and pasteurization.

Timber and by-products: Solar panels are used in the timber industry in the processes of drying, thermodiffusion beams, pre-heating water, and in the preparation of pulp.

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