MAR GREGORIOS COLLEGE
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DEPARTMENT OF ELECTRONICS & COMMUNICATION SCIENCE

SUBJECT NAME: BASIC CIRCUIT THEORY

SUBJET CODE: SG21A

SEMESTER: I

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BASIC CIRCUIT THEORY

UNIT I

Resistors : Introduction to linear and non linear components (active and passive) – Types of resistors (wire wound, carbon composition, film type, Cermets') – Resistor color coding – power rating of resistors – Series and Parallel combination of resistors. Capacitors : Capacitance-Factors controlling capacitance-Types of capacitors: Fixed Capacitors, Variable Capacitors – Non electrolytic and electrolytic capacitors. Voltage rating of capacitors – capacitors in series and parallel – Energy stored in capacitors.

UNIT II

Inductors : Inductors (air core, iron core, ferrite core) – comparison of different cores – Inductance of an Inductor – Mutual Inductance – Coefficient of coupling – Variable Inductors – Inductors in Series and Parallel without M – Reactance and Impedance offered by a coil – Q factor Transformer: working – turns ratio – voltage ratio – current ratio – power in secondary – autotransformers – transformer efficiency – core losses – types of cores.

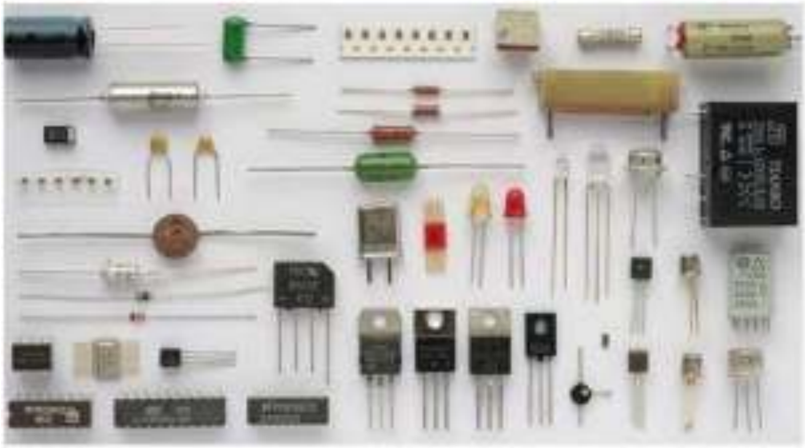
UNIT V

Applications of Basic components: Filters (Low Pass Filter, High Pass Filter using passive components.) AC signal: RMS value– average value–. AC analysis (Pure resistive, Pure inductive circuit and Pure capacitive circuit)

UNIT – 1 - RESISTORS

Electronic Components

Similar to a brick that constructs a wall, a component is the basic brick of a circuit. A **Component** is a basic element that contributes for the development of an idea into a **circuit** for execution.Each component has a few basic properties and the component behaves accordingly. It depends on the motto of the developer to use them for the construction of the intended circuit. The following image shows a few examples of electronic components that are used in different electronic circuits.



They can either be **Active Components** or **Passive Components**.

Active Components

- Active Components are those which conduct upon providing some external energy.
- Active Components produce energy in the form of voltage or current.
- **Examples** − Diodes, Transistors, Transformers, etc.

Passive Components

- Passive components are those which start their operation once they are connected. No external energy is needed for their operation.

- Passive components store and maintain energy in the form of voltage or current.
- **Examples** − Resistors, Capacitors, Inductors, etc.

We also have another classification as **Linear** and **Non-Linear** elements.

Linear Components

- Linear elements or components are the ones that have linear relationship between current and voltage.
- The parameters of linear elements are not changed with respect to current and voltage.
- **Examples** − Diodes, Transistors, Transformers, etc.

Non-linear Components

- Non-linear elements or components are the ones that have a non-linear relationship between current and voltage.
- The parameters of non-linear elements are changed with respect to current and voltage.
- **Examples** − Resistors, Capacitors, Inductors, etc.

These are the components intended for various purposes, which altogether can perform a preferred task for which they are built. Such a combination of different components is known as a **Circuit**.

Electronic Circuits

A certain number of components when connected on a purpose in a specific fashion makes a **circuit**. A circuit is a network of different components. There are different types of circuits.

The following image shows different types of electronic circuits. It shows Printed Circuit Boards which are a group of electronic circuits connected on a board.

Electronic circuits can be grouped under different categories depending upon their operation, connection, structure, etc. There are different types of Electronic Circuits.

Active Circuit

- A circuit that is build using Active components is called as **Active Circuit**.
- It usually contains a power source from which the circuit extracts more power and delivers it to the load.
- Additional Power is added to the output and hence output power is always greater than the input power applied.
- The power gain will always be greater than unity.

Passive Circuit

- A circuit that is build using Passive components is called as **Passive Circuit**.
- Even if it contains a power source, the circuit does not extract any power.
- Additional Power is not added to the output and hence output power is always less than the input power applied.
- The power gain will always be less than unity.

Types of Resistors:

Resistors are available in different size, Shapes and materials. We will discuss all possible resistor types one by one in detail.

There are two basic types of resistors.

- **Linear Resistors**
- **Non Linear Resistors**

Linear Resistors:

Those resistors, whose values change with the applied voltage and temperature, are called linear resistors. In other words, a resistor, whose 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.

- **Fixed Resistors**
- **Variable Resistors**

Fixed Resistors

As the name tells everything, fixed resistor is a resistor which has a specific value and we can't change the value of fixed resistors.

Types of Fixed resistors.

- **Carbon Composition Resistors**
- **Wire Wound Resistors**
- **Thin Film Resistors**
- **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.

Characteristic of Fixed Resistors

Generally, they are very cheap and small in size, hence, occupy less space. They are reliable and available in different ohmic and power ratings. Also, fixed resistor can be easily connected to the circuit and withstand for more voltage.In other hand, they are less stable means their temperature coefficient is very high. Also, they make a slight noise as compared to other types of resistors.

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 equipments 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.In addition, the power rating of a high power wire wound resistor is 500 Watts and the available resistance value of these resistors are is 0.1 ohm – 100k Ohms.

Advantages and Disadvantage of Wire wound Resistors

Wire wound resistors make lower noise than carbon composition resistors. Their performance is well in overload conditions. They are reliable and flexible and can be used with DC and Audio frequency range. Disadvantage of wire wound resistor is that they are costly and can't be used in high frequency equipments.

Application of Wire Wound Resistors

Wire wound resistors used where high sensitivity, accurate measurement and balanced current control is required, e.g. as a shunt with ampere meter. Moreover, Wire wound resistors are generally used in high power rating devices and equipments, Testing and measuring devices, industries, and control equipments.

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.

- **Carbon Film Resistors**
- **Metal Film Resistors**

Carbon Film Resistors

Carbon Film resistors contains 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.

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.

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.

- **Metal Oxide Resistors**
- **Cermet Film Resistors**
- **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.

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 are 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

As the name indicates, these are resistors whose values can be changed through a dial, knob, and screw or manually by a proper method. In these types of resistors, there is a sliding arm, which is connected to the shaft and the value of resistance can be changed by rotating the arm. They are used in the radio receiver for volume control and tone control resistance.

Following are the further types of Variable Resistors

- **Potentiometers**
- **Rheostats**
- **Trimmers**

Potentiometers

Potentiometer is a three terminal device which is used for controlling the level of voltage in the circuit. The resistance between two external terminals is constant while the third terminal is connected with moving contact (Wiper) which is variable. The value of resistance can be changed by rotating the wiper which is connected to the control shaft.

Potentiometer Construction

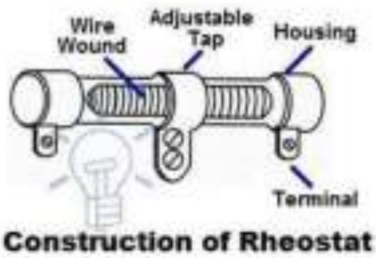
This way, Potentiometers can be used as a voltage divider and these resistors are called variable composition resistors. They are available up to 10 Mega Ohms.

Different Types of Potentiometers

Rheostats

Rheostats are a two or three terminal device which is used for the current limiting purpose by hand or manual operation. Rheostats are also known as **tapped resistors** or **variable wire wound resistors**.

To make a rheostat, they wire wind the Nichrome resistance around a ceramic core and then assembled in a protective shell. A metal band is wrapped around the resistor element and it can be used as a Potentiometer or Rheostats (See the below note for **difference between Rheostat and Potentiometer**).



Variable **wire wound resistors** are available in the range of 1 ohm up to 150 Ohms. The available power rating of these resistors is 3 to 200 Watts. While the most used Rheostats according to power rating is between 5 to 50 Watts.

What is the main Difference between Potentiometer and Rheostats?

Basically, there is no difference between Potentiometer and Rheostat. Both are variable resistors. The main difference is the use and circuit operation, i.e. for which purpose we use that variable resistor.For example, if we connect a circuit between resistor element terminals (where one terminal is a general end of the resistor element while the other one is sliding contact or wiper) as a variable resistor for controlling the circuit current, then it is Rheostats.On the other hand, if we do the same as mentioned above for controlling the level of voltage, then this variable resistor would be called a potentiometer.

Trimmers

There is an additional screw with Potentiometer or variable resistors for better efficiency and operation and they are known as Trimmers. The value of resistance can be changed by changing the position of screw to rotate by a small screwdriver.

Trimmer Construction

They are made from carbon composition, carbon film, cermet and wire materials and available in the range of 50 Ohms up to 5 mega ohms. The power rating of Trimmers potentiometers are from 1/3 to ¾ Watts.

Non Linear Resistors

We know that, nonlinear resistors are those resistors, where the current flowing through it does not change according to Ohm's Law but, changes with change in temperature or applied voltage.

In addition, if the flowing current through a resistor changes with change in body temperature, then these kinds of resistors are called Thermisters. If the flowing current through a resistor change with the applied voltages, then it is called a Varistors or VDR (Voltage Dependent Resistors).

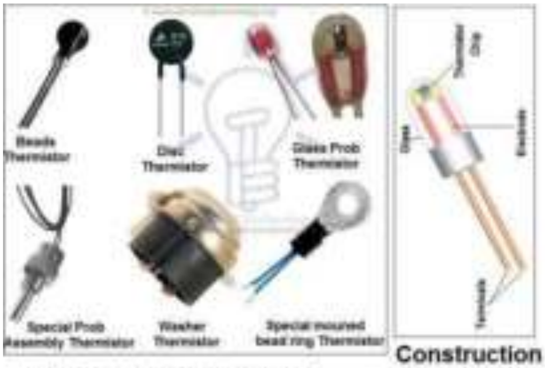
Following are the additional types of Non Linear Resistors.

- **Thermisters**
- **Varisters (VDR)**
- **Photo Resistor or Photo Conductive Cell or LDR**

Thermisters

Thermister is a two terminal device which is very sensitive to temperature. In other words, Thermister is a type of variable resistor which notices the change in temperature. Thermisters are made from the cobalt, Nickel, Strontium and the metal oxides of Manganese. The Resistance of a

Thermister is inversely proportional to the temperature, i.e. resistance increases when temperature decrease and vice versa.



Types of Thermistor Construction of Thermistor

It means, Thermisteres has a negative temperature coefficient (NTC) but there is also a PTC (Positive Temperature Coefficient) which is made from barium titanate semiconductor materials and their resistance increases with increase in temperature.

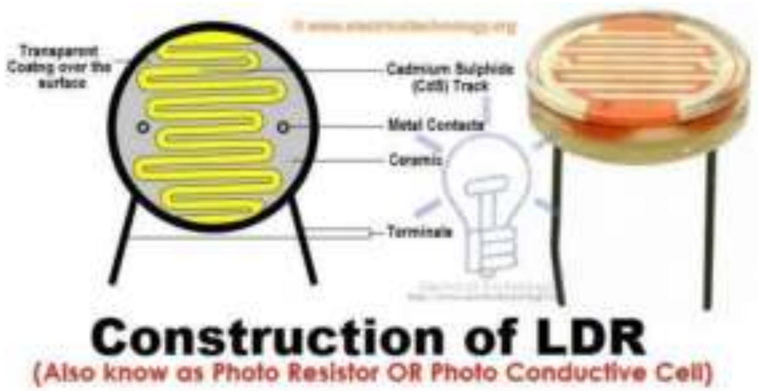
Varisters (VDR)

Varisters are voltage dependent Resistors (VDR) which is used to eliminate the high voltage transients. In other words, a special type of variable resistors used to protect circuits from destructive voltage spikes is called varisters. When voltage increases (due to lighting or line faults) across a connected sensitive device or system, then it reduces the level of voltage to a secure level i.e. it changes the level of voltages.

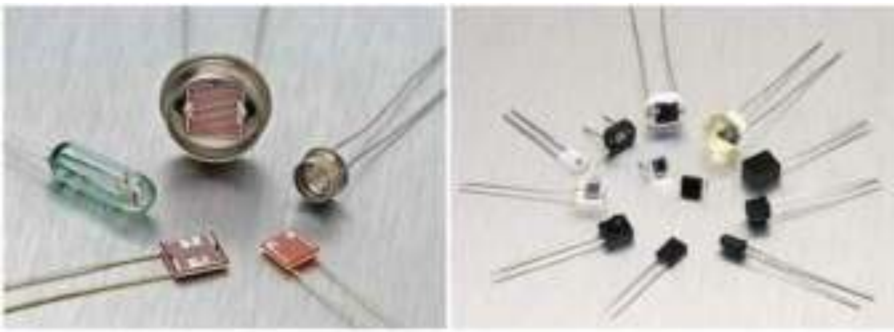
Types of Varister

Photo Resistor or Photo Conductive Cell or LDR (Light Dependent Resistors)

Photo Resistor or LDR (Light Dependent Resistors) is a resistor whose terminal value of resistance changes with light intensity. In other words, those resistors, whose resistance values changes with the falling light on their surface is called Photo Resistor or Photo Conductive Cell or LDR (Light Dependent Resistor). The material which is used to make these kinds of resistors is called photo conductors, e.g. cadmium sulfide, lead sulfide etc.



When light falls on the photoconductive cells (LDR or Photo resistor), then there is an increase in the free carriers (electron hole pairs) due to light energy, which reduce the resistance of semiconductor material (i.e. the quantity of light energy is inversely proportional to the semiconductor material). It means photo resistors have a negative temperature coefficient.



Application and Uses of Photo Resistors/Photo Conductive Cells or LDR

These types of resistors are used in burglar alarm, Door Openers, Flame detectors, Smock detectors, light meters, light activated relay control circuits, industrial, and commercial automatic street light control and photographic devices and equipments.

Application of Resistors

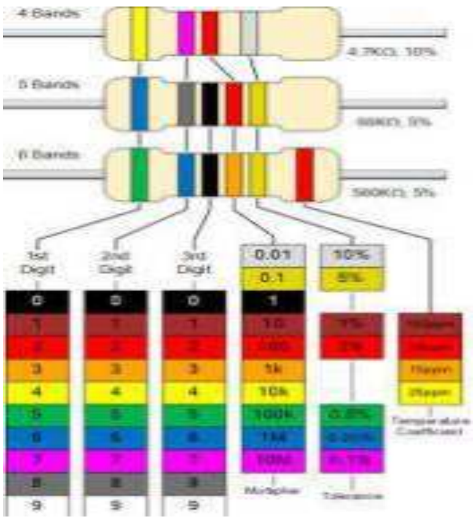
Practically, both types of resistors (Fixed and Variable) are generally used for the following purposes.

Resistors are used:

- For Current control and limiting
- To change electrical energy in the form of heat energy
- As a shunt in Ampere meters
- As a multiplier in a Voltmeter
- To control temperature
- To control voltage or Drop
- For protection purposes, e.g. Fusible Resistors
- In laboratories
- In home electrical appliances like heater, iron, immersion rod etc.
- Widely used in the electronics industries

Types of Resistors Color Code Calculation

To find out the color code of a resistor, here is a standard mnemonic: B B Roy of Great Britain has a Very Good Wife (BBRGBVGW). This sequence color code helps to find the resistor value by seeing colors on resistors.



4 Bands Resistor Color Code Calculation

In the above 4 bands resistor:

- The first digit or band indicates, a first significant figure of a component.
- The second digit indicates, a second significant figure of a component.
- The third digit indicates the decimal multiplier.
- The fourth digit indicates the tolerance of value in percentage.

To calculate the color code of the above 4 band resistor, the 4-band resistors consist of colors: yellow, violet, orange, and silver.

Yellow-4, violet-7, orange-3, silver –10% based on BBRGBVGW
The color code value of the above resistor is 47×10^3 =4.7Kilo Ohms, 10%.

5 Bands Resistor Color Code Calculation

In the above 5 bands resistors, the first three colors indicate significant values, and the fourth and fifth colors indicate multiplying and tolerance values.

To calculate the color code of the above 5 band resistor, 5 band resistors consist of colors: blue, grey, black, orange, and gold.

Blue- 6, Grey- 8, Black- 0, Orange- 3, Gold- 5%
The color code value of the above resistor is 68×10^3 = 6.8Kilo Ohms, 5%.

6 Bands Resistor Color Code Calculation

In the above 6 bands resistors, the first three colors indicate significant values; the Fourth color indicates multiplying factor, the fifth color indicates tolerance and the sixth indicates TCR.

To calculate the color code of the above 6 color-band resistors,
6 band resistors consist of colors: green, blue, black, yellow, gold, and orange.

Green-5, blue-6, Black-0, yellow-4, Orange-3

The color code value of the above resistor is 56×10^4 =560Kilo Ohms, 5%.This is all about color-code identification for resistance values.

Resistor Power Rating

Resistors are used for many applications in a circuit. But all resistors are not suitable for all the applications. Resistors are selected using different parameters.Resistor color codes helps to read resistance, tolerance and voltage. Other than these three values, there is another important parameter required, for using the resistor in a circuit. This is power rating of a resistor.It is very important to use correct power rated resistor in the circuit to prevent the circuit from damaging.

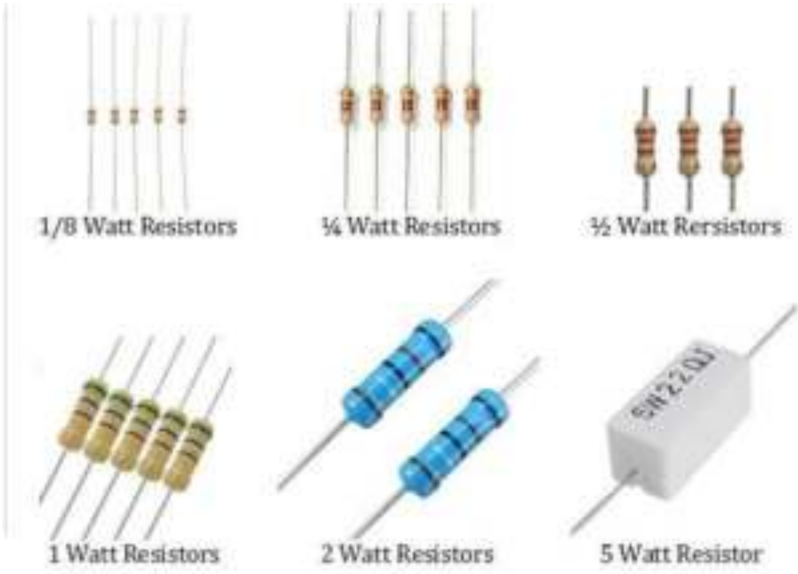
What is the meaning of power rating?

- Resistor power rating can be defined as the maximum power a resistor can handle safely without any damage.
- We know that, resistor dissipates the excess energy in form of heat. Power rating indicates the maximum heat a resistor can dissipate safely.
- Increasing the power more for few percent than rating, will burn the resistor.

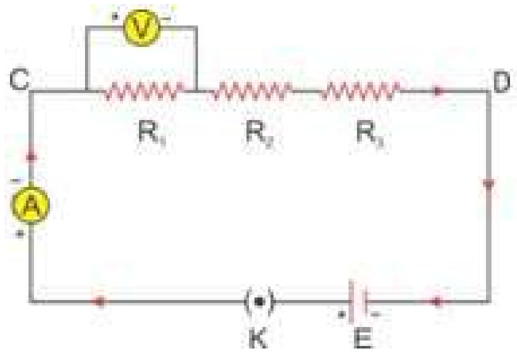
How resistors are rated?

- The resistor power rating is rated in watts, which are units of power. Hence it is also termed as wattage.
- Generally, larger the resistor more power it can handle.
- As the wattage of the resistor increases cost also increases.
- Resistors generally start from 1/8th watt to many kilo watts. Resistor wattage can be noticed by seeing the size of the resistor.

Resistors with high wattage are called power resistors. Below is the figure showing resistors with their wattage.



Expression for the resistors in series:



R_1, R_2 and R_3 are the three resistors connected in series between points C and D as shown. I is the current and V is the PD across points C and D.Then Rs is the effective resistance in a circuit and V_1, V_2 and V_3 are the potentials across the three resistors such that

$V = V_1 + V_2 + V_3$ ---- (1)

Using Ohm's law, the total potential difference

$V = I\,Rs$

and $V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$

Substituting these values in equation 1, we get

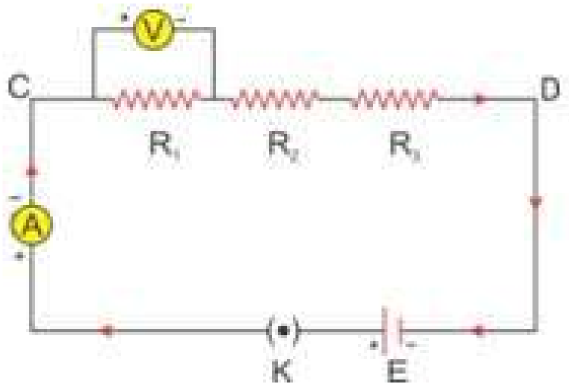
$IR_S = IR_1 + IR_2 + IR_3$

$\therefore R_S = R_1 + R_2 + R_3$

For n number of resistors connected in series,

$R_S = R_1 + R_2 + R_3 + R_4 + \text{-----} + R_n$

Expression for the resistors in parallel:



R_1, R_2 and R_3 are the three resistors connected in parallel between points C and D as shown in the figure.Let I_1, I_2 and I_3 be the currents passing through R_1, R_2 and R_3, respectively.

Let V be the potential difference between points C and D. The current I will be given by

$I = I_1 + I_2 + I_3$ ----- (1)

Let R_P be the effective resistance in the circuit.

Using Ohm's law, we get

$I_1 = \frac{V}{R_1},\ I_2 = \frac{V}{R_2},\ I_3 = \frac{V}{R_3}$ and $I = \frac{V}{R_P}$

Putting these values in equation 1, we get

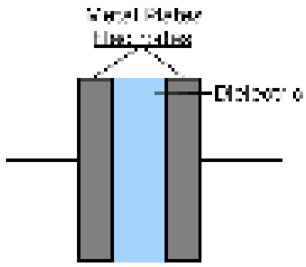
$$\frac{V}{R_P} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\therefore \frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

For n number of resistors connected in parallel, we get $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots\ldots + \frac{1}{R_n}$

Capacitor:

A capacitor is a two-terminal passive electronic component that stores charge in an electric field between its metal plates. it is made up of two metal plates (electrodes) separated by an insulator known as the **dielectric**.



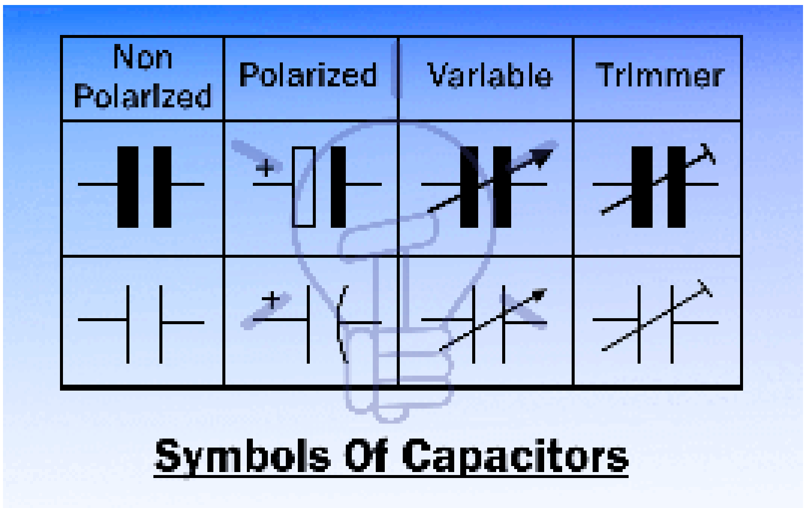
Capacitor

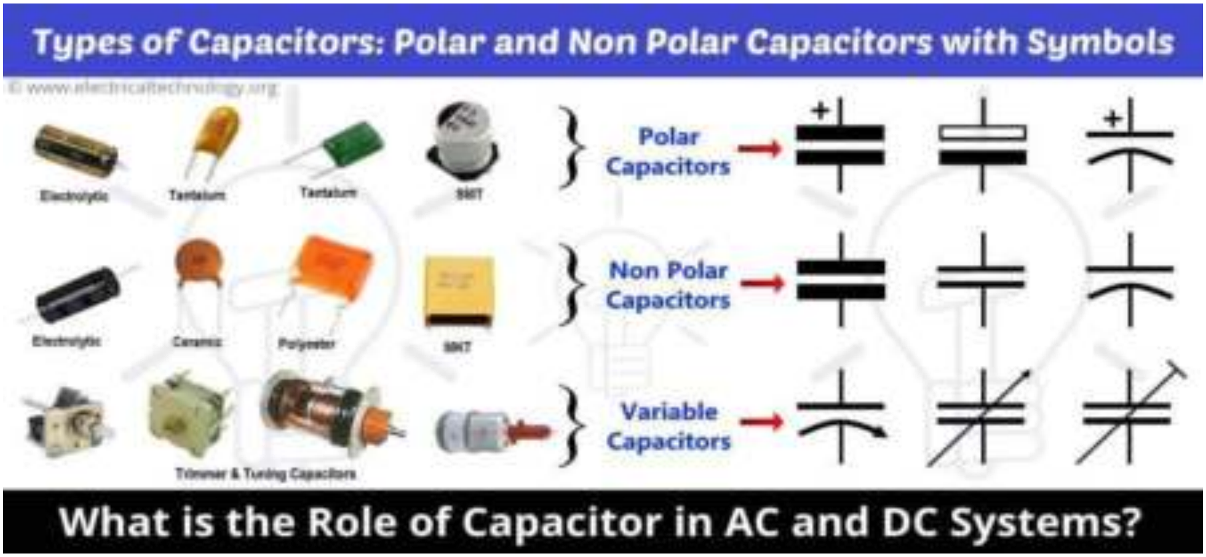
Capacitance

The **capacitance** is the ability of a capacitor to store charge in its metal plates (Electrodes). Its unit is **Farad F**.**One Farad** is the amount of capacitance when a charge of **one-coulomb** causes the potential difference of **one volt** across its terminals. The capacitance is always positive, it cannot be negative.

Symbols Of Different Types Of Capacitors

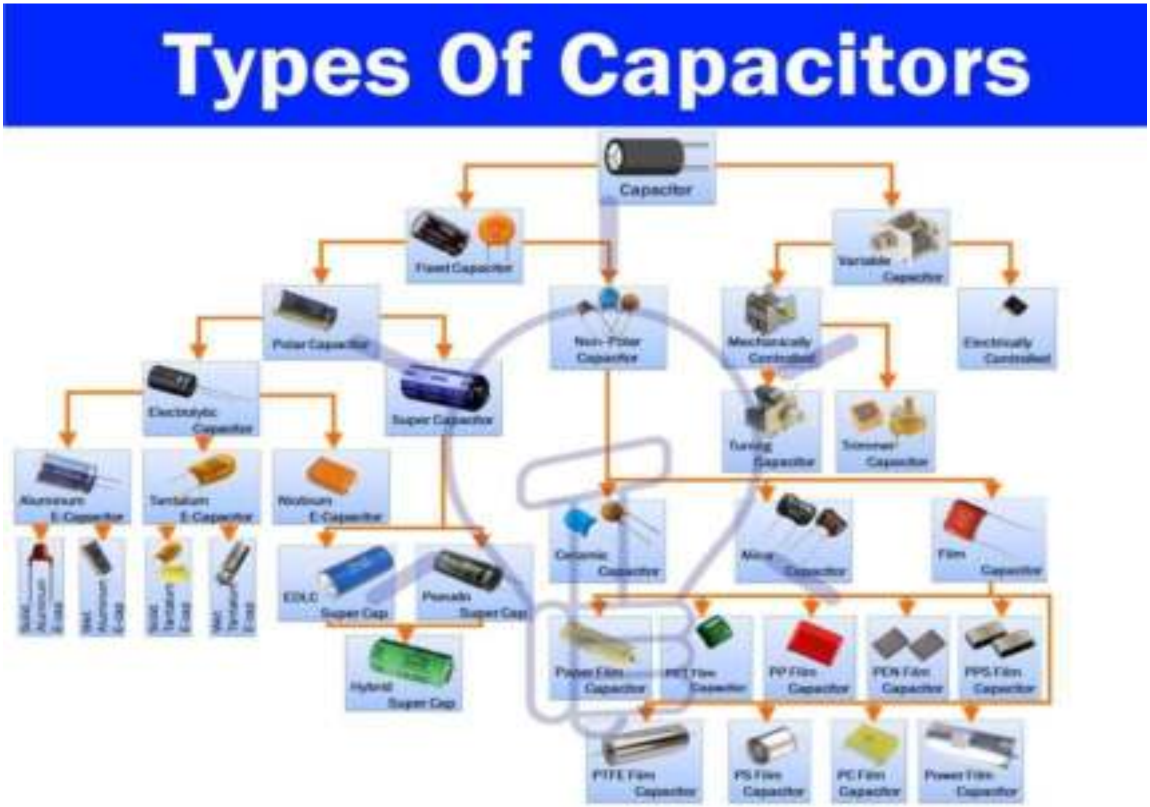
Symbols of different Types of capacitors & its alternative symbols are given below.





Types Of Capacitors

There are different types of Capacitors classified on the basis of their sizes, shapes & materials. Different types of capacitors are given below with details.



The two main types of capacitors are **fixed capacitors** and **variable capacitors**.

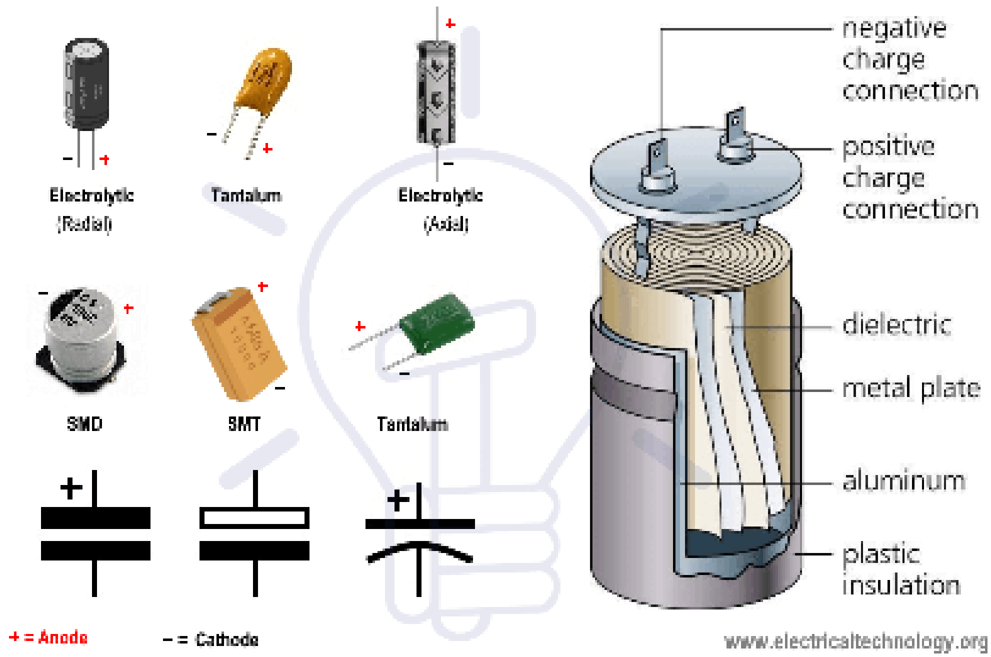
1) Fixed Capacitors:

As the name suggests, the fixed capacitor has a fixed capacitance value. It cannot be changed. Fixed capacitors are further divided into two types i.e.

1. *PolarCapacitors*
2. *Non-polar Capacitors*

Polar Capacitors:

Polar capacitors or **polarized capacitors** are such type of a capacitor whose terminals (electrodes) have polarity; positive and negative.The positive terminal should be connected to positive of supply and negative to negative. Reversing the polarity will destroy the capacitor. These type of capacitors are only used in **DC** applications.



Polar Capacitor Construction, Symbols & Terminal Identification

Polar capacitors are further classified into two types:

1.ElectrolyticCapacitors

2. Supercapacitors

Electrolytic Capacitors:

An electrolytic capacitor is a type of polar capacitor that uses an electrolyte as one of its electrodes to maintain heavy charge storage. It is made up of two metal plates whose positive (anode) plate is covered with an insulating oxide layer through **anodization**. This insulating layer acts as the dielectric. The electrolyte is used as the second terminal cathode. The electrolytes can be solid, liquid or gas type material.Such Types of capacitors have a high capacitance value ranging from **1 µF** to **47000 µF**. They are only used in **DC** circuits.

The electrolytic capacitors are classified into three families

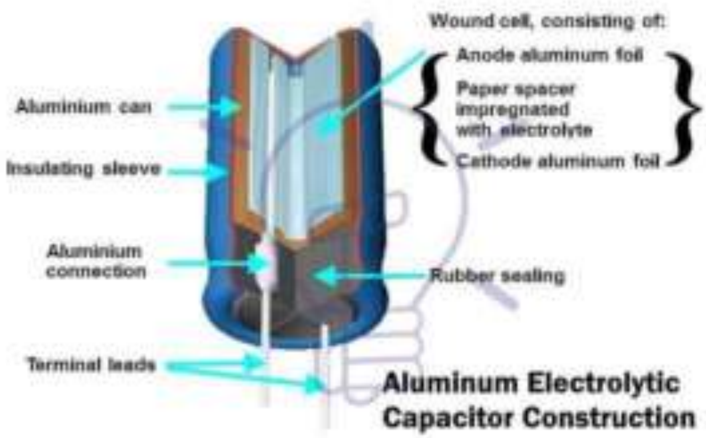
1. AluminumElectrolyticCapacitors

2. TantalumElectrolytic Capacitors

3. Niobium Electrolytic Capacitors

1) Aluminum Electrolytic Capacitors

In the aluminum Electrolytic capacitor, the electrodes used are made of pure aluminum. However, the anode (positive) electrode is made by forming an insulating layer of aluminum oxide (**Al_2O_3**) through anodization. The electrolyte (solid or non-solid) is placed on the insulating surface of the anode. This electrolyte technically acts as the cathode. The second aluminum electrode is placed on top of electrolyte which acts as its electrical connection to the negative terminal of the capacitor.



Aluminum Electrolytic Capacitor Construction

Depending on its electrolyte, they are divided into two sub-types

1. Non-Solid or Wet Aluminum Electrolytic Capacitors

2. Solid Aluminum Electrolytic Capacitors (SAL's)

Non-Solid Aluminum Electrolytic Capacitors

Non-solid aluminum electrolytic capacitors use liquid or gel electrolyte. They are made of two foils of aluminum with a paper in between which is impregnated with a liquid or gel-like electrolyte. The anode aluminum foil is oxidized to form (**AL_2O_3**) dielectric. The cathode foil serves the purpose of electrical contact for the electrolyte. Although, the cathode foil has a natural oxide layer formed by air which increases its capacitance.

Non-Solid Aluminum Electrolytic Capacitor

Advantages And Disadvantages

Advantages

- Inexpensive
- Self-healing mechanism, it forms a new oxide form after applying voltage.

Disadvantages

- Due to evaporation, dry out over time reducing health.
- ESR increases with time.
- Only used in DC circuits.
- They are sensitive to mechanical stress.

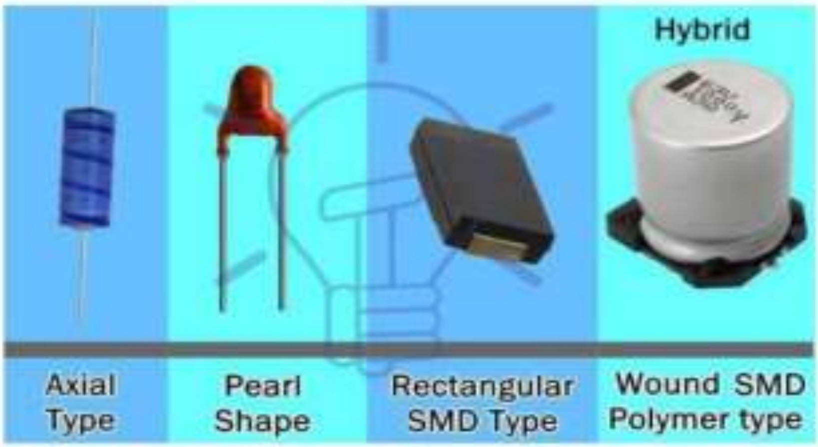
Application

- Power factor correction.
- Flash capacitor for a camera.
- I/O filters in AC power supplies
- Coupling, decoupling.

Solid Aluminum Electrolytic Capacitors (SAL's)

SAL has the same construction design as wet electrolytic capacitor except they use solid electrolytes like;

- **Manganese dioxide** (MnO_2)
- **Polymer electrolyte**
- **Hybrid electrolytes** (solid polymer with liquid)



Solid Aluminum Electrolytic Capacitors

The electrolyte is sandwiched between two foils of aluminum after anodization of anode foil. They are then folded together for **pearl style** or wound for **the radial style**.

Advantages And Disadvantages

Advantages

- Due to its dry nature of electrolyte, there is no evaporation
- They have longer life-span
- They have low ESR

Disadvantages

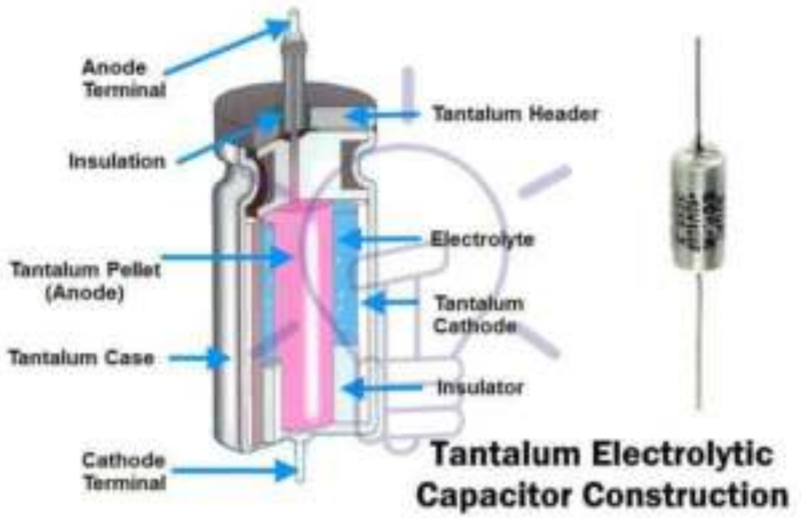
- They are expensive
- No self-healing mechanism except hybrid polymer capacitor

Applications

Their application uses are similar to a non-solid electrolytic capacitor.

2) Tantalum Electrolytic Capacitors

Such type of electrolytic capacitor uses **tantalum metal** as an anode electrode. Tantalum pallet is oxidized to form an insulating layer of oxide that acts as the dielectric. This pallet is dipped into an electrolyte (solid or liquid). The electrolyte acts as a cathode. However, a layer of **graphite and silver** is coated on top of the electrolyte for cathode electrical connection.



Due to its thin oxide layer, tantalum capacitors have a high capacitance per volume as compared to other electrolytic capacitors. They are smaller in size.Depending on the state of its electrolyte, they are classified into two subfamilies

1. Wet or Non-Solid Tantalum Electrolytic Capacitors

2. Solid Electrolytic Capacitors

Wet or Non-Solid Tantalum Electrolytic Capacitors

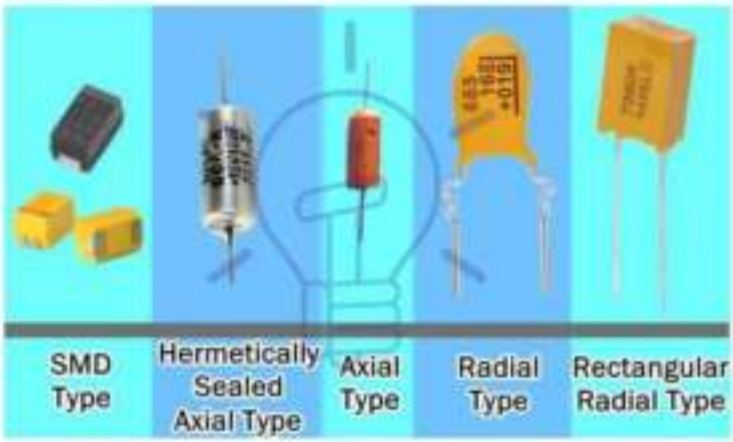
Wet tantalum capacitor uses liquid electrolyte such as **sulphuric acid** because the tantalum oxide layer is inert and stable. These capacitors operate on relatively high voltages up to **630 v** with lowest leakage current compared to other electrolytic capacitors.

Non-Solid Tantalum Electrolytic Capacitor

Solid Tantalum Electrolytic Capacitors

Solid tantalum capacitor uses solid electrolytes such as manganese dioxide (MnO_2) or polymer.

Molded-Case Tantalum Caps



Solid Tantalum Electrolytic Capacitors

MnO_2 electrolytes have high stability whereas polymer electrolytes conductivity deteriorates with time.

Applications Of Tantalum Capacitor

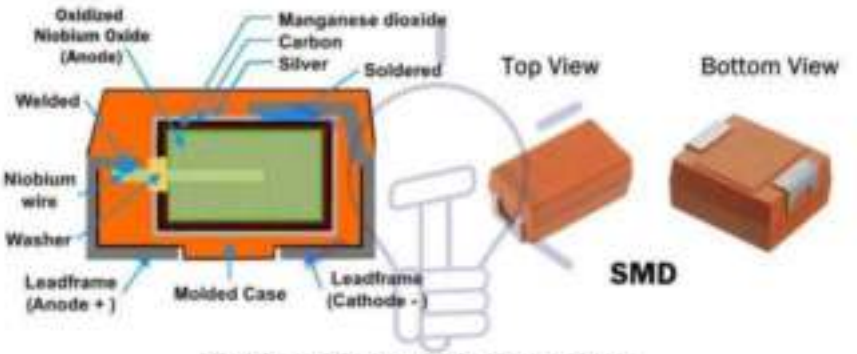
- Due to high capacitance per volume, it can replace aluminum electrolytic capacitor where temperature increases due to the dense packing of components.
- They are used in medical electronics for its high-quality results.
- Due to its low leakage current, they are used in **sample & hold** circuits.
- Most common application is filtering in computer power supplies due to its small size and reliability.

Advantages And Disadvantages

- They are available in small size and high capacitance.
- It is very stable and reliable, thus having longer life-span.
- It can operate on a wide range of temperature from **-55° C** to **+125° C**.
- They are expensive.
- They cannot tolerate reverse voltages.

Niobium Electrolytic Capacitors

In niobium electrolytic capacitor the anode is made of **niobium metal** (Niobium monoxide). It is oxidized through anodization to form an insulating layer of **niobium pentoxide**. This layer acts as the dielectric.

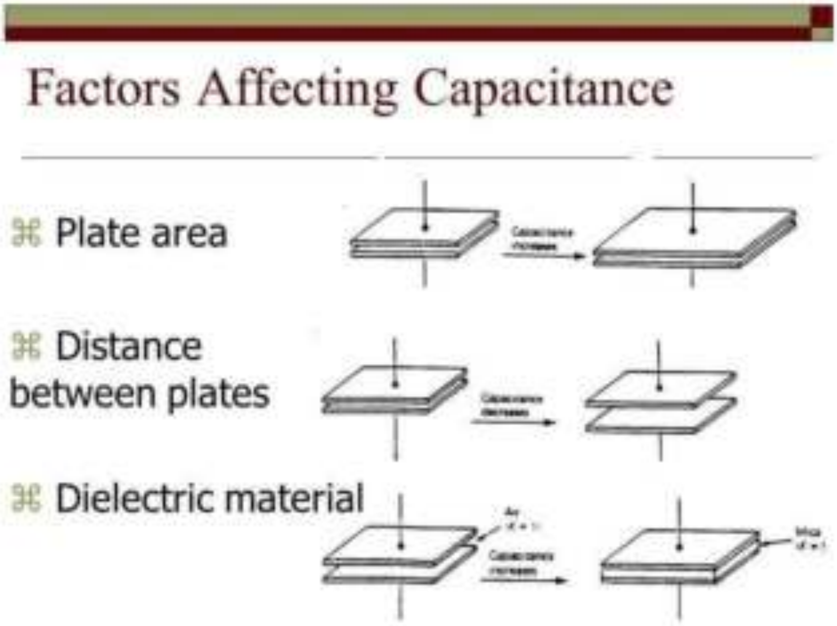


Niobium Electrolytic Capacitor

The electrolyte used in niobium electrolytic capacitor is **solid** i.e. either **manganese dioxide** or **polymer** electrolyte. This electrolyte covers the surface of the anode. The electrolyte acts as the cathode.A graphite and silver layer is placed on top of the electrolyte for electrical contact of cathode terminal.

Factors affecting the capacitance of a parallel-plate capacitor

The factors which affect the capacitance of a parallel-plate capacitor are:



- Overlapping area of the plates (A). The capacitance increases as the area of overlap increases since a larger plate area provides more room to accommodate the increase charge.
- Distance between the plates (d). The capacitance increases as the distance between the plates decreases, since the electric field then becomes more concentrated.
- Material between the plates. This introduces a constant called the absolute permittivity (ε). The constant ε is actually the product of two constants, the permittivity of space (ε_o) which has a value of 885 x 10^{-12} Fm^{-1} and the relative permittivity (ε_r), which is basically a multiplication factor (no units) that indicates how many more times the material is able to concentrate the electric flux compared with space. For example, if waxed paper is inserted between the plates instead of air, the ability to concentrate a flux (the permittivity) is multiplied by approximately 3, therefore the relative permittivity (ε_r) of waxed paper is approximately 3.

We may summarise this in equation form as:

$$C = \varepsilon A/d$$

Voltage Rating on a Capacitor

The voltage rating on a capacitor is the maximum amount of voltage that a capacitor can safely be exposed to and can store.Capacitors are storage devices. They hold a certain size charge (1µF, 100µF, 1000µF, etc.) at a certain voltage (10V, 25V, 50V, etc.). So when choosing a capacitor you just need to know what size charge you want and at which voltage.

Capacitor in different voltage ratings

Because you may need different voltages for a circuit depending on what circuit you're dealing with. Remember, capacitors supply voltage to a circuit just like a battery does. The only difference is a capacitor discharges its voltage much quicker than a battery, but it's the same concept in how they both supply voltage to a circuit. A circuit designer wouldn't just use any voltage for a circuit but a specific voltage which is needed for the circuit. For one circuit, 12 volts may be needed. A capacitor with a 12V rating or higher would be used in this case. In another, 50 volts may be needed. A capacitor with a 50V rating or higher would be used. This is why capacitors come in different voltage ratings, so that they can supply circuits with different voltages, fitting the power (voltage) needs of the circuit.

Take note that a capacitor's voltage rating is not the voltage that the capacitor will charge up to, but only the maximum amount of voltage that a capacitor should be exposed to and can store safely.

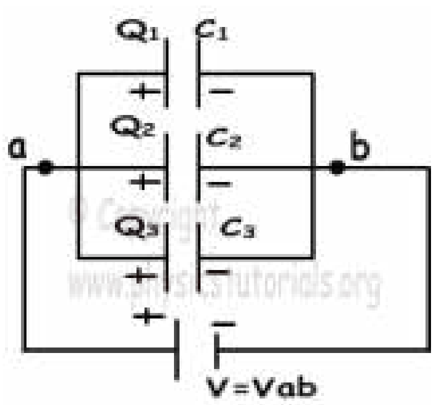
For the capacitor to charge up to the desired voltage, the circuit designer must design the circuit specificially for the capacitor to charge up to that voltage. A capacitor may have a 50-volt rating but it will not charge up to 50 volts unless it is fed 50 volts from a DC power source. The voltage rating is only the maximum voltage that a capacitor should be exposed to, not the voltage that the capacitor will charge up to. A capacitor will only charge to a specific voltage level if fed that level of voltage from a DC power source.

A good rule for choosing the voltage ratings for capacitors is not to choose the exact voltage rating that the power supply will supply it. It is normally recommended to give a good amount of room when choosing the voltage rating of a capacitor. Meaning, if you want a capacitor to hold 25 volts, don't choose exactly a 25 volt-rated capacitor. Leave some room for a safety margin just in case the power supply voltage ever increased due to any reasons. If you measured the voltage of a 9V battery supply, you would notice that it reads above 9 volts when it's new and has full life. If you used an exact 9-volt rated capacitor, it would be exposed to a higher voltage than the maximum specified voltage (the voltage rating). Usually, in a case such as this, it shouldn't be a problem, but nevertheless, it's a good safety margin and engineering practice to do this. It will be wrong choosing a higher voltage-rated capacitor than the voltage that the power supply will supply it, but can definitely go wrong choosing a lower voltage-rated capacitor than the voltage that it will be exposed to. If you charge up a capacitor with a lower voltage rating than the voltage that the power supply will supply it, you risk the chance of the capacitor exploding and becoming defective and unusable. So don't expose a capacitor to a higher voltage than its voltage rating. The voltage rating is the **maximum** voltage that a capacitor is meant to be exposed to and can store. Some say a good engineering practice is to choose a capacitor that has double the voltage rating than the power supply voltage you will use to charge it. So if a capacitor is going to be exposed to 25 volts, to be on the safe side, it's best to use a 50 volt-rated capacitor.

Also, note that the voltage rating of a capacitor is also referred to at times as the working voltage or maximum working voltage (of the capacitor). So when seeing the (maximum) working voltage specification on a datasheet, this value refers to the maximum continuous voltage that a capacitor can withstand without becoming damaged.

Capacitors in Series and Parallel

Systems including capacitors more than one has equivalent capacitance. Capacitors can be connected to each other in two ways. They can be connected in series and in parallel. We will see capacitors in parallel first.In this circuit capacitors are connected in parallel.



Because, left hand sides of the capacitors are connected to the potential a, and right hand sides of the capacitors are connected to the potential b. In other words we can say that each capacitor has same potential difference. We find the charge of each capacitor as;

$\mathbf{Q_1=C_1.V}$

$\mathbf{Q_2=C_2.V}$

$\mathbf{Q_3=C_3.V}$

Total charge of the system is found by adding up each charge.

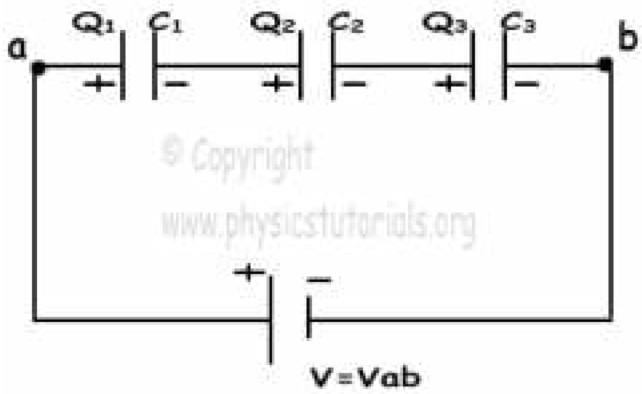
$\mathbf{Q_{total}=C_{eq}.V}$

$\mathbf{Q_{total}= Q_1+Q_2+Q_3=C_1.V+C_2.V+C_3.V=V.(C_1+C_2+C_3)=C_{eq}}$

$\mathbf{C_{eq}=C_1+C_2+C_3}$

As you can see, we found the equivalent capacitance of the system as $C_1+C_2+C_3$

Now we will see the capacitors in series;



In capacitors in series, each capacitor has same charge flow from battery. In this circuit, +Q charge flows from the positive part of the battery to the left plate of the first capacitor and it attracts –Q charge on the right plate, with the same idea, -Q charge flows from the battery to the right plate of the third capacitor and it attracts +Q on the left plate. Other capacitors are also charged with same way. To sum up we can say that each capacitor has same charge with batter.

$C_1.V_1=Q$

$C_2.V_2=Q$, $V=V_1+V_2+V_3$ and $Q=C_{eq}.V$

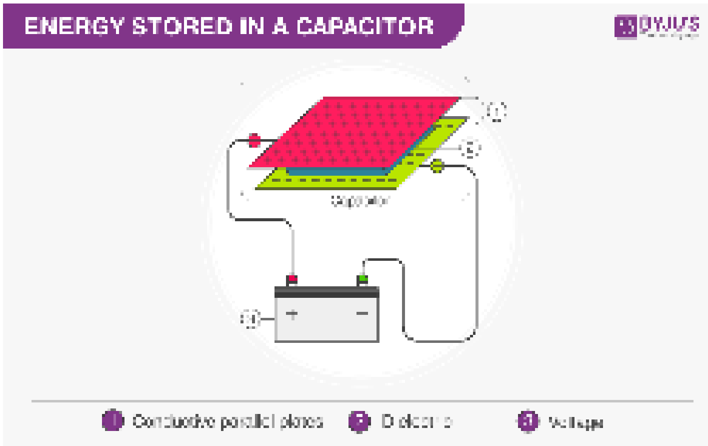
$C_3.V_3=Q$

$$\frac{Q}{C_{eq}}=\frac{Q}{C_1}+\frac{Q}{C_2}+\frac{Q}{C_3}=Q\left(\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}\right)$$

Equivalent Capacitance becomes;

$$\frac{1}{C_{eq}}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}$$

Energy stored in a capacitor



The energy stored in a capacitor is nothing but the electric potential energy and is related to the voltage and charge on the capacitor. If the capacitance of a conductor is C, then it is initially uncharged and it acquires a potential difference V when connected to a battery. If q is the charge on the plate at that time, then

$q=CV$

The work done is equal to the product of the potential and charge. Hence, $W = Vq$

If the battery delivers a small amount of charge dQ at a constant potential V, then the work done is

$dW=Vdq=q/Cdq$

Now, the total work done in delivering a charge of an amount q to the capacitor is given by

$W=\int q/Cdq=1/C[q^2/2]=1/2[q^2/C]$

Therefore the energy stored in a capacitor is given by

$U=1/2[q^2/C]$

Substituting q=CV in the equation above, we get

$U=1/2\ [CV]^2$

The energy stored in a capacitor is given by the equation $U=1/2[CV]^2$.

Example: If the capacitance of a capacitor is 50 F charged to a potential of 100 V, Calculate the energy stored in it.

Solution:

We have a capacitor of capacitance 50 F that is charged to a potential of 100 V. The energy stored in the capacitor can be calculated as follows

$U=1/2[CV]^2$

Substituting the values, we get

$U=1/2[50(100)^2]=250\times10^3 J$

Applications of Capacitor Energy

Following are a few applications of capacitor energy:

- A defibrillator that is used to correct abnormal heart rhythm delivers a large charge in a short burst to a person's heart. Applying large shocks of electric current can stop the arrhythmia and allow the body's natural pacemaker to resume its normal rhythm. A defibrillator uses the energy stored in the capacitor.
- The audio equipment, uninterruptible power supplies, camera flashes, pulsed loads such as magnetic coils and lasers use the energy stored in the capacitors.
- Super capacitors are capable of storing a large amount of energy and can offer new technological possibilities.

UNIT - 2

Inductance

The property of an inductor to get the voltage induced by the change of current flow, is defined as Inductance. Inductance is the ratio of voltage to the rate of change of current.The rate of change of current produces change in the magnetic field, which induces an EMF in opposite direction to the voltage source. This property of induction of EMF is called as the **Inductance**.

The formula for inductance is

Inductance = voltage / rate of change of current

Units −

- The unit of Inductance is **Henry**. It is indicated by **L**.
- The inductors are mostly available in mH (milli Henry) and μH (microHenry).

A coil is said to have an inductance of **one Henry** when an EMF of **one volt** is self-induced in the coil where the current flowing changed at a rate of **one ampere per second**.

Self-Inductance

If a coil is considered in which some current flows, it has some magnetic field, perpendicular to the current flow. When this current keeps on varying, the magnetic field also changes and this changing magnetic field, induces an EMF, opposite to the source voltage. This opposing EMF produced is the **self-induced voltage** and this method is called as **self-inductance**.

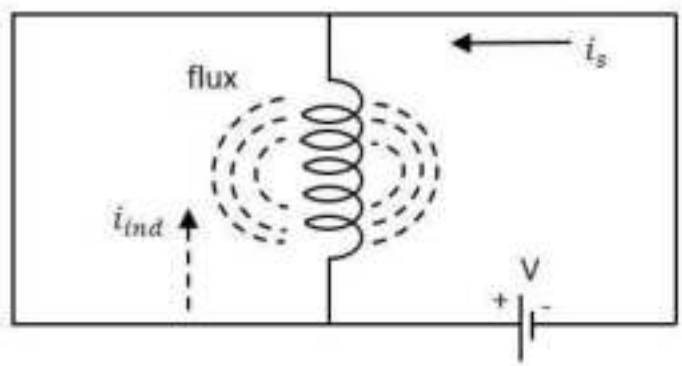


Image Showing Source Current, Magnetic field and Induced Current

The current $\mathbf{i_s}$ in the figure indicate the source current while $\mathbf{i_{ind}}$ indicates the induced current. The flux represents the magnetic flux created around the coil. With the application of voltage, the current $\mathbf{i_s}$ flows and flux gets created. When the current $\mathbf{i_s}$ varies, the flux gets varied producing $\mathbf{i_{ind}}$.This induced EMF across the coil is proportional to the rate of change in current. The higher the rate of change in current the higher the value of EMF induced.

We can write the above equation as

$E \alpha dI/dt$

$E=LdI/dt$

Where,

- **E** is the EMF produced
- **dI/dt** indicates the rate of change of current
- **L** indicates the co-efficient of inductance.

Self-inductance or Co-efficient of Self-inductance can be termed as

$L=EdI/dt$

The actual equation is written as

$E=-LdI/dt$

The minus in the above equation indicates that **the EMF is induced in opposite direction to the voltage source** according to Lenz's law.

Mutual Inductance

As the current carrying coil produces some magnetic field around it, if another coil is brought near this coil, such that it is in the magnetic flux region of the primary, then the varying magnetic flux induces an EMF in the second coil. If this first coil is called as **Primary coil**, the second one can be called as a **Secondary coil**.When the EMF is induced in the secondary coil due to the varying magnetic field of the primary coil, then such phenomenon is called as the **Mutual**

Inductance.

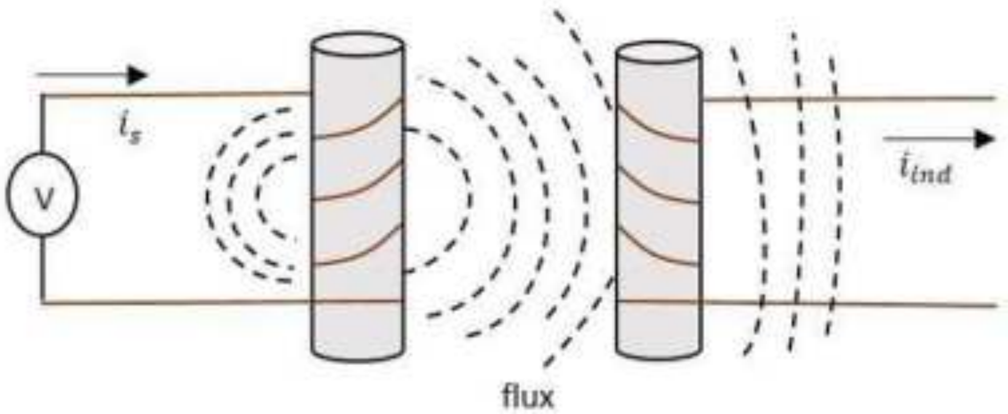


Image showing Mutual Inductance

The current $\mathbf{i_s}$ in the figure indicate the source current while $\mathbf{i_{ind}}$ indicates the induced current. The flux represents the magnetic flux created around the coil. This spreads to the secondary coil also.With the application of voltage, the current $\mathbf{i_s}$ flows and flux gets created. When the current $\mathbf{i_s}$ varies, the flux gets varied producing $\mathbf{i_{ind}}$ in the secondary coil, due to the Mutual inductance property.

The change took place like this.

$V_pI_p \rightarrow B \rightarrow V_sI_s$

Where,

- $\mathbf{V_p}$ $\mathbf{i_p}$ Indicate the Voltage and current in Primary coil respectively
- **B** Indicates Magnetic flux
- $\mathbf{V_s}$ $\mathbf{i_s}$ Indicate the Voltage and current in Secondary coil respectively

Mutual inductance **M** of the two circuits describes the amount of the voltage in the secondary induced by the changes in the current of the primary.

$V(\text{Secondary}) = -M\Delta I/\Delta t$

Where $\Delta I/\Delta t$ the rate of change of current with time and **M** is the co-efficient of Mutual inductance. The minus sign indicates the direction of current being opposite to the source.

Units −

The units of Mutual inductance isVolt=Mamps/sec

Fromtheaboveequation, M=volt.sec/amp=Henry(H)

Depending upon the number of turns of the primary and the secondary coils, the magnetic flux linkage and the amount of induced EMF varies. The number of turns in primary is denoted by N_1 and secondary by N_2. The co-efficient of coupling is the term that specifies the mutual inductance of the two coils.

Factors affecting Inductance

There are a few factors that affect the performance of an inductor. The major ones are discussed below.

Length of the coil

The length of the inductor coil is inversely proportional to the inductance of the coil. If the length of the coil is more, the inductance offered by that inductor gets less and vice versa.

Cross sectional area of the coil

The cross sectional area of the coil is directly proportional to the inductance of the coil. The higher the area of the coil, the higher the inductance will be.

Number of turns

With the number of turns, the coil affects the inductance directly. The value of inductance gets square to the number of turns the coil has. Hence the higher the number of turns, square of it will be the value of inductance of the coil.

Permeability of the core

The **permeability** μ of the core material of inductor indicates the support the core provides for the formation of a magnetic field within itself. The **higher** the permeability of the core material, the **higher** will be the inductance.

Coefficient of Coupling

This is an important factor to be known for calculating Mutual inductance of two coils. Let us consider two nearby coils of N_1 and N_2 turns respectively.The current through first coil i_1 produces some flux Ψ_1. The amount of magnetic flux linkages is understood by weber-turns.

Let the amount of magnetic flux linkage to the second coil, due to unit current of i_1 be

$N_2\varphi_1/i_1$

This can be understood as the Co-efficient of Mutual inductance, which means

$M=N_2\varphi_1/i_1$

Hence the Co-efficient of Mutual inductance between two coils or circuits is understood as the weber-turns in one coil due to 1A of current in the other coil.If the self-inductance of first coil is L_1, then$L_1i_1=N_1\varphi_1=>L_1/N_1\varphi_1/i_1$

$M=N_2L_1/N_1$

Similarly, coefficient of mutual inductance due to current i_2 in the second coil is

$M=N_1\varphi_2/i_2$⋯⋯⋯⋯(1)

If self-inductance of second coil is L_2

$L_2i_2=N_2\varphi_2$

$L_2N_2=\varphi_2i_2$Therefore,

$M=N_1L_2/N_2$⋯⋯⋯⋯2

Multiplying 1 and 2, we get

$M \times M = N_2 L_1/N_1 \times N_1 L_2/N_2$

$M^2 = L_1 L_2 \Rightarrow M = \sqrt{L_1 L_2}$

The above equation holds true when the whole changing flux of primary coil links with the secondary coil, which is an ideal case. But in practice, it is not the case. Hence, we can write as

$M \neq \sqrt{L_1 L_2}$

And$M/\sqrt{L_1 L_2} = K \neq 1$

Where K is known as the coefficient of coupling.

The **Coefficient of coupling K** can be defined as the ratio of actual coefficient of mutual inductance to the ideal maximum coefficient of mutual inductance.If the value of k is near to unity, then the coils are said to be tightly coupled and if the value of k = 0, then the coils are said to be loosely coupled.

Applications of Inductors

There are many applications of Inductors, such as −

- Inductors are used in filter circuits to sense high-frequency components and suppress noise signals
- To isolate the circuit from unwanted HF signals.
- Inductors are used in electrical circuits to form a transformer and isolate the circuits from spikes.
- Inductors are also used in motors.

Different types of Inductors

Inductors are available in different shapes and has different uses. Their sizes vary depending upon the material used to manufacture them. The main classification is done as fixed and variable inductors. An inductor of few Henries may be in a dumbbell shape at the size of a simple resistor.

A fixed inductor always has silver as its first color in color coding.The Core of the Inductor is its heart. There are many types of Inductors according to the core material used.

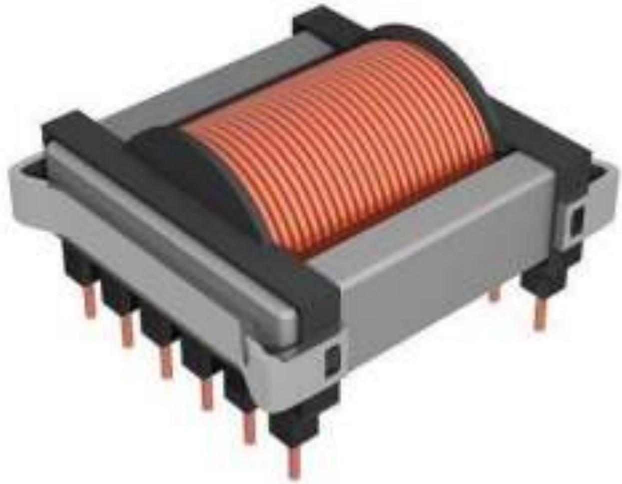
Air-core Inductor

The commonly seen inductor, with a simple winding is this air-Core Inductor. This has nothing but **air as the core** material. The non-magnetic materials like plastic and ceramic are also used as core materials and they also come under this air-core Inductors. The following image shows various air-core inductors.

These Inductors offer a minimum signal loss at the applications having a very high magnetic field strength. Also, there exists no core losses as there is no solid core material.

Iron-Core Inductor

These Inductors have Ferromagnetic materials, such as ferrite or iron, as the core material. The usage of such core materials helps in the increase of inductance, due to their high magnetic permeability. **Permeability** measures the ability of supporting the formation of magnetic fields within the materials. The following image shows how an Iron-core Inductor looks like −



The inductors that have ferromagnetic core materials just like these, suffer from core losses and energy losses at high frequencies. These Inductors are used in the manufacture of few types of transformers.

Toroidal Inductors

These Inductors have a magnetic material as the core substance to which the wire is wound. These are in circular ring shape, just as shown in the following figure.

The main advantage of this type of inductors is that, due to the circular shape, symmetry is achieved in the whole shape of the inductor, due to which there are minimum losses in the magnetic flux. These inductors are mostly used in AC circuit applications.

Laminated Core Inductors

These are the inductors that have laminated thin steel sheets, such as stacks, as the core materials. Usually for an inductor, if the loop area is increased for the current to travel, the energy losses will be more. Whereas, in these laminated core Inductors, thin steel sheets of stacks are helpful in blocking the eddy currents, which minimize the loop action.

The following figure shows an image of a laminated core inductor.

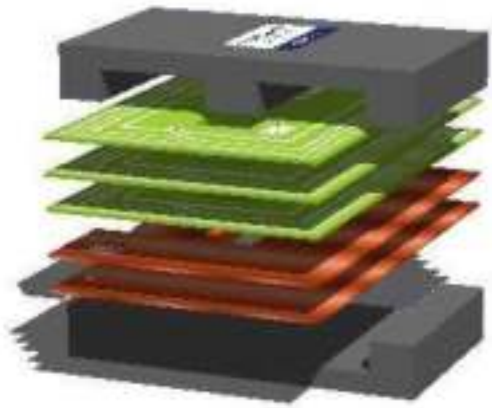


Figure showing Layers of Laminated sheets placed to manufature a Laminated core inductor

The main advantage of these inductors is minimizing the energy loss with its construction. These laminated core inductors are mostly used in the manufacture of transformers.

Powdered Iron Core Inductors

As the name implies, the core of these inductors have magnetic materials with some air gaps in it. But this kind of construction provides an advantage to the core, to store high level of energy compared with the other types. The following figure shows an image of a Powdered Iron core Inductor.

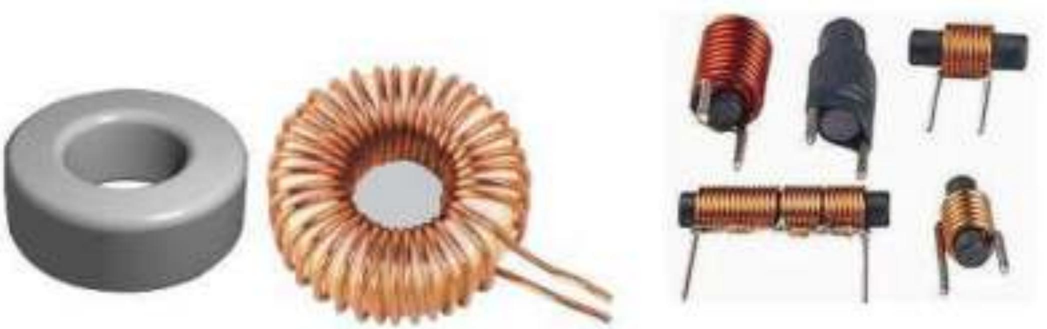
Property of an Inductor

According to the Faraday's law of Electromagnetic induction, When the current flowing through an inductor changes, the time-varying magnetic field induces a voltage in the conductor.

According to lens law, the direction of induced EMF opposes the change in current that created it. Hence, **induced EMF is opposite to the voltage** applied across the coil. This is the property of an inductor.

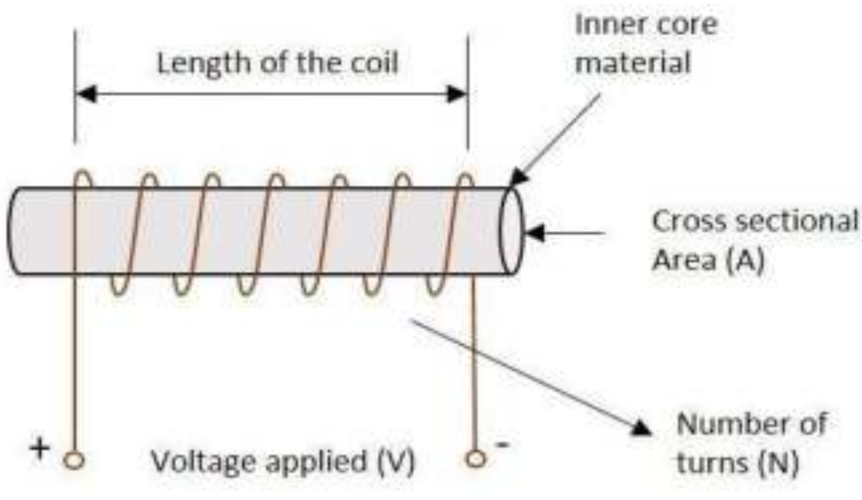
The following figure shows how an inductor looks like.

An inductor blocks any AC component present in a DC signal. The inductor is sometimes wrapped upon a core, for example a ferrite core. It then looks as in the figure below.



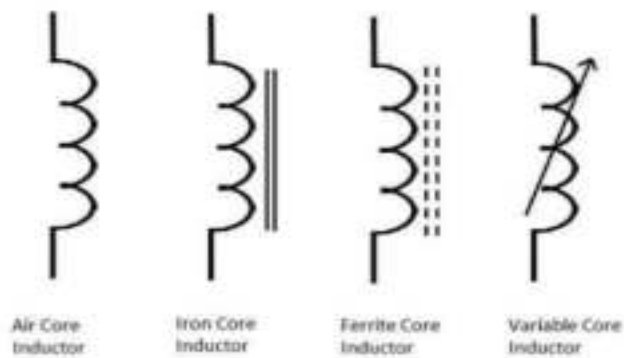
Core   Core wounded with wire   Inductors having different types of core

The following figure shows an inductor with various parts labelled.



Symbols

The symbols of various types of inductors are as given below.



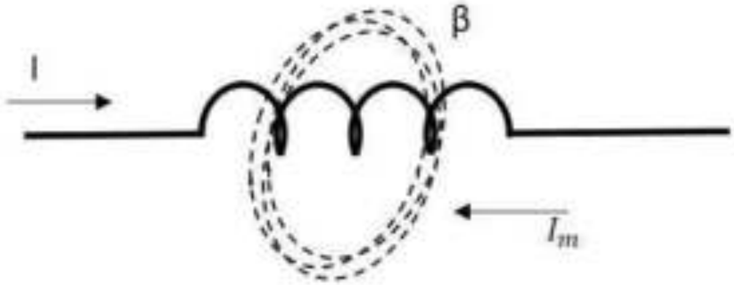
Storage of Energy

One of the Basic properties of electromagnetism is that the current when flows through an inductor, a magnetic field gets created perpendicular to the current flow. This keeps on building up. It gets stabilized at some point, which means that the inductance won’t build up after that. When the current stops flowing, the magnetic field gets decreased.This magnetic energy gets turned into electrical energy. Hence energy gets stored in this temporarily in the form of magnetic field.

Working of an Inductor

According to the theory of Electromagnetic Induction, any varying electric current, flowing in a conductor, produces a magnetic field around that, which is perpendicular to the current. Also, any varying magnetic field, produces current in the conductor present in that field, whereas the current is perpendicular to the magnetic field.Now, if we consider an inductor which is made up of a conducting coil and when some current passes through the inductor, a magnetic field is created perpendicular to it. The following figure indicates an inductor with magnetic field around it.

Now, here we have a varying magnetic field, which creates some current through the conductor. But this current is produced such that it opposes the main current, which has produced the magnetic field.If this current is named as I_m which means the current produced due to the magnetic field and the magnetic field is indicated by β, the following figure indicates it.



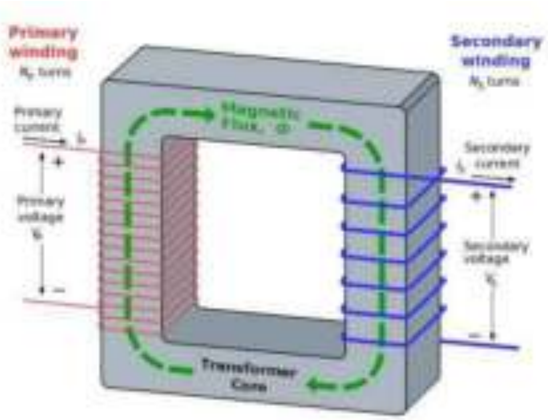
This opposing current gains strength with the varying magnetic field, which gains energy by the input supply frequency. Hence as the input current becomes more and more AC with high frequency, the resulting opposing current also gains its strength in opposite direction to the very cause producing it. Now, this opposing current, tries to stop the high frequency AC to pass through the inductor, which means "blocking of AC".

Powdered Iron core Inductor

These inductors provide very low eddy current losses and hysteresis losses. These are available at lowest prices and have very good inductance stability.

Transformer

According to the principle of **Electromagnetic Induction**, varying flux can induce an EMF in a coil. By the principle of **Mutual induction**, when another coil is brought beside such coil, the flux induces EMF into the second coil.Now, the coil which has the varying flux is called as the **Primary Coil** and the coil into which EMF is induced is called as the **Secondary Coil**, while the two coils together makes a unit called as a **Transformer**.A transformer has a primary coil to which input is given and a secondary coil from which the output is collected. Both of these coils are wound on a core material. Usually an insulator forms the **Core** of the transformer.The following figure shows a practical transformer.

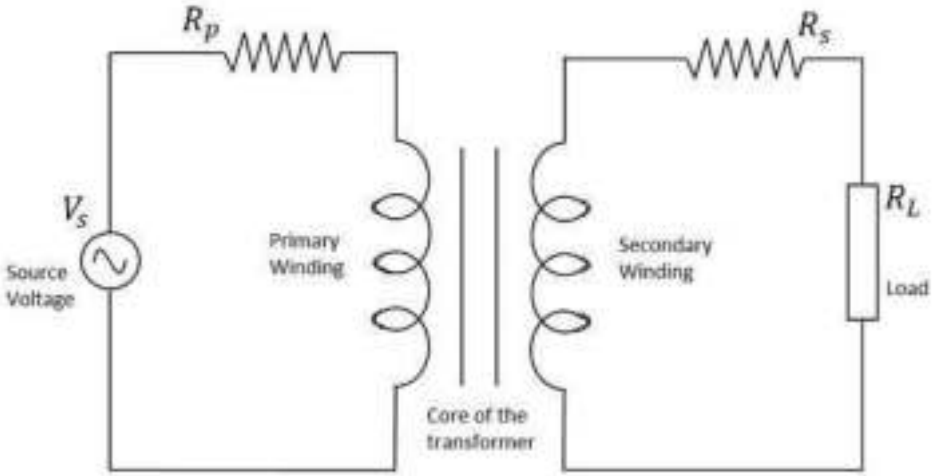


From the above figure, it is evident that few notations are common.

- **N_p** = Number of turns in the primary winding
- **N_s** = Number of turns in the secondary winding
- **I_p** = Current flowing in the primary of the transformer
- **I_s** = Current flowing in the secondary of the transformer
- **V_p** = Voltage across the primary of the transformer
- **V_s** = Voltage across the secondary of the transformer
- **Φ** = Magnetic flux present around the core of the transformer.

Transformer in a Circuit

The following figure shows how a transformer is represented in a circuit. The primary winding, the secondary winding and the core of the transformer are also represented in the following figure.



Hence, when a transformer is connected in a circuit, the input supply is given to the primary coil so that it produces varying magnetic flux with this power supply and that flux is induced into the secondary coil of the transformer, which produces the varying EMF of the varying flux. As the flux should be varying, for the transfer of EMF from primary to secondary, a transformer always works on alternating current AC.

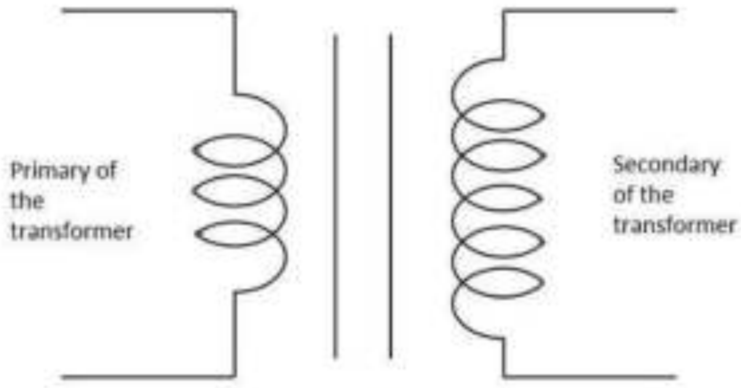
Step-up and Step-down

Depending upon the number of turns in the secondary winding, the transformer can be called as a **Step up** or a **Step down** transformer.

The main point to be noted here is that, there will not be any difference in the primary and secondary **power** of the transformer. Accordingly, if the voltage is high at secondary, then low current is drawn to make the power stable. As well, if the voltage in the secondary is low, then high current is drawn so as the power must be same as the primary side.

Step Up

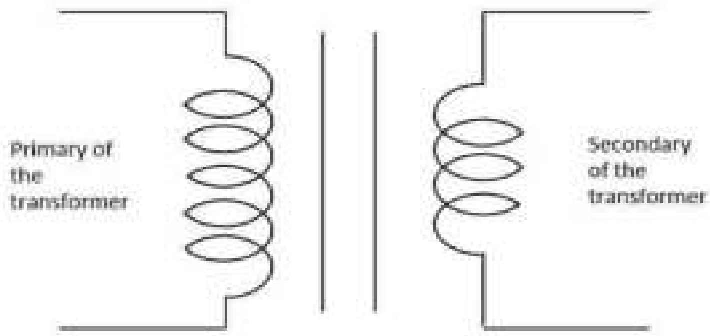
When the secondary winding has more number of turns than the primary winding, then the transformer is said to be a **Step-up** transformer. Here the induced EMF is greater than the input signal.



Step-up transformer

Step Down

When the secondary winding has lesser number of turns than the primary winding, then the transformer is said to be a **Step-down** transformer. Here the induced EMF is lesser than the input signal.



Step-down transformer

Turns Ratio

As the number of turns of primary and secondary windings affect the voltage ratings, it is important to maintain a ratio between the turns so as to have an idea regarding the voltages induced.The ratio of number of turns in the primary coil to the number of turns in the secondary coil is called as the "**turns ratio**" or "**the ratio of transformation**". The turns ratio is usually denoted by **N**.

N=Turnsratio=NumberofturnsonPrimary/ NumberofturnsonSecondary=N_p / N_s

The ratio of the primary to the secondary, the ratio of the input to the output, and the turns ratio of any given transformer will be the same as its **voltage ratio**. Hence this can be written as

$N_p/N_s=V_p/V_s=N=$Turnsratio

The turns ratio also states whether the transformer is a step-up or a step-down transformer. For example, a turns ratio of 1:3 states that the transformer is a step-up and the ratio 3:1 states that it is a step-down transformer.

Working:

Basically a transformer consists of two inductive coils; primary winding and secondary winding. The coils are electrically separated but magnetically linked to each other. When, primary winding is connected to a source of alternating voltage, alternating magnetic flux is produced around the winding. The core provides magnetic path for the flux, to get linked with the secondary winding. Most of the flux gets linked with the secondary winding which is called as 'useful flux' or main 'flux', and the flux which does not get linked with secondary winding is called as 'leakage flux'. As the flux produced is alternating (the direction of it is continuously changing), EMF gets induced in the secondary winding according to Faraday's law of electromagnetic induction. This emf is called 'mutually induced emf', and the frequency of mutually induced emf is same as that of supplied emf. If the secondary winding is closed circuit, then mutually induced current flows through it, and hence the electrical energy is transferred from one circuit (primary) to another circuit (secondary).

Efficiency of a Transformer:

The efficiency of a transformer is defined as the ratio of output in watt (or kW) to input in watt (or kW), and is represented by the letter 'Ƞ' (and is also known as commercial efficiency). The expression is given by,

$$Efficiency = \frac{Output\ Power}{Input\ Power}$$

$$= \frac{Output\ Power}{Output\ Power + Losses}\quad or$$

$$= \frac{Input\ Power - Losses}{Input\ Power}$$

A transformer is a highly efficient device and has very small losses. The different losses that occur in a transformer are iron or core losses, copper losses, stray losses. The stray loss of a transformer is comparatively very small and can be neglected. Since the remaining losses are not constant, they will be different at different loads, and thus efficiency also varies with the variation of load on the transformer.

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + P_c}$$

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + (I_1^2 R_1 + I_2^2 R_2)}$$

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{02}}$$

or

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_1^2 R_{01}}$$

Where,

- The iron or core losses P_i (sum of hysteresis loss and eddy current loss) in a transformer can be obtained from a no-load test. The core losses practically remain constant if the input voltage is constant.
- The copper losses P_c can be calculated by performing a short-circuit test on the transformer. These losses vary as the square of the load current.
- V_2 = Secondary terminal voltage.
- I_1 = Primary winding current.

I_2 = Secondary load current.

- Cos φ_2 = Power factor of the load (for purely resistive load it is 1).
- R_1 & R_2 = Primary and secondary winding resistance.
- R_{01} = Total resistance referred to the primary side.
- R_{02} = Total resistance referred to the secondary side.

Taking the above equation,

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{02}}$$

Where,

- $R_{02} = R_2 + R_1 K^2$
- $I_2^2 R_{02}$ = Total copper loss in the windings

Dividing with I_2 on both numerator and denominator. we get,

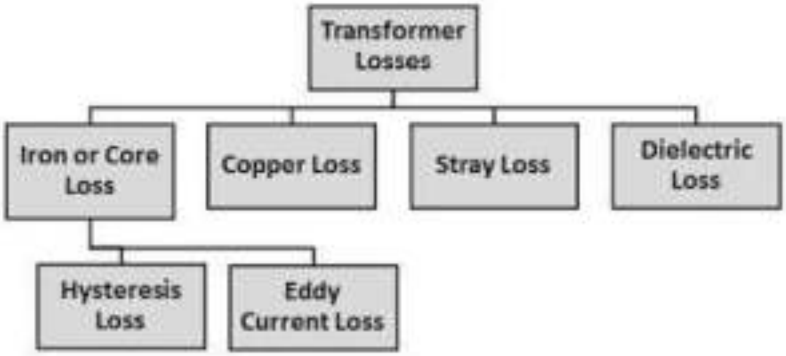
$$\eta = \frac{V_2 \cos\phi_2}{V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{02}}$$

Since the secondary voltage V_2 is kept almost constant for every transformer. For efficiency to be maximum for a particular power factor the denominator should be minimum.

Types of Losses in a Transformer - Iron & Copper Losses

Since the transformer is a static machine it doesn't contain any moving or rotating parts as compared to an induction motor. So there are no friction and windage losses due to bearings and due to air resistance. Hence, the various types of losses of a transformer occurring in the windings and core material are,

- Iron or core losses
  - Hysteresis loss
  - Eddy current loss
- Copper or Winding Loss
- Stray loss
- Dielectric loss



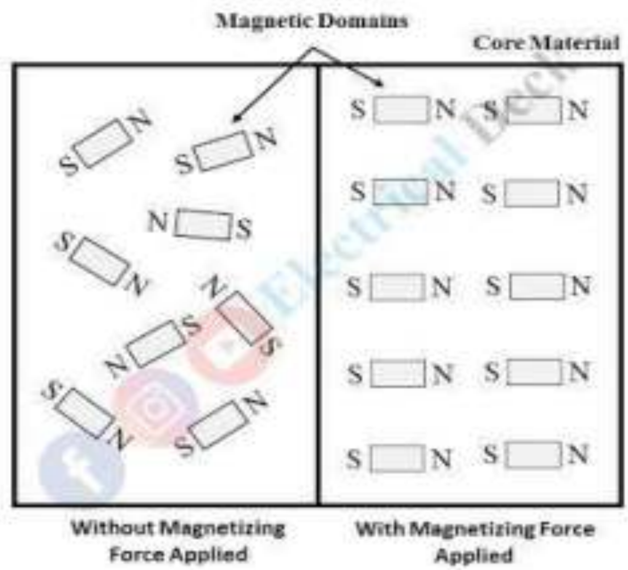
Iron or Core Losses:

The losses in the magnetic core which links both the windings by magnetic induction are called iron or core losses of the transformer. The iron practically remains constant under all load conditions i.e., they are independent or irrespective of the load condition. Hence, the iron losses are also called constant losses, and they are composed of two losses. They are,

- Hysteresis loss
- Eddy current loss

Hysteresis Loss:

Since the supply given to the transformer is alternating, the nature of the magnetic flux in the core will be also in alternating nature. Due to this, the randomly oriented magnetic domains which behave like a small magnet will be oriented in the direction of mmf applied. As the nature of magnetic flux applied is alternating the core material undergoes a cycle of magnetization and demagnetization effect.



Due to this, the one directionally oriented domains will take the reverse direction for every cycle. So that there will be extra energy consumed in the form of power loss known as 'Hysteresis Loss'.

Eddy Current Loss:

The core of the transformer is made up of conducting material. The laminated sheets which form the core limb will induce their own emf in each sheet when subjected to alternating flux. This results in the circulation of currents in each sheet and causes power loss known as 'Eddy Current Loss'. Since the frequency and flux density of the core material remains constant these losses also called 'Constant losses'. Therefore, the total iron or core or constant loss is the sum of both hysteresis and eddy current losses.

Minimization of Iron Losses:

- The hysteresis losses of the transformer cannot be eliminated completely but can be reduced by choosing a low hysteresis coefficient material like silicon steel.
- The eddy current losses can be reduced by making very thin laminations of silicon steel.

Copper Loss or Winding Loss :

We know that every material posses some resistance even it can be of conducting type. This resistance causes power loss ($I^2 R$) in the conducting material used for the windings of the transformer. The conducting material used for winding is mostly of copper, hence it is called 'Copper Loss'.

Stray Loss:

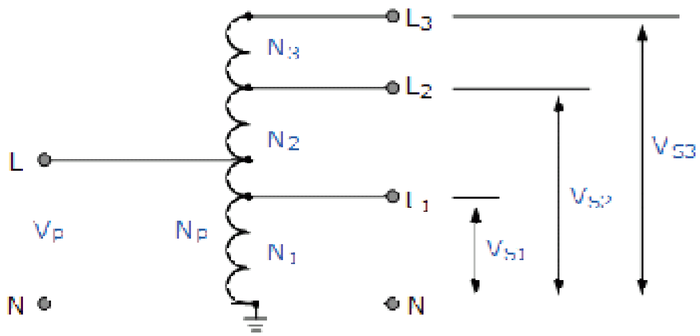
The transformer works on the principle of mutual induction i.e., emf induced in the secondary winding is by linkage of flux produced by the primary winding. But, in practice, all the flux produced by the primary winding does not link with secondary winding completely. There will wastage of flux which does not link with secondary winding as the leakage. This leakage flux will cause some losses in the transformer known as 'Stray Loss'.

Dielectric Loss :

As the name suggests these losses depend upon the dielectric strength of the insulating medium used in the transformer (generally oil). Due to the continuous operation of the transformer, the dielectric material used losses its dielectric strength and causes some losses which reduce the overall efficiency of the transformer. These losses can be minimized by periodic testing of the insulating material used.

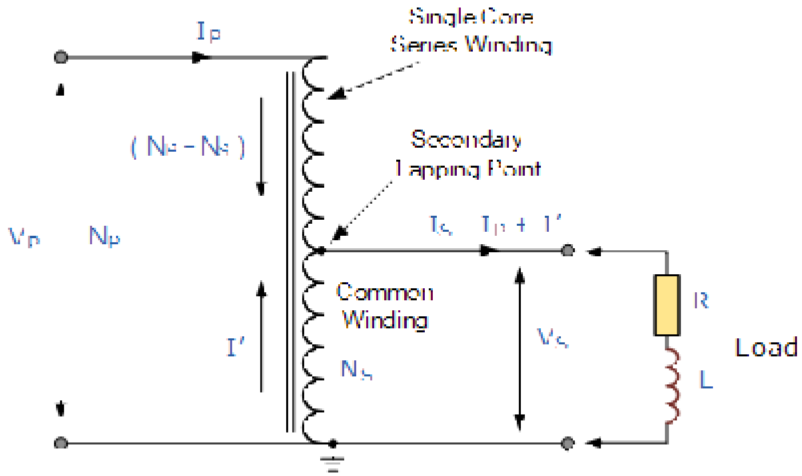
The Autotransformer

The primary and secondary windings of an Autotransformer are linked together both electrically and magnetically reducing the cost over conventional transformers



Unlike the previous voltage transformer which has two electrically isolated windings called: the primary and the secondary, an **Autotransformer** has only one single voltage winding which is common to both sides. This single winding is "tapped" at various points along its length to provide a percentage of the primary voltage supply across its secondary load. Then the *autotransformer* has the usual magnetic core but only has one winding, which is common to both the primary and secondary circuits.Therefore in an autotransformer the primary and secondary windings are linked together both electrically and magnetically. The main advantage of this type of transformer design is that it can be made a lot cheaper for the same VA rating, but the biggest disadvantage of an autotransformer is that it does not have the primary/secondary winding isolation of a conventional double wound transformer.The section of winding designated as the primary part of the winding is connected to the AC power source with the secondary being part of this primary winding. An autotransformer can also be used to step the supply voltage up or down by reversing the connections. If the primary is the total winding and is connected to a supply, and the secondary circuit is connected across only a portion of the winding, then the secondary voltage is "stepped-down"

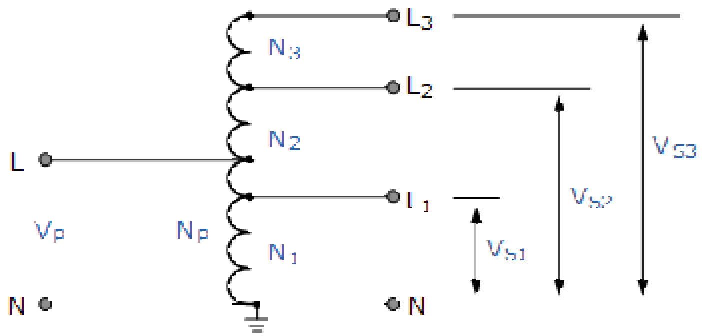
Autotransformer Design



When the primary current I_P is flowing through the single winding in the direction of the arrow as shown, the secondary current, I_S, flows in the opposite direction. Therefore, in the portion of the winding that generates the secondary voltage, V_S the current flowing out of the winding is the difference of I_P and I_S.

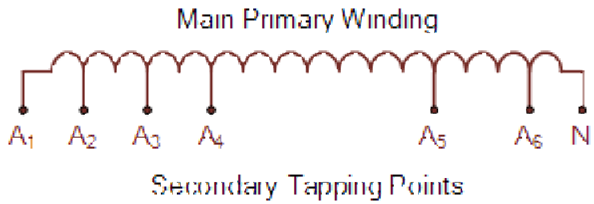
The **Autotransformer** can also be constructed with more than one single tapping point. Auto-transformers can be used to provide different voltage points along its winding or increase its supply voltage with respect to its supply voltage V_P as shown.

Autotransformer with Multiple Tapping Points



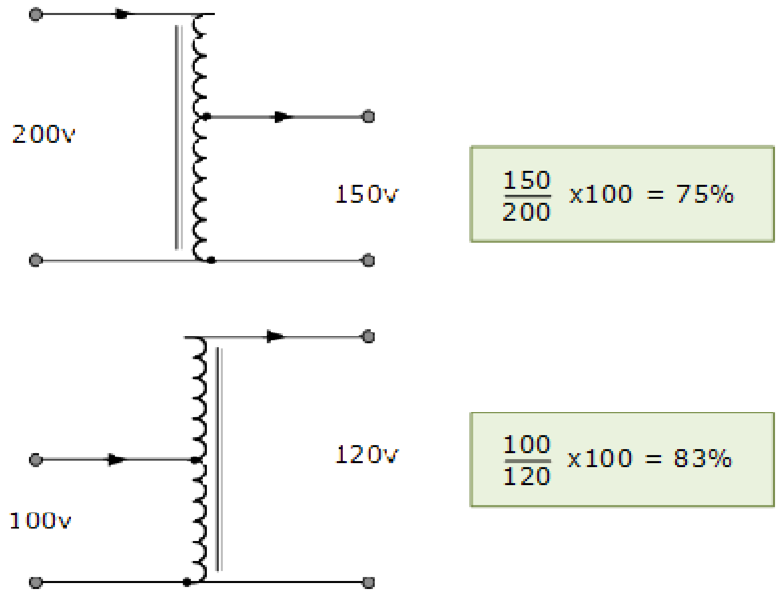
The standard method for marking an auto-transformer windings is to label it with capital (upper case) letters. So for example, A, B, Z etc to identify the supply end. Generally the common neutral connection is marked as N or n. For the secondary tapping's, suffix numbers are used for all tapping points along the auto-transformers primary winding. These numbers generally start at number "1" and continue in ascending order for all tapping points as shown.

Autotransformer Terminal Markings



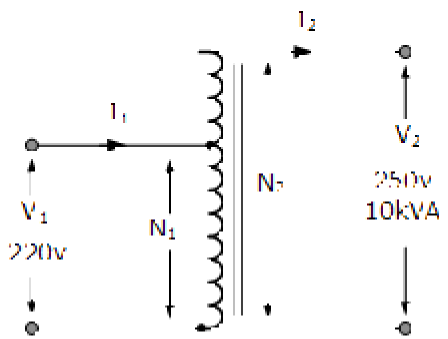
An autotransformer is used mainly for the adjustments of line voltages to either change its value or to keep it constant. If the voltage adjustment is by a small amount, either up or down, then the transformer ratio is small as V_P and V_S are nearly equal. Currents I_P and I_S are also nearly equal.

Therefore, the portion of the winding which carries the difference between the two currents can be made from a much smaller conductor size, since the currents are much smaller saving on the cost of an equivalent double wound transformer.However, the regulation, leakage inductance and physical size (since there is no second winding) of an autotransformer for a given VA or KVA rating are less than for a double wound transformer.Autotransformer's are clearly much cheaper than conventional double wound transformers of the same VA rating. When deciding upon using an autotransformer it is usual to compare its cost with that of an equivalent double wound type.This is done by comparing the amount of copper saved in the winding. If the ratio "n" is defined as the ratio of the lower voltage to the higher voltage, then it can be shown that the saving in copper is: n*100%. For example, the saving in copper for the two autotransformers would be:



Autotransformer Example

An **autotransformer** is required to step-up a voltage from 220 volts to 250 volts. The total number of coil turns on the transformer main winding is 2000. Determine the position of the primary tapping point, the primary and secondary currents when the output is rated at 10KVA and the economy of copper saved.



$$\frac{N_1}{N_2} = \frac{V_1}{V_2} \quad \therefore N_1 = \frac{N_2 \times V_1}{V_2}$$

$$\frac{2000 \times 220}{250} = 1760 \text{ turns}$$

Thus the primary current is 45.4 amperes, the secondary current drawn by the load is 40 amperes and 5.4 amperes flows through the common winding. The economy of copper is 88%.

Disadvantages of an Autotransformer

- The main disadvantage of an autotransformer is that it does not have the primary to secondary winding isolation of a conventional double wound transformer. Then an autotransformer can not safely be used for stepping down higher voltages to much lower voltages suitable for smaller loads.
- If the secondary side winding becomes open-circuited, load current stops flowing through the primary winding stopping the transformer action resulting in the full primary voltage being applied to the secondary terminals.
- If the secondary circuit suffers a short-circuit condition, the resulting primary current would be much larger than an equivalent double wound transformer due to the increased flux linkage damaging the autotransformer.
- Since the neutral connection is common to both the primary and secondary windings, earthing of the secondary winding automatically Earth's the primary as there is no isolation between the two windings. Double wound transformers are sometimes used to isolate equipment from earth.

The *autotransformer* has many uses and applications including the starting of induction motors, used to regulate the voltage of transmission lines, and can be used to transform voltages when the primary to secondary ratio is close to unity.

An autotransformer can also be made from conventional two-winding transformers by connecting the primary and secondary windings together in series and depending upon how the connection is made, the secondary voltage may add to, or subtract from, the primary voltage.

The Variable Autotransformer

As well as having a fixed or tapped secondary that produces a voltage output at a specific level, there is another useful application of the auto transformer type of arrangement which can be used to produce a variable AC voltage from a fixed voltage AC supply. This type of **Variable Autotransformer** is generally used in laboratories and science labs in schools and colleges and is known more commonly as the **Variac**.

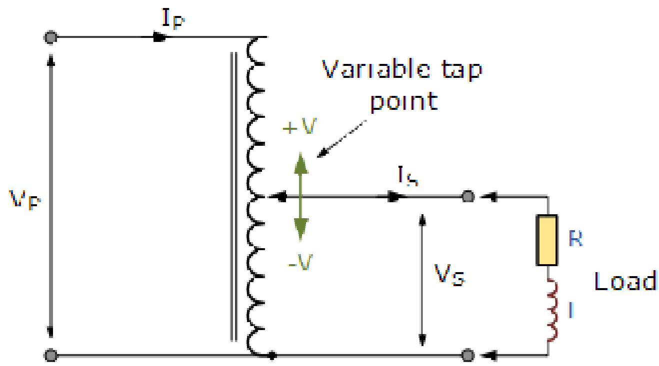
The construction of a variable autotransformer, or variac, is the same as for the fixed type. A single primary winding wrapped around a laminated magnetic core is used as in the auto transformer but instead of being fixed at some predetermined tapping point, the secondary voltage is tapped through a carbon brush.

This carbon brush is rotated or allowed to slide along an exposed section of the primary winding, making contact with it as it moves supplying the required voltage level.

Then a variable autotransformer contains a variable tap in the form of a carbon brush that slides up and down the primary winding which controls the secondary winding length and hence the secondary output voltage is fully variable from the primary supply voltage value to zero volts.

The variable autotransformer is usually designed with a significant number of primary windings to produce a secondary voltage which can be adjusted from a few volts to fractions of a volt per turn. This is achieved because the carbon brush or slider is always in contact with one or more turns of the primary winding. As the primary coil turns are evenly spaced along its length. Then the output voltage becomes proportional to the angular rotation.

Variable Autotransformer



We can see that the variac can adjust the voltage to the load smoothly from zero to the rated supply voltage. If the supply voltage was tapped at some point along the primary winding, then potentially the output secondary voltage could be higher than the actual supply voltage. Variable autotransformer's can also be used for the dimming of lights and when used in this type of application, they are sometimes called "dimmerstats".

Variacs are also very useful in electrical and electronics workshops and labs as they can be used to provide a variable AC supply. But caution needs to be taken with suitable fuse protection to ensure that the higher supply voltage is not present at the secondary terminals under fault conditions.

The **Autotransformer** have many advantages over conventional double wound transformers. They are generally more efficient for the same VA rating, are smaller in size, and as they require less copper in their construction, their cost is less compared to double wound transformers of the same VA rating. Also, their core and copper losses, I^2R are lower due to less resistance and leakage reactance giving a superior voltage regulation than the equivalent two winding transformer.

In the next tutorial about **Transformers** we will look at another design of transformer which does not have a conventional primary winding wound around its core. This type of transformer is commonly called a *Current Transformer* and is used to supply ammeters and other such electrical power indicators.

UNIT – III

3.0 INTRODUCTION:

The interconnection of various electric elements in a prescribed manner comprises asanelectriccircuitinordertoperformadesiredfunction.Theelectricelementsincludecontrolled and uncontrolled source of energy, resistors, capacitors, inductors, etc. Analysis ofelectric circuits refers to computations required to determinethe unknown quantities such asvoltage, current and power associated with one or more elements in the circuit. To contributeto the solution of engineering problems one must acquire the basic knowledge of electriccircuit analysis and laws. Many other systems, like mechanical, hydraulic, thermal, magneticand power system are easy to analyze and model by a circuit. To learn how to analyze themodels of these systems, first one needs to learn the techniques of circuit analysis. We shalldiscuss briefly some of the basic circuit elements and the laws that will help us to develop thebackgroundof subject.

3.1 BASIC ELEMENTS & INTRODUCTORY CONCEPTS:

ElectricalNetwork:

A combination of various electric elements (Resistor, Inductor, Capacitor, Voltagesource, Current source) connected in any manner what so ever is called an electrical network.Wemayclassifycircuit elementsin two categories, passiveand activeelements.

PassiveElement:

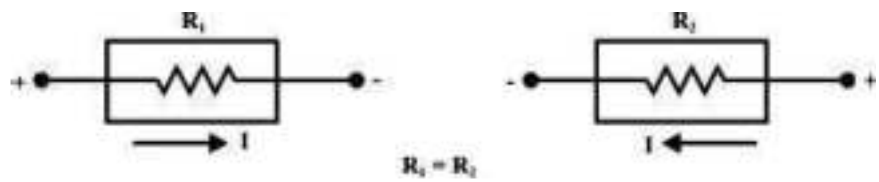
The element which receives energy (or absorbs energy) and then either converts it intoheat(R)orstoredit inan electric (C)or magnetic (L) fieldis calledpassiveelement.

ActiveElement:

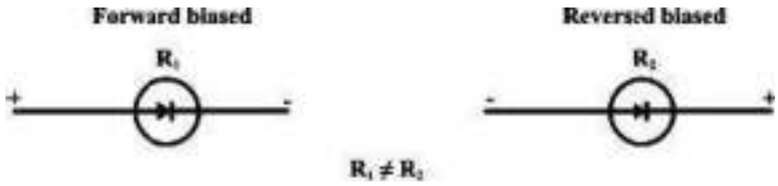
The elements that supply energy to the circuit is called active element.Examples ofactive elements include voltage and current sources, generators, and electronic devices thatrequire power supplies. A transistor is an active circuit element, meaning that it can amplifypower of a signal. On the other hand, transformer is not an active element because it does notamplify thepowerlevelandpowerremainssamebothinprimary andsecondary sides.Transformeris an exampleof passiveelement.

BilateralElement:

Conductionofcurrentinbothdirectionsinanelement(example:Resistance;Inductance;Capacitance)withsame magnitudeistermedas bilateralelement.



Conductionofcurrentinonedirectionistermedasunilateral(example:Diode,Transistor)element.



Meaningof Response:

Anapplicationofinputsignaltothesystemwillproduceanoutputsignal,thebehaviorofoutput signal with time is known as the responseofthe system.

PotentialEnergyDifference:

Thevoltageorpotentialenergydifferencebetweentwopointsinanelectriccircuitis theamountofenergyrequired tomoveaunit chargebetweenthetwo points.

Ohm's Law: Ohm'slawstatesthatthe currentthroughaconductorbetween twopointsisdirectlyproportional to the potential difference or voltage across the two points, and inverselyproportional to the resistance between them. The mathematical equation that describes thisrelationshipis:

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

where I is the current through the resistance in units of amperes, V is the potentialdifferencemeasured across the resistance in units of volts, and R is the resistance of theconductorinunitsofohms.Morespecifically,Ohm'slawstatesthattheRinthisrelationisconstant,independentofthecurrent.

1.2. KIRCHOFF'SLAW

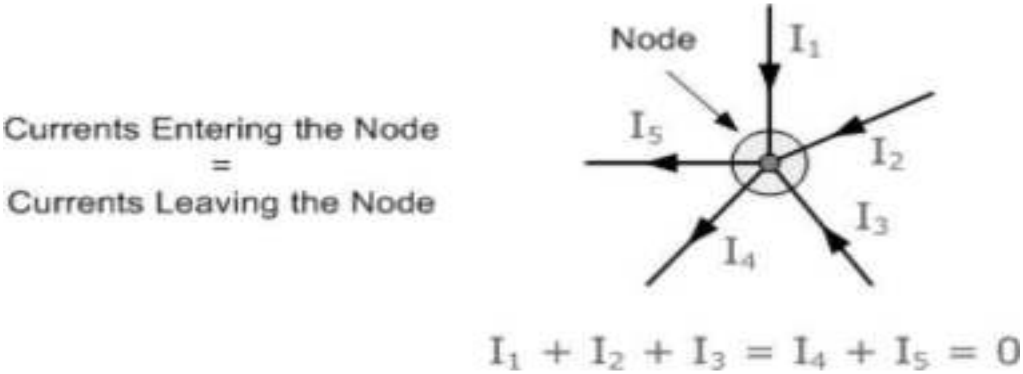
Kirchoff'sFirstLaw-TheCurrentLaw,(KCL)

"The total current or charge entering a junction or node is exactly equal to the chargeleaving the node as it has no other place to go except to leave, as no charge is lost within thenode".

In other words the algebraic sum of ALL the currents entering and leaving a node mustbeequal to zero,

I(exiting)+I(entering)=0.

ThisideabyKirchoffis known asthe Conservation ofCharge.



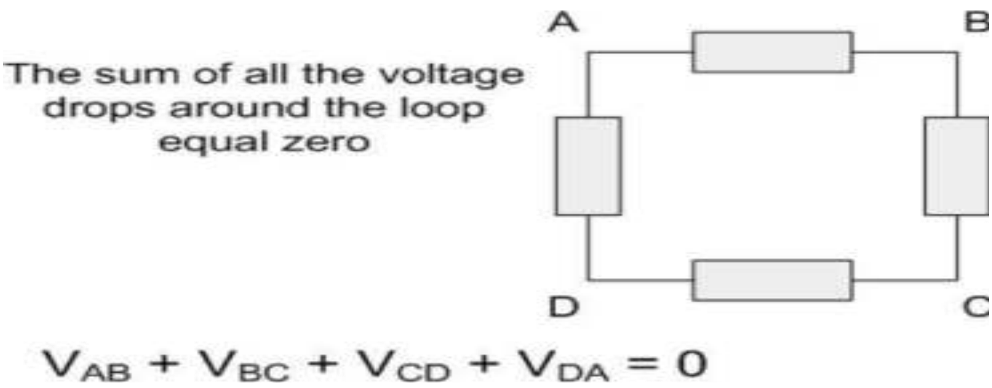
Here, the 3 currents entering the node, I1, I2, I3 are all positive in value and the 2currentsleavingthenode,I4andI5arenegativein value.
Then this means we can also rewrite the equation
as;I1+ I2 +I3-I4- I5 =0

Kirchoff'sSecondLaw -TheVoltageLaw,(KVL)

″In any closed loop network, the total voltage around the loop is equal to the sum of allthe voltage drops within the same loop″ which is also equal to zero. In other words thealgebraic sum of all voltages within the loop must be equal to zero. This idea by Kirchoff isknownas the Conservation ofEnergy**.**

Starting at any point in the loop continue in the same direction noting the direction ofall the voltage drops, either positive or negative, and returning back to the same starting point.It is important to maintain the same direction either clockwise or anti-clockwise or the finalvoltagesum will not be equal to zero.

WecanuseKirchoff'svoltagelawwhen analyzingseriescircuits.



1.3. PROBLEMSANDCALCULATIONS:

Problem1:

Acurrentof0.5Aisflowingthroughtheresistanceof10Ω.Findthepotentialdifferencebetweenits ends.

Solution:

CurrentI =

0.5A.Resistance R =

10ΩPotentialdifference

V=?

V=IR

=0.5 ×10

=5V.

Problem:2

Asupplyvoltageof220Visappliedtoa100Ωresistor.Findthecurrentflowingthrough it.

Solution:

VoltageV=220VResistanceR=

100ΩCurrentI =V/

R

=2 2 0 /100

=2.2 A.

Problem:3

Calculatetheresistanceoftheconductorifacurrentof2Aflowsthroughitwhenthepotentia ldifferenceacrossits endsis 6V.

Solution:

CurrentI

=2A.Potentialdi

fference=V= 6.Resistance R

=V/I

=6 /2

=3 ohm.

Problem:4

Calculatethecurrentandresistanceofa100W,200Velectricbulb.

Solution:

Power,P =100W

Voltage,V=200VPowerp=VICurr
ent I=P/V

=100/200

=0.5A

ResistanceR=V/I

=200/0.5

=400W.

Problem:5

Calculatethepowerratingoftheheatercoilwhenusedon220Vsupply*taking5Amps.*

Solution:

Voltage,V=220VC
urrent, I =
5A,Power,P =
VI

$=220 \times 5$

=1100W

=1.1 KW.

Problem:6

Acircuitismadeof0.4Ωwire,a150Ωbulbanda120Ωrheostat*connectedinseries.Determinethetotalresistanceoftheresistanceofthecircuit.*

Solution:

Resistance of the wire=0.4Ω Resistance of bulb= 1 5 0 Ω Resistance of rheostat

=120ΩInseries,

Totalresistance,R =0.4 +150 +120

=270.4Ω

Problem:7

Threeresistancesofvalues2Ω,3Ωand5Ωareconnectedinseriesacross20V,D.Csupply .Calculate(a)equivalentresistanceofthecircuit(b)thetotalcurrentofthecircuit(c)thevoltagedropacrosseach resistorand(d)thepowerdissipatedineachresistor.

Solution:

TotalresistanceR=R_1+R_2+R_3.

=2 +3+5=10Ω

Voltage =20V

TotalcurrentI = V/R

=20/10=2A.Voltagedropacross2ΩresistorV
$_1$=IR_1

$=2\times2=4$ volts.

Voltagedropacross3ΩresistorV_2=IR_2

$=2\times3=6$ volts.

Voltagedropacross5Ωresistor V_3=IR_3

$=2\times5=10$ volts.

Powerdissipatedin2ΩresistorisP_1=I_2R_1

$=22\times2=8$ watts.

Powerdissipatedin3resistorisP_2 = I_2 R_2.

$=22\times3=12$ watts.

Powerdissipatedin5resistorisP_3 = I_2R_3

=22 ×5 =20 watts.

Problem:8

Alamp can work ona50 voltmainstaking2 amps.Whatvalueoftheresistancemustbeconnectedinserieswithitsothatitcanbeoperatedfrom200voltmainsgivingthesamepower.

Solution:

Lamp voltage, V=50V Current, I =2

amps.Resistance of the lamp = V/I =50/25 =

25 ΩResistance connected in series with

lamp = r.Supplyvoltage=200 volt.

CircuitcurrentI=2A

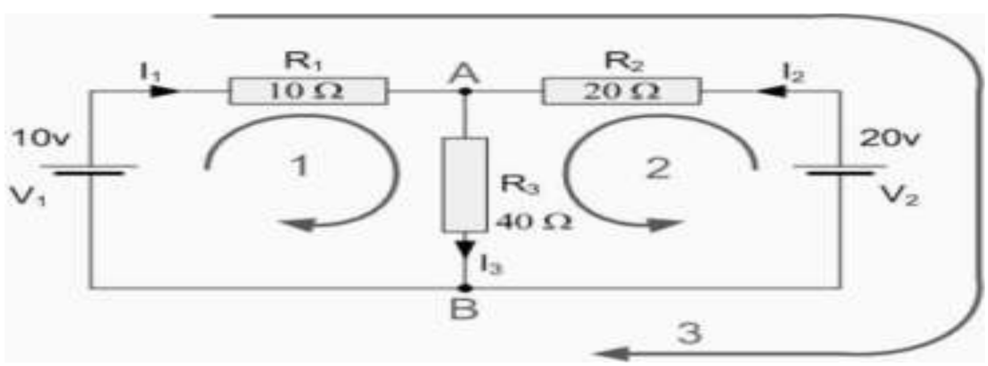
TotalresistanceR_t=V/I=200/2=100Ω

R_t=R+r 100=25 +r

r=75Ω

Problem:9

Findthecurrent flowingin the40ΩResistor,R3



Solution:

Thecircuithas3branches,2nodes(Aand B) and 2independentloops.UsingKirchoff's CurrentLaw, KCLthe equations aregivenas;

AtnodeA:$I_1+I_2=I_3$Atn odeB:$I_3 = I_1+ I_2$

Using Kirchoff's Voltage Law, KVL the equations are given as;Loop1isgivenas: 10= $R_1xI_1+R_3xI_3$ =$10I_1$ +$40I_3$

Loop 2 is given as: 20 = R_2 x I_2 + R_3 x I_3 = $20I_2$ + $40I_3$Loop3 isgivenas: 10-20=$10I_1$-$20I_2$

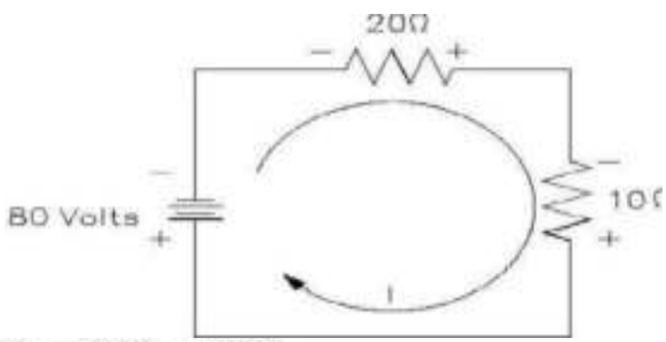
AsI3isthesumofI_1 +I_2wecan rewritetheequationsas;Eq.No

1:10 $=10I_1+40(I_1+I_2)=50I_1+40I_2$
Eq.No2:20= $20I_1+40(I_1+ I_2)=40I_1 +60I_2$

Wenowhavetwo"SimultaneousEquations"thatcanbereducedtogiveusthevalueofbothI_1andI_2
Substitutionof I_1 intermsof I_2givesusthevalueof I_1 as-0.143Amps

Substitutionof I_2intermsofI_1givesusthevalue ofI_2 as
+0.429AmpsAs:$I_3=I_1+I_2$
The current flowing in resistor R_3 is given as: -0.143 + 0.429 = 0.286
Ampsand the voltage across the resistor R_3 is given as : 0.286 x 40 = 11.44
volts**Problem:10**
Findthecurrent in acircuitusingKirchhoff'svoltagelaw

Solution:



$80 = 20(I) + 10(I)$

$80 = 30(I)$

$I = 80/30 = 2.66$ amperes

1.4. DCCIRCUITS:

- ADCcircuit(DirectCurrentcircuit)isanelectricalcircuitthatconsistsofanycombinationofconstantvoltagesources,constantcurrentsources,andresistors.Inthiscase,thecircuitvoltagesandcurrents areconstant,i.e.,independentoftime.Moretechnically,a DCcircuithasnomemory.Thatis,a particularcircuitvoltageor currentdoes not depend on the past value of any circuit voltage or current. This implies that thesystemofequationsthatrepresentaDCcircuitdonotinvolveintegralsorderivatives.
- If a capacitor and/or inductor is added to a DC circuit, the resulting circuit is not, strictlyspeaking,aDCcircuit.However,mostsuchcircuitshaveaDCsolution.Thissolutiongivesthecircuitvoltagesandcurrentswhenthecircuitisin DCsteadystate.Moretechnically,suchacircuitisrepresentedbyasystemofdifferential equations.Thesolutionstotheseequationsusuallycontainatimevaryingortransientpartaswell as constant or steady state part. It is this steady state part that is the DC solution. Therearesome circuitsthatdonothave a DCsolution.Two simple examplesare aconstantcurrentsourceconnectedtoacapacitorandaconstantvoltagesourceconnectedtoaninductor.
- Inelectronics, itiscommon torefer toa circuitthat ispowered by a DCvoltage sourcesuch as a battery or the output of a DC power supply as a DC circuit even though what ismeantis that thecircuit is DC powered.

1.5. ACCIRCUITS:

FundamentalsofAC:

- Analternating current(AC)isanelectricalcurrent,where themagnitudeofthecurrentvaries in a cyclical form, as opposed to direct current, where the polarity of the current staysconstant.
- The usual waveform of an AC circuit is generally that of a sine wave, as these results in themostefficienttransmissionofenergy.Howeverincertainapplicationsdifferentwaveformsareused, suchastriangularorsquarewaves.
- Used generically, AC refers to the form in which electricity is delivered to businesses andresidences. However, audio and radio signals carried on electrical wire are also examples ofalternatingcurrent.Intheseapplications,animportantgoalisoftentherecoveryofinformationencoded(ormodulated)ontotheACsignal.

1.6. DIFFERENCEBETWEENACANDDC:

Current that flows continuouslyinonedirectionis c a l l e ddirect c u r r e n t .Alternatingcurrent(A.C)isthecurrentthatflowsinonedirectionforabrieftimethenreverses andflows in opposite direction for a similar time. The source for alternating currentis called a.cgeneratororalternator.

Cycle:

- Onecompletesetofpositiveandnegativevaluesofanalternatingquantityiscalledcycle.

Frequency:

- Thenumberofcyclesmadebyanalternatingquantitypersecondiscalledfrequency.Theunitof frequencyis Hertz(Hz)

AmplitudeorPeakvalue:

- Themaximumpositiveornegativevalueofanalternatingquantityiscalledamplitudeorpeakvalue.

Averagevalue:

- Thisistheaverageofinstantaneousvaluesofanalternatingquantityoveronecompletecycleofthewave.

Timeperiod:

- Thetimetakentocompleteonecompletecycle.

Averagevaluederivation:

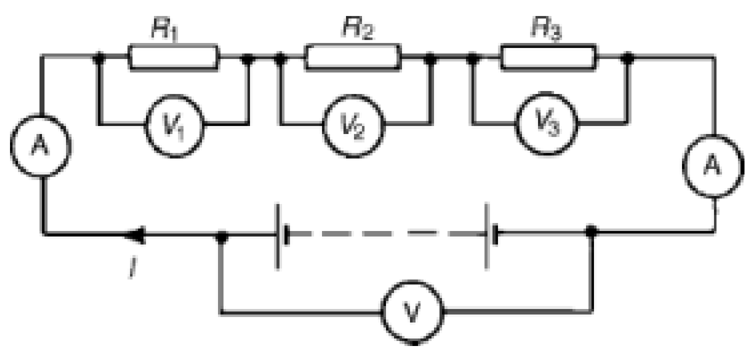
Leti=theinstantaneousvalueofcurrentandi=Imsinθ

Where,Imisthemaximumvalue.

Resistorsinseriesandparallelcircuits:

Seriescircuits:

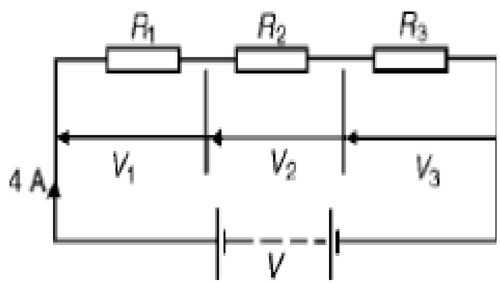
Figure shows three resistorsR1, R2 and R3 connected endto end, i.e. in series, with a batterysource of V volts. Since the circuit is closed a current I will flow and the p.d. across each resistormaybedeterminedfromthe voltmeterreadingsV1, V2 and V3



Inaseriescircuit

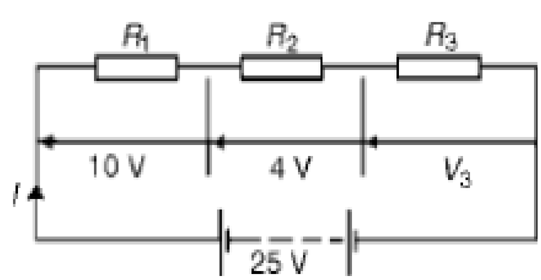
(a) the currentIisthe sameinallpartsofthe circuitandhence thesame readingisfound oneachofthetwo ammeters shown,and
(b) the sum of the voltages V1, V2 and V3 is equal to the total applied voltage, V,
i.e.V=V1 +V2+V3
FromOhm'slaw:
V1=IR1,V2=IR2,V3 =IR3 andV=IR
whereRisthetotalcircuitresistance.
Since V =V1 + V2 +
V3thenIR=IR1+IR2+IR3
DividingthroughoutbyIgivesR
=R1 +R2 +R3
Thus for a series circuit, the total resistance is obtained by adding together the values of the separateresistances.

Problem 1: For the circuit shown in Figure 5.2, determine (a) the battery voltage V, (b) the totalresistance of the circuit, and (c) the values of resistance of resistors R1, R2 and R3, given that thep.d.'sacross R1, R2 andR3 are5V, 2Vand 6V respectively.



(a) Batteryvoltage V=V1 +V2 +V3
=5 +2 +6=13V
(b) TotalcircuitresistanceR=V/I
=13/4=3.25Ω
(c) ResistanceR1 =V1/I
=5/4
=1.25Ω
ResistanceR2=V2/I
=2/4
=0.5Ω
ResistanceR3=V3/I
=6/4
=1.5Ω

Problem 2. For the circuit shown in Figure determine the p.d. across resistor *R*3. If the totalresistance of the circuit is 100_, determine the current flowing through resistor *R*1. Find also thevalueofresistor *R*2.



P.d.acrossR3,V3=25−10−4=11VCurr
entI=V/ R

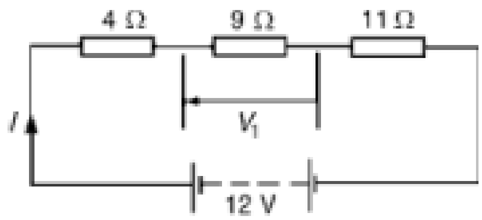
=25/100

=0.25A, which is the current flowing in each resistorResistanceR2 =V2/I

=4/0.25

=16Ω

Problem 3: A 12V battery is connected in a circuit having three series-connected resistors havingresistancesof4Ω,9Ωand11Ω.Determinethecurrentflowingthrough,andthep.d.acrossthe9Ωresistor. Findalso thepower dissipated in the11 Ωresistor.



Total resistance R=4 + 9 + 11=24 ΩCurrentI=V/ R

=12/24

=0.5A,which isthecurrentin the9Ωresistor.

P.d.across the 9_resistor, $V1 = I×9$=0.5 ×9

=4.5V

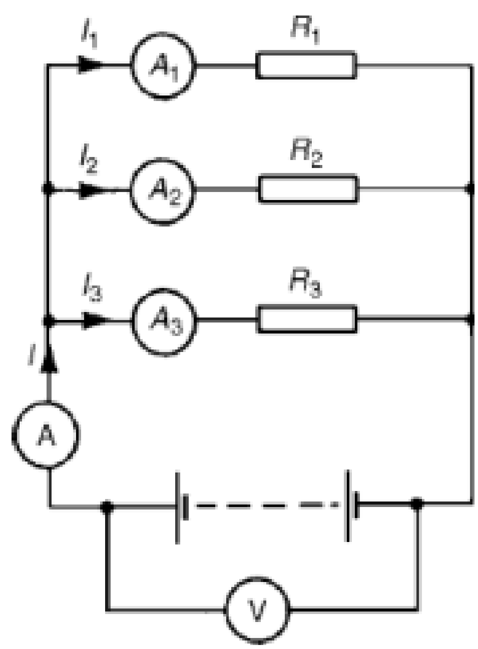
Powerdissipatedinthe 11Ωresistor, $P= I2R$=0.52(11)

=0.25(11)

=2.75W

1.7. PARALLELNETWORKS:

Problem1: Figureshowsthreeresistors,R1,R2andR3connectedacrosseachother,i.e.inparallel,across abatterysource
ofVvolts.



Inaparallelcircuit:
(a) the sum of the currents I1, I2 and I3 is equal to
thetotalcircuitcurrent,I,i.e.I=I1+I2+I3,and
(b) thesourcep.d., Vvolts, isthe same across each of the

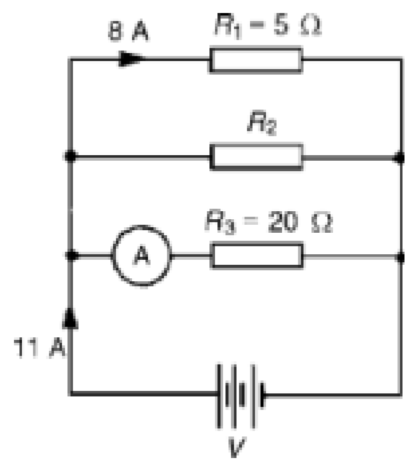
resistors.
FromOhm'slaw:
I1 =V/R1
,I2 =V/R2
,I3 =V/R3
andI=V/R
whereRisthetotalcircuitresistance.
SinceI=I1 + I2+I3
then
V/R=V/R1+V/R2+V/R3
Dividingthroughout byVgives:

$$\boxed{\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}}$$

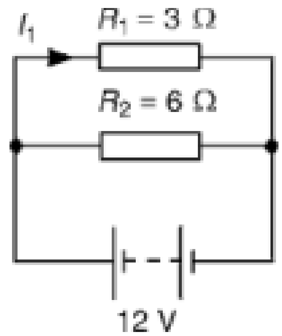
ThisequationmustbeusedwhenfindingthetotalresistanceRofaparallelcircuit.Forthespecialcaseoftwo resistorsinparallel

$$\boxed{R=\frac{R_1R_2}{R_1+R_2}}$$

Problem2: Forthecircuit showninFigure, determine(a)thereadingon theammeter,and(b) thevalue ofresistor R2.

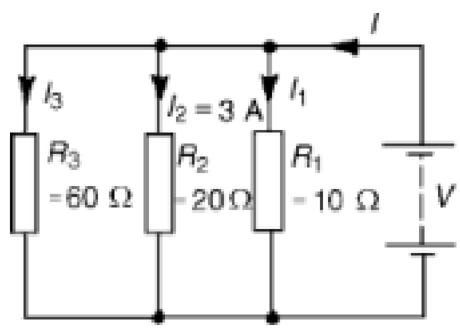


P.d. across R1 is thesameas the supplyvoltage V.
Hencesupplyvoltage,V=8×5=40V
(a) Reading on ammeter, I =
VR3=40/20=2A
(b) Current flowing through R2
=11−8−2=1AHence,R2=V/I2=40/1=40Ω



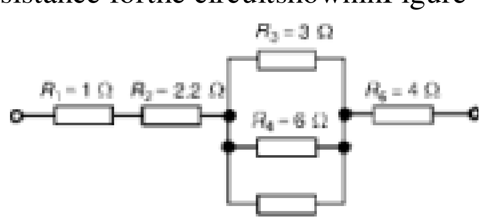
(a) The total circuit resistance R is given
by1/R=1/R1+1/R2=1/3+1/6
1/R=2 +1/6=3/6
Hence,R=6/3=2Ω
(b) Current in the 3 Ω resistance, I1 =
VR1=12/3=4A

Problem3: ForthecircuitshowninFigurefind(a)thevalueofthesupplyvoltageVand(b)thevalueofcurrentI .



(a)P.d.across20Ωresistor=I2R2=3×20=60V,hencesupplyvoltageV=60Vsincethecircuitisconnected in parallel.
(b)CurrentI1=V/R1=60/10=6A;I2=3AI3=V
/R3=60/60=1A
Current I=I1+I2+I3and hence
I=6+3+1=10AAlternatively,
1/R=1/60+1/20+1/10=1 +3 +6/60=10/60
HencetotalresistanceR=6010=6ΩCu
rrentI=V/R=60/6=10A

Problem4: Findtheequivalentresistance forthe circuitshowninFigure



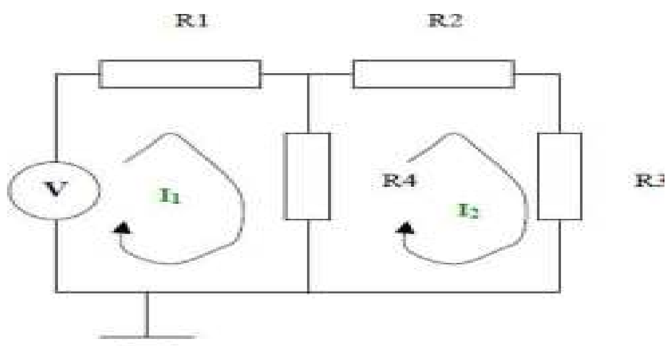
*R*3, *R*4 and*R*5 are connected in parallel and their equivalent resistance *R* is given by:1/*R*=1/3+1/6+1/18=6 +3 +1/18=10/18
Hence*R*=18/10=1.8Ω
Thecircuitisnowequivalenttofourresistorsinseriesandtheequivalentcircuitresistance =1+2.2+1.8+4=9Ω

1.8. MESHANALYSIS:

This is an alternative structured approach to solving the circuit and is based on calculating meshcurrents. A similar approach to the node situation is used. A set of equations (based on KVL foreach mesh) is formed and the equations are solved for unknown values. As many equations areneededas unknown mesh currents exist.
Step1:Identifythemeshcurrents
Step2:Determinewhichmeshcurrentsareknown
Step2:Write equationforeach meshusingKVLandthatincludes themesh
currentsStep3: Solve theequations

Step1:
Themeshcurrentsareasshownin thediagramonthenextpage

Step2:
Neitherofthe meshcurrents is known



Step3:
KVL can be applied to the left hand side loop. This states the voltages around the loop sum to zero.When writing down the voltages across each resistor Ohm's law is used. The currents used in theequationsarethemesh currents.
$I_1R_1 + (I_1 - I_2) R_4 - V = 0$
KVL can beappliedto the right handside loop.This states thevoltagesaround the loop sum tozero. When writing down the voltages across each resistor Ohm's law is used. The currents used intheequations arethe mesh currents.
$I_2R_2 + I_2R_3 + (I_2 - I_1)R_4 = 0$

Step4:
Solvingtheequationsweget

$$I_1 = V\frac{R_2 + R_3 + R_4}{R_1R_2 + R_1R_3 + R_1R_4 + R_2R_4 + R_3R_4}$$

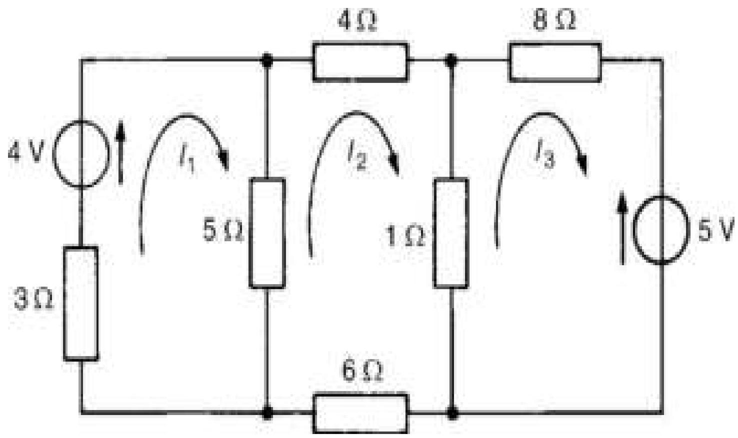
$$I_2 = V\frac{R_4}{R_1R_2 + R_1R_3 + R_1R_4 + R_2R_4 + R_3R_4}$$

Theindividualbranchcurrentscanbeobtainedfromthethesemeshcurrentsandthenodevoltagescanalso becalculated usingthis information. Forexample:

$$V_C = I_2 R_3 = V \frac{R_3 R_4}{R_1 R_2 + R_1 R_3 + R_1 R_4 + R_2 R_4 + R_3 R_4}$$

Problem1:

Usemesh-currentanalysistodeterminethecurrentflowingin(a)the5Ωresistance,and(b)the1Ωresistanceof thed.c. circuitshownin Figure.



ThemeshcurrentsI$_1$,I$_2$and I$_3$ areshowninFigure

UsingKirchhoff's voltagelaw:

Forloop1,(3+5) $I_1 - I_2 = 4$..(1)

Forloop2, (4+1+6 +5) $I_2 - (5)I_1 - (1)I_3 = 0$… .... (2)

Forloop3,(1+8) $I_3 - (1)\ I_2 = -5$ .... (3)

Thus

$8I_1 - 5I_2 - 4 = 0$

$-5I_1 + 16I_2 - I_3 = 0$

$-I_2 + 9I_3 + 5 = 0$

$$\frac{I_1}{\begin{vmatrix} -5 & 0 & -4 \\ 16 & -1 & 0 \\ -1 & 9 & 5 \end{vmatrix}} = \frac{-I_2}{\begin{vmatrix} 8 & 0 & -4 \\ -5 & -1 & 0 \\ 0 & 9 & 5 \end{vmatrix}} = \frac{I_3}{\begin{vmatrix} 8 & -5 & -4 \\ -5 & 16 & 0 \\ 0 & -1 & 5 \end{vmatrix}}$$

$$= \frac{-1}{\begin{vmatrix} 8 & -5 & 0 \\ -5 & 16 & -1 \\ 0 & -1 & 9 \end{vmatrix}}$$

Usingdeterminants,

$$\frac{I_1}{-5\begin{vmatrix}-1 & 0\\ 9 & 5\end{vmatrix} - 4\begin{vmatrix}16 & -1\\ -1 & 9\end{vmatrix}} = \frac{-I_2}{8\begin{vmatrix}-1 & 0\\ 9 & 5\end{vmatrix} - 4\begin{vmatrix}-5 & -1\\ 0 & 9\end{vmatrix}}$$

$$= \frac{I_3}{-4\begin{vmatrix}-5 & 16\\ 0 & -1\end{vmatrix} + 5\begin{vmatrix}8 & -5\\ -5 & 16\end{vmatrix}}$$

$$= \frac{-1}{8\begin{vmatrix}16 & -1\\ -1 & 9\end{vmatrix} + 5\begin{vmatrix}-5 & -1\\ 0 & 9\end{vmatrix}}$$

$$\frac{I_1}{-5(-5) - 4(143)} = \frac{-I_2}{8(-5) - 4(-45)}$$

$$= \frac{I_3}{-4(5) + 5(103)}$$

$$= \frac{-1}{8(143) + 5(-45)}$$

$$\frac{I_1}{-547} = \frac{-I_2}{140} = \frac{I_3}{495} = \frac{-1}{919}$$

$$\text{Hence } I_1 = \frac{547}{919} = 0.595\text{ A},$$

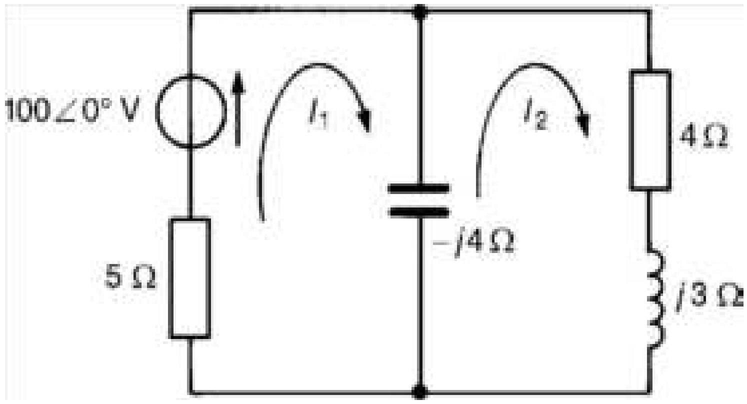
$$I_2 = \frac{140}{919} = 0.152\text{ A, and}$$

$$I_3 = \frac{-495}{919} = -0.539\text{ A}$$

(a) Currentinthe5Ωresistance= $I_1 - I_2$
=0.595 −0.152
=0.44A

(b) Currentinthe1Ω resistance= $I_2 - I_3$
=0.152 −(−0.539)
=0.69A

Problem 2: For the a.c. network shown in Figure determine, using mesh-current analysis, (a) themesh currents *I*1 and *I*2 (b) the current flowing in the capacitor, and (c) the active power deliveredbythe 100∠0◦V voltagesource.



(a)Forthefirstloop

$(5-j4)I_1-(-j4I_2) = 100\angle 0^\circ$ ....(1)

Forthesecondloop

$(4+j3-j4)I_2-(-j4I_1)=0$..(2)

Rewritingequations(1)and (2) gives:

$(5-j4)I_1+j4I_2-100=0$

$j4I_1 + (4-j) I2+0=0$

Thus,usingdeterminants,

(b) Current flowing

$= I_1 - I_2$

$= 10.77\angle 19$

$= 4.44 + j12$

i.e. the current

(c) Source power P

(Check: power

an

$$\frac{I_1}{\begin{vmatrix} j4 & -100 \\ (4-j) & 0 \end{vmatrix}} = \frac{-I_2}{\begin{vmatrix} (5-j4) & -100 \\ j4 & 0 \end{vmatrix}} = \frac{1}{\begin{vmatrix} (5-j4) & j4 \\ j4 & (4-j) \end{vmatrix}}$$

$$\frac{I_1}{(400-j100)} = \frac{-I_2}{j400} = \frac{1}{(32-j21)}$$

Hence $I_1 = \dfrac{(400-j100)}{(32-j21)} = \dfrac{412.31\angle -14.04^\circ}{38.28\angle -33.27^\circ}$

$= 10.77\angle 19.23^\circ$ A $=$ **10.8∠−19.2° A,** correct to one decimal place

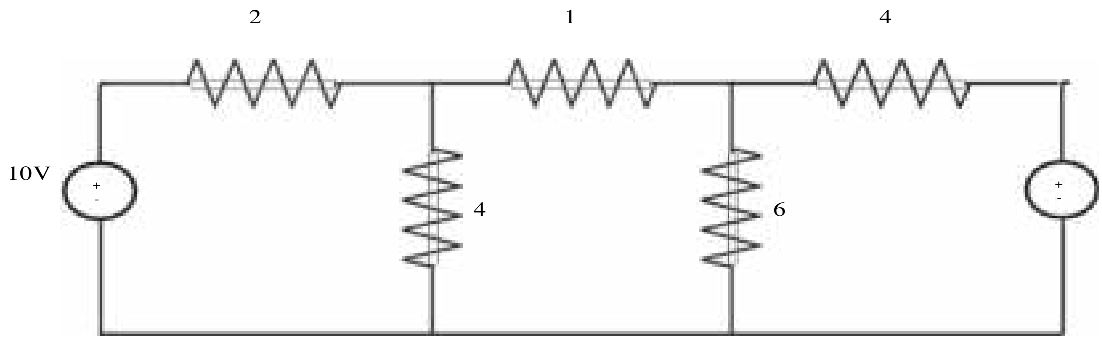
$$I_2 = \frac{400\angle -90^\circ}{38.28\angle -33.27^\circ} = 10.45\angle -56.73^\circ \text{ A}$$

$= \mathbf{10.5\angle -56.7^\circ}$ **A,**

Thustotal powerdissipated =579.97 +436.81

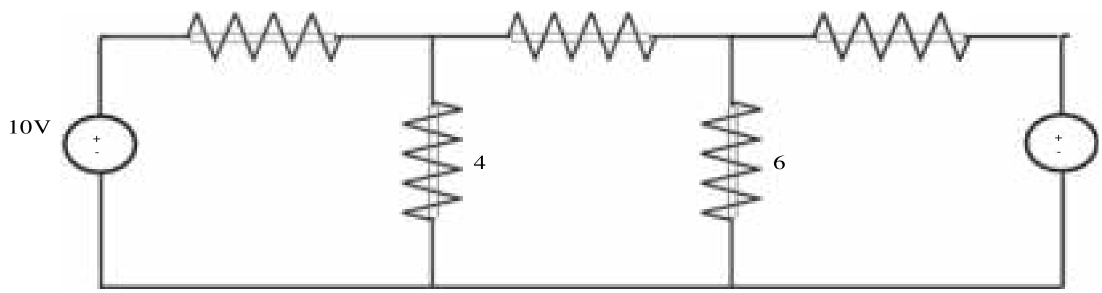
=1016.8W=1020W

Problem3: Calculatecurrentthrough6Ω resistanceusingloopanalysis.(AU-JUNE-12)



Solution:

2 1 4



Case(1):Consider loopABGH; ApplyKVL.

$10=2I1+4(I_1-I_2)$

$10=6I_1-4I_2$ ---------------------(1)

Consider loop

BCFG$I_2+6(I_2+I_3)+4(I_2-$

$I_1)=0$

$1_1I_2+6I_3-4I_1=0$ -------------- (2)

Consider loop

CDEF$20=4I_3+6(I$

$_2=I_3)$

$20=10I_3+6I_2$-------------------(3)

D= 6-4 0
-4116
0 6 10

= 10
0
20

D =[6 (110 – 36) +4(-40)]=284.

$$D_1 = \begin{vmatrix} 10 & -4 & 0 \\ 0 & 11 & 6 \\ 20 & 6 & 10 \end{vmatrix}$$

D_1 =10[110-36+(-120)]

=260

$$D_2 = \begin{vmatrix} 6 & 10 & 0 \\ -4 & 0 & 6 \\ 0 & 20 & 10 \end{vmatrix}$$

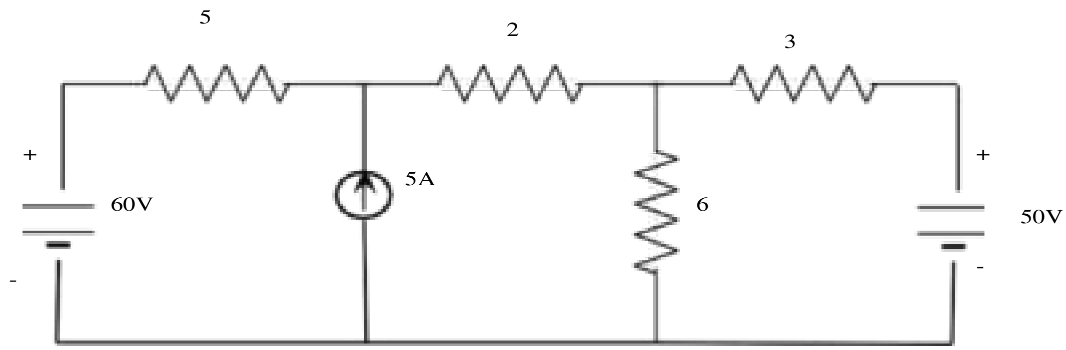
D_2 =6(-120)-10(-40)=-320

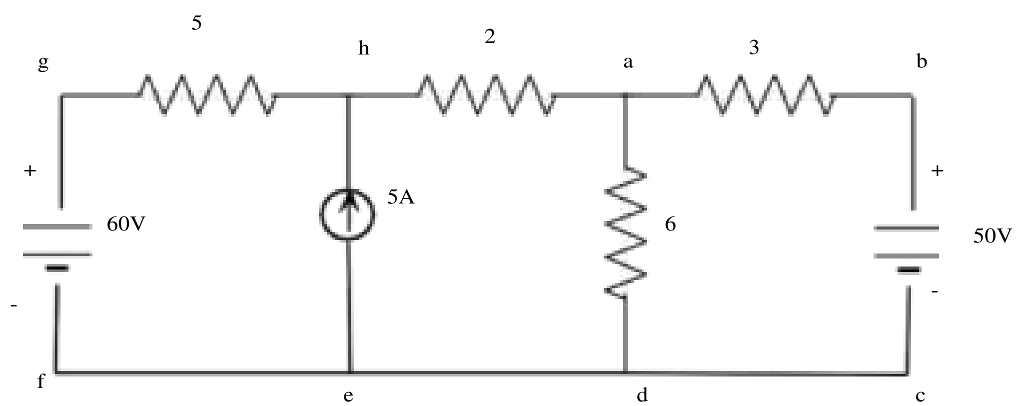
$$D_3 = \begin{vmatrix} 6 & -4 & 10 \\ -4 & 11 & 0 \\ 0 & 6 & 20 \end{vmatrix}$$

D_3 =6(220)+4(-80)+10(-24)
D_3 =760

I_1 =D_1/D =260/284= 0.915A
I_2 = D_2/D = -320/284 = -
1.1267AI_3 =D_3/D =760/284 =
2.676A
Currentthrough6Ωresistance= I_2+I_3
=-1.1267+2.676=1.55A

Problem4: Findthecurrentthroughbrancha-busingmeshanalysis.(JUN-09)





Solution:
Considerloops
Loop HADE → $5I_1+2I_2+6(I_2-I_3)$ =
$605I_1+8I_2-6I_3=60$ ---------- (1)
LoopABCDA→$3I_3+6(I_3-I_2)=-50$
$3I_3+6I_3-6I_2=-50$
$9I_3-6I_2=-50$ -----------(2)
$I_2-I_1=5A$ -------------------------- (3)
From(1),(2)&(3).

$$D=\begin{vmatrix} -1 & 1 & 0 \\ 5 & 8 & -6 \\ 0 & -6 & 9 \end{vmatrix}$$

=-1(72-36)-1(45)

D=-81.

$$D_3 = \begin{vmatrix} -1 & 1 & 5 \\ 5 & 8 & 60 \\ 0 & -6 & -50 \end{vmatrix}$$

= -1(-400+360)-(-250)+5(-30)

= 40+250-150

D_3 = 140.

$I_3 = D_3/D = 140/-81 = -1.7283$

Thecurrent throughbranch ab is1.7283A which isflowingfrom bto a.

1.9. NODALANALYSIS:

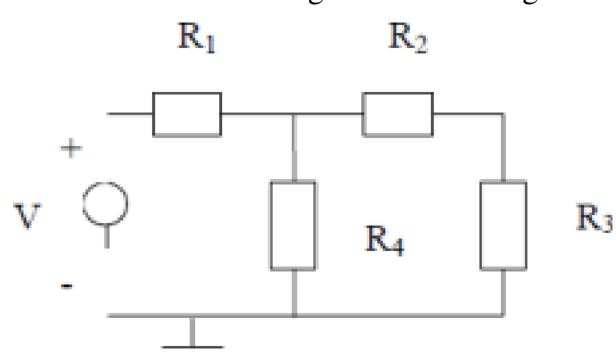
Nodal analysis involves looking at a circuit and determining all the node voltages in thecircuit. The voltage at any given node of a circuit is the voltage drop between that node and areferencenode(usuallyground). Oncethe nodevoltagesareknown anyofthe currentsflowinginthecircuitcanbedetermined.Thenodemethodoffersanorganizedwayofachievingthis.

Approach:

Firstly all the nodes in the circuited are counted and identified. Secondly nodes at which thevoltage is already known are listed. A set of equations based on the node voltages are formed andthese equations are solved for unknown quantities. The set of equations are formed using KCL ateach node. The set of simultaneous equations that is produced is then solved. Branch currents canthenbefound oncethenodevoltages areknown. This can bereducedtoaseries of steps:

Step1:Identifythe nodes
Step2: Chooseareferencenode
Step 3: Identify which node voltages are known if
anyStep4:Identifythe BRANCH currents
Step5: UseKCLto write an equation for each unknown
nodevoltageStep6: Solve theequations

Thisisbest
illustratedwithanexample.Findallcurrentsandvoltagesinthefollowingcircuitusingthenodemethod. (In



thisparticular caseit can besolvedin otherways aswell)

Step1:

Thereare fournodes inthecircuit.A,B,C andD

Step2:

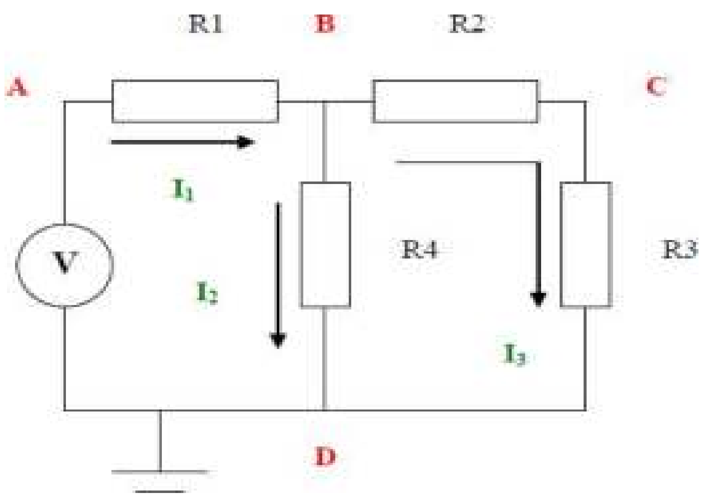
Ground,nodeD isthereferencenode.

Step3:

Nodevoltage BandC areunknown. Voltage at AisV andat Dis 0

Step4:

Thecurrentsareasshown. Thereare3differentcurrents



Step5:
Ineedto create two equationssoIapplyKCLat node BandnodeCThestatement ofKCLfor nodeBisas follows:

$$\frac{V - V_B}{R_1} + \frac{V_C - V_B}{R_2} + \frac{-V_B}{R_4} = 0$$

Thestatement ofKCLfor nodeC is as follows:

$$\frac{V_C - V_B}{R_2} + \frac{-V_B}{R_3} = 0$$

Step6:
WenowhavetwoequationstosolveforthetwounknownsVBandVC.Solvingtheabovetwoequations we get:

$$V_C = V\frac{R_3R_4}{R_1R_2 + R_1R_3 + R_1R_4 + R_2R_4 + R_3R_4}$$

$$V_B = V\frac{R_4(R_2 + R_3)}{R_1R_2 + R_1R_3 + R_1R_4 + R_2R_4 + R_3R_4}$$

FurtherCalculations
Thenodevoltagesareknowallknown.Fromthesewecangetthebranchcurrentsbyasimpleapplication ofOhm'sLaw:

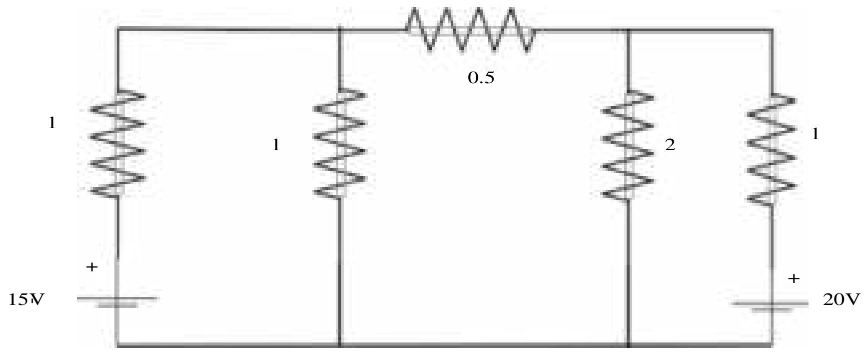
$$I_1 = (V - V_B) / R_1$$

$$I_2 = (V_B - V_C) / R_2$$

$$I_3 = (V_C) / R_3$$

$$I_4 = (V_B) / R_4$$

Problem1: Findthecurrentthrougheachresistorofthecircuitshowninfig,usingnodalanalysis



Solution:

Atnode1,

$-I_1-I_2-I_3=0$
$-[V_1-15/1]-[V_1/1][V_1-V_2/0.5]=0$
$-V_1+15-V_1-2V_1+2V_2 =0$
$4V_1-2V_2 =15$.................................(1)

Atnode2,

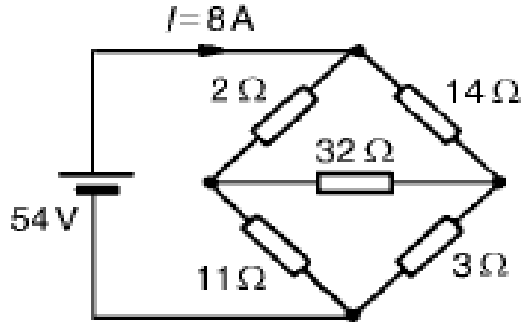
I_3-I4-I5=0
$V_1-V_2/0.5 – V_2/2 – V_2-20/1 =$
$02V_1-2V_2-0.5V_2-V_2 +20 =0$
$2V_1-3.5V_2 =-20$------------------- (2)

Multiplying(2)by2&subtractingfrom(1)

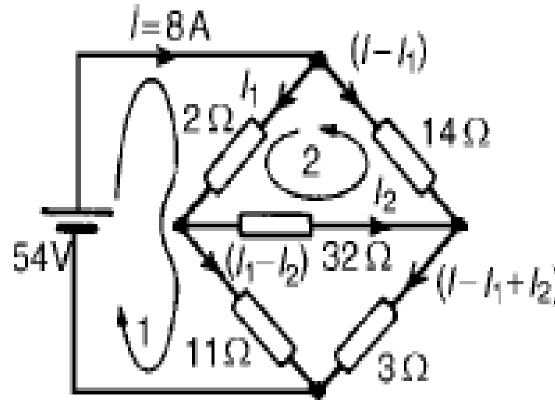
$5V_2=55V_2$
=
11VV=9.2
5V

$I_1=V_1-5/1=9.25-15 =-5.75A=5.75I_2$
$=V_1/1 = 9.25A$
$I_3 =V_1-V_2/0.5=-3.5A =3.5A\leftarrow$
I4=$V_2/2$ =5.5A
I5=V_2-20/I=11-20/1=-9A=9A.

Problem2: ForthebridgenetworkshowninFiguredeterminethecurrentsineachoftheresistors.(DEC-07)



Let the current in the 2 resistor be I_1, and then by Kirchhoff's current law, the current in the 1₄resistor is (I -I_1). Let the current in the 32 resistor be I_2 as shown in Figure Then the current in the 1₁resistor is (I_1 - I_2) and that in the 3 resistor is (I - I_1 + I_2). Applying Kirchhoff's voltage law to loop 1andmovingin aclockwisedirection as showninFigure gives:

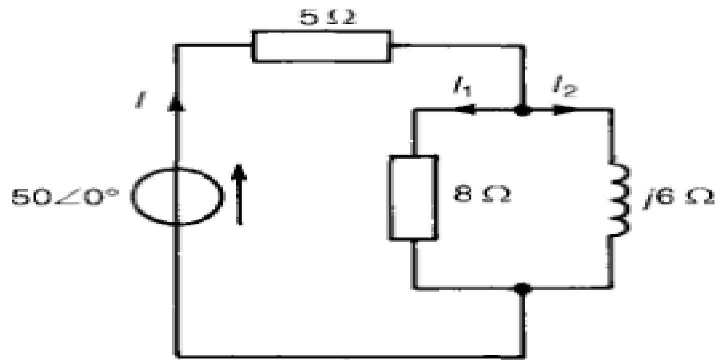


54 = $2I_1$ +11(I_1 _-
I_2)i.e.$13I_1$ -$11I_2$ =54
ApplyingKirchhoff'svoltagelawtoloop2andmovinginananticlockwisedirecti
onas shown in Figure gives:

0=$2I_1$ +$32I_2$-14(I-I_1)

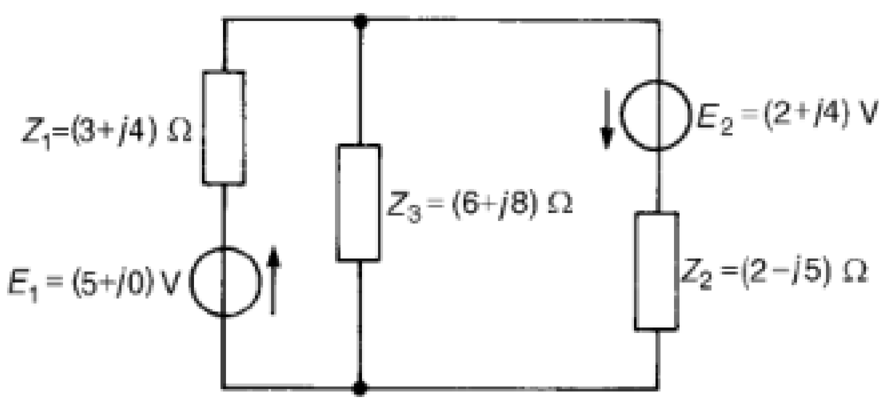
However I=8 A
Hence 0 = $2I_1$ + $32I_2$ – 14(8 -
_I_1)i.e.$16I_1$+$32I_2$=11₂
Equations (1) and (2) are simultaneous equations with two unknowns, I_1 and
I_2.16* (1)gives: $208I_1$_-$176I_2$=864
13*(2) gives:$208I_1$+$416I_2$ =1456
(4)-(3) gives: $592I_2$=592,I_2 =1 A
SubstitutingforI2in (1)gives:
$13I_1$ -1_1=54
I_1 =65/1_3 =5 A
Hence,
thecurrentflowinginthe2resistor=I_1=5A
the current flowing in the 14resistor = I -I_1 = 8 -5 = 3
Athecurrent flowinginthe32resistor = I_2=1 A
thecurrentflowingin the 11resistor=I_1- I_2=5 -1=4 Aand
thecurrentflowinginthe 3resistor=I-I_1+I_2=8-5 +1=4 A

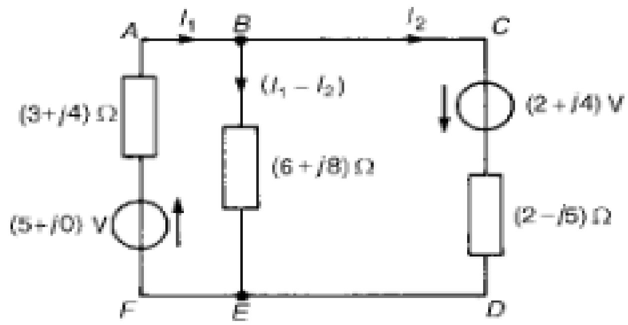
Problem3: Determinethevaluesof currentsI,I1andI2showninthenetworkofFigure



Totalcircuitimpedance,
Z_T=5+(8)(j6)/8+ j6
=5 +(j48)(8-j6)/8^2+6^2
=5 +(j384 + 288)/100
=(7.88 +j3.84) or 8.776 25.98° A
CurrentI=V/Z_T
=50∟ 0°/8.77∟ 25.98°
=5.7066−25.98° A
Current I1=I(j6/8+j6)
=(5.702∟5.98°)(6∟90°)/10∟ 36.87°
=3.426∟27.15° A
CurrentI2=I(8/(8+j6)
=(5.70∟-25.98°)*8∟ 0°/10∟ 36.87°
=4.5666−62.85° A
[Note:I=I1 + I2=3.42∟27.15°+4.56∟-62.85°
=3.043 +j1.561+2.081 -j4.058
=5.124 -j2.497 A =5.706 -25.98° A

Problem4: Forthea.c.networkshowninFigure,determinethecurrentflowingineachbranchusingKirchhoff's laws.





$$\text{from which, } \boldsymbol{I_1} = \frac{20+j55}{64+j27} = \frac{58.52\angle 70.02^\circ}{69.46\angle 22.87^\circ} = \mathbf{0.842\angle 47.15^\circ\ A}$$

$$= (0.573 + j0.617)\ \text{A}$$

$$= \mathbf{(0.57 + j0.62)\ A}, \text{ correct to two decimal places.}$$

From equation (1), $5 = (9 + j12)(0.573 + j0.617) - (6 + j8)I_2$

$$5 = (-2.247 + j12.429) - (6 + j8)I_2$$

$$\text{from which, } \boldsymbol{I_2} = \frac{-2.247 + j12.429 - 5}{6 + j8}$$

$$= \frac{14.39\angle 120.25^\circ}{10\angle 53.13^\circ}$$

$$= \mathbf{1.439\angle 67.12^\circ A} = (0.559 + j1.326)\ \text{A}$$

$$= \mathbf{(0.56 + j1.33)A}, \text{ correct to two decimal places.}$$

The current in the $(6 + j8)\Omega$ impedance,

$$\boldsymbol{I_1 - I_2} = (0.573 + j0.617) - (0.559 + j1.326)$$

$$= \mathbf{(0.014 - j0.709)A \text{ or } 0.709\angle -88.87^\circ\ A}$$

An alternative method of solving equations (1) and (2) is shown below, using determinants.

$$(9 + j12)I_1 - (6 + j8)I_2 - 5 = 0 \qquad (1)$$

$$-(6 + j8)I_1 + (8 + j3)I_2 - (2 + j4) = 0 \qquad (2)$$

$$\text{Thus}\quad \frac{I_1}{\begin{vmatrix} -(6+j8) & -5 \\ (8+j3) & -(2+j4) \end{vmatrix}} = \frac{-I_2}{\begin{vmatrix} (9+j12) & -5 \\ -(6+j8) & -(2+j4) \end{vmatrix}}$$

$$= \frac{1}{\begin{vmatrix} (9+j12) & -(6+j8) \\ -(6+j8) & (8+j3) \end{vmatrix}}$$

$$\frac{I_1}{(-20+j40)+(40+j15)} = \frac{-I_2}{(30-j60)-(30+j40)}$$

$$= \frac{1}{(36+j123)-(-28+j96)}$$

$$\frac{I_1}{20+j55} = \frac{-I_2}{-j100} = \frac{1}{64+j27}$$

$$\text{Hence}\quad I_1 = \frac{20+j55}{64+j27} = \frac{58.52\angle 70.02^\circ}{69.46\angle 22.87^\circ}$$

$$= \mathbf{0.842\angle 47.15^\circ\ A}$$

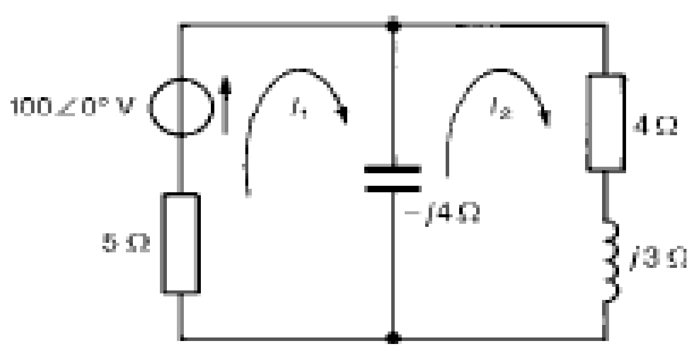
$$\text{and}\qquad I_2 = \frac{100\angle 90^\circ}{69.46\angle 22.87^\circ} = \mathbf{1.440\angle 67.13^\circ\ A}$$

The current flowing in the $(6 + j8)\ \Omega$ impedance is given by:

$$I_1 - I_2 = 0.842\angle 47.15^\circ - 1.440\angle 67.13^\circ A$$

$$= \mathbf{(0.013 - j0.709)\ A\ or\ 0.709\angle -88.95^\circ\ A}$$

Problem 5: For the a.c. network shown in Figuredetermine, using mesh-current analysis, (a) themesh currents $I_1$and I_2 (b) the current flowing in the capacitor, and (c) the active power deliveredbythe 1006 0° Vvoltagesource.



(a) For the first loop $(5 - j4)I_1 - (-j4I_2) = 100\angle 0^\circ$ (1)

For the second loop $(4 + j3 - j4)I_2 - (-j4I_1) = 0$ (2)

Rewriting equations (1) and (2) gives:

$$(5 - j4)I_1 + j4I_2 - 100 = 0 \qquad (1')$$

$$j4I_1 + (4 - j)I_2 + 0 = 0 \qquad (2')$$

Thus, using determinants,

$$\frac{I_1}{\begin{vmatrix} j4 & -100 \\ (4-j) & 0 \end{vmatrix}} = \frac{-I_2}{\begin{vmatrix} (5-j4) & -100 \\ j4 & 0 \end{vmatrix}} = \frac{1}{\begin{vmatrix} (5-j4) & j4 \\ j4 & (4-j) \end{vmatrix}}$$

$$\frac{I_1}{(400 - j100)} = \frac{-I_2}{j400} = \frac{1}{(32 - j21)}$$

Hence $$I_1 = \frac{(400 - j100)}{(32 - j21)} = \frac{412.31\angle -14.04^\circ}{38.28\angle -33.27^\circ}$$

$$= 10.77\angle 19.23^\circ \text{ A} = \mathbf{10.8\angle -19.2^\circ \text{ A}},$$

correct to one decimal place

$$I_2 = \frac{400\angle -90^\circ}{38.28\angle -33.27^\circ} = 10.45\angle -56.73^\circ \text{ A}$$

$$= \mathbf{10.5\angle -56.7^\circ \text{ A}},$$

correct to one decimal place

(b) Current flowing in capacitor $= I_1 - I_2$

$$= 10.77\angle 19.23^\circ - 10.45\angle -56.73^\circ$$

$$= 4.44 + j12.28 = 13.1\angle 70.12^\circ \text{ A}$$

i.e., **the current in the capacitor is 13.1 A**

(c) Source power $P = VI\cos\phi = (100)(10.77)\cos 19.23°$

$= \mathbf{1016.9\ W} = 1020$ W,

correct to three significant figures.

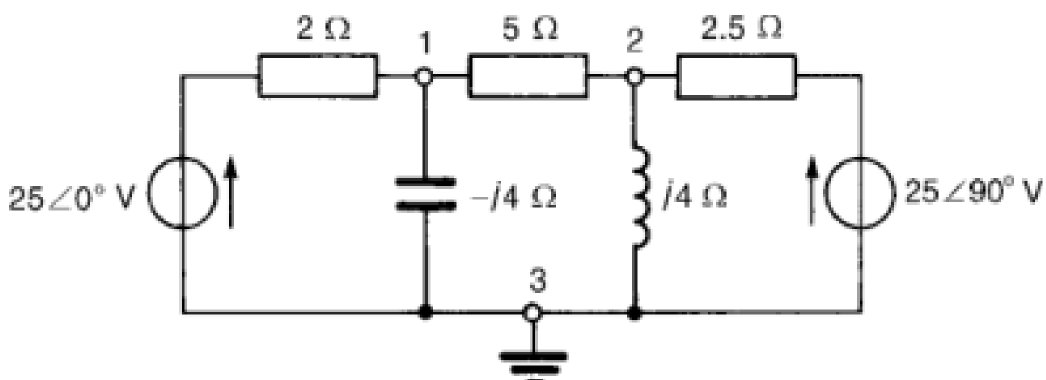
(Check: power in 5 Ω resistor $= I_1^2(5) = (10.77)^2(5) = 579.97$ W

and power in 4 Ω resistor $= I_2^2(4) = (10.45)^2(4) = 436.81$ W

Thus total power dissipated $= 579.97 + 436.81$

$= 1016.8$ W $= 1020$ W, correct to three significant figures.)

Problem 6: In the network of Figure use nodal analysis to determine (a) the voltage at nodes 1 and2, (b) the current in the j4 Ω inductance, (c) the current in the 5 Ω resistance, and (d) the magnitudeofthe activepower dissipated in the 2.5 Ωresistance.(AUDEC-10)



(a) At node 1, $\frac{V_1 - 25\angle 0^\circ}{2} + \frac{V_1}{-j4} + \frac{V_1 - V_2}{5} = 0$

Rearranging gives:

$$\left(\frac{1}{2} + \frac{1}{-j4} + \frac{1}{5}\right) V_1 - \left(\frac{1}{5}\right) V_2 - \frac{25\angle 0^\circ}{2} = 0$$

i.e., $$(0.7 + j0.25)V_1 - 0.2V_2 - 12.5 = 0 \qquad (1)$$

At node 2, $\frac{V_2 - 25\angle 90^\circ}{2.5} + \frac{V_2}{j4} + \frac{V_2 - V_1}{5} = 0$

Rearranging gives:

$$-\left(\frac{1}{5}\right) V_1 + \left(\frac{1}{2.5} + \frac{1}{j4} + \frac{1}{5}\right) V_2 - \frac{25\angle 90^\circ}{2.5} = 0$$

i.e., $$-0.2V_1 + (0.6 - j0.25)V_2 - j10 = 0 \qquad (2)$$

Thus two simultaneous equations have been formed with two unknowns, V_1 and V_2. Using determinants, if

$$(0.7 + j0.25)V_1 - 0.2V_2 - 12.5 = 0 \qquad (1)$$

and $$-0.2V_1 + (0.6 - j0.25)V_2 - j10 = 0 \qquad (2)$$

then $$\frac{V_1}{\begin{vmatrix} -0.2 & -12.5 \\ (0.6 - j0.25) & -j10 \end{vmatrix}} = \frac{-V_2}{\begin{vmatrix} (0.7 + j0.25) & -12.5 \\ -0.2 & -j10 \end{vmatrix}}$$

$$= \frac{1}{\begin{vmatrix} (0.7 + j0.25) & -0.2 \\ -0.2 & (0.6 - j0.25) \end{vmatrix}}$$

i.e.,

$$\frac{V_1}{(j2+7.5-j3.125)} = \frac{-V_2}{(-j7+2.5-2.5)}$$

$$= \frac{1}{(0.42-j0.175+j0.15+0.0625-0.04)}$$

and $$\frac{V_1}{7.584\angle -8.53^\circ} = \frac{-V_2}{-7\angle 90^\circ} = \frac{1}{0.443\angle -3.23^\circ}$$

Thus **voltage,** $\boldsymbol{V_1} = \dfrac{7.584\angle -8.53^\circ}{0.443\angle -3.23^\circ} = 17.12\angle -5.30^\circ$ V

$= \mathbf{17.1\angle -5.3^\circ}$ **V**, correct to one decimal place,

and **voltage,** $\boldsymbol{V_2} = \dfrac{7\angle 90^\circ}{0.443\angle -3.23^\circ} = 15.80\angle 93.23^\circ$ V

$= \mathbf{15.8\angle 93.2^\circ}$ **V**, correct to one decimal place.

(b) The current in the $j4\ \Omega$ inductance is given by:

$\dfrac{V_2}{j4} = \dfrac{15.80\angle 93.23^\circ}{4\angle 90^\circ} = \mathbf{3.95\angle 3.23^\circ}$ **A flowing away from node 2**

(c) The current in the 5 Ω resistance is given by:

$$I_5 = \frac{V_1 - V_2}{5} = \frac{17.12\angle -5.30^\circ - 15.80\angle 93.23^\circ}{5}$$

i.e., $$I_5 = \frac{(17.05 - j1.58) - (-0.89 + j15.77)}{5}$$

$$= \frac{17.94 - j17.35}{5} = \frac{24.96\angle -44.04^\circ}{5}$$

$= \mathbf{4.99\angle -44.04^\circ}$ **A flowing from node 1 to node 2**

(d) The active power dissipated in the 2.5 Ω resistor is given by

$$P_{2.5} = (I_{2.5})^2(2.5) = \left(\frac{V_2 - 25\angle 90^\circ}{2.5}\right)^2 (2.5)$$

$$= \frac{(0.89 + j15.77 - j25)^2}{2.5} = \frac{(9.273\angle -95.51^\circ)^2}{2.5}$$

$$= \frac{85.99\angle -191.02^\circ}{2.5} \text{ by de Moivre's theorem}$$

$$= 34.4\angle 169^\circ \text{ W}$$

5.1. RESISTANCESINSERIES

IftheendingterminaloftheresistanceR$_1$isconnectedtothebeginningterminalof the resistance R_2 and the ending terminal of R_2 is connected to the beginningterminal of the resistance R_3 and so on then the resistances R_1, R_2, R_3, etc., are saidtobeconnectedinseries.

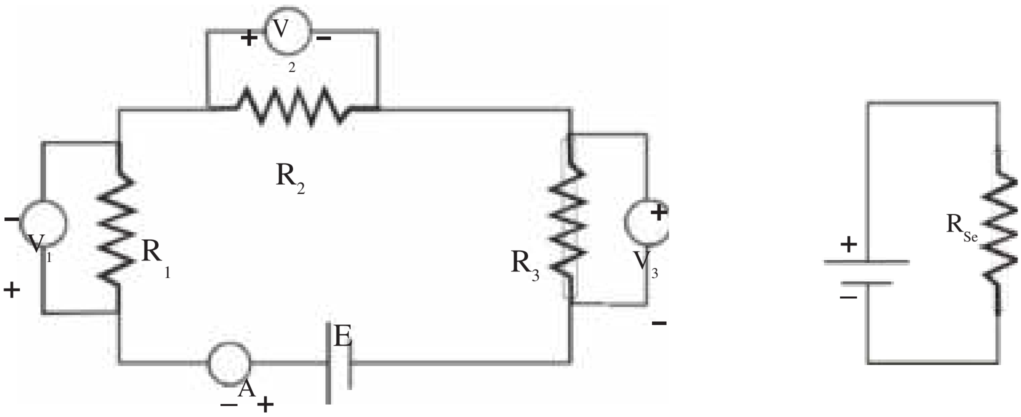
Inseriescircuits,theelementsintheseriescanbeconnectedinanyorder.For example, R_2, R_3, R_1, etc., instead of R_1, R_2 R_3 etc. In series circuits, the same current willflowthroughalltheelementsinseries.

In D.C. series circuits, while connecting the elements in series, one should bevery careful of the polarities of the meters used to measure the currents or voltagesorthepolaritiesoftheequipment.Positivepolaritiesofthemetersortheequipmentsshouldalwaysbeconnectedtothepositiveofthesupplypointandthenegativeterminalsshould be connected to the negative of the supply point.While two equipments areconnected in series, the positive of the first equipment should be connected to thepositive terminal of the supply point.Negative terminal of the first equipment shouldbeconnectedtothepositiveterminalofthesecondequipmentandthenegativeterminalof the second equipment should be connected to the positive terminal of the thirdequipmentandsoon.

Ammeters are used to measure the currents. The ammeters should always beconnectedinseriesinthecircuitsothatthecurrenttobemeasuredflowsthroughtheammeters.In order that, the voltage drop across the ammeter to be very very

smallsothatfullcurrentflowsthroughthecircuit,theresistanceoftheammetershouldbeveryverysmall.Hence,iftheammeterisconnectedacrossthesupplyor acrosstwopoints having large voltage drop, very heavy current will flow through the ammeterandtheammeterwillgetburnt.

Voltmeters are used to measure the voltage of the supply or voltage dropbetweentwopointsinorderthatthevoltmeterdoesnotdrawmorecurrentsoast o



(a)SeriesCircuit **(b)EquivalentcircuitforFig.(a)**

Fig.1.10*CircuitwithResistancesinSeries*

allow full current in the circuit, the voltmeters should have very high resistance.Ifthe voltmeter is connected in series, it causes high voltage drop across it and thevoltage supplied to the remaining circuit will be less.Hence, voltmeters should beconnectedonlyinparallelandnotinseries.

IntheclosedcircuitABCDAgiveninFig.1.10(a),applyingKirchoff'sVoltageLaw,wehave,

$$E - V_1 - V_2 - V_3 = 0 \qquad ....(1.9.1)$$

$$E - IR_1 - IR_2 - IR_3 = 0 \qquad ....(1.9.1a)$$

or $$IR_1 + IR_2 + IR_3 = E \qquad ....(1.9.1b)$$

or $$I(R_1 + R_2 + R_3) = E \qquad ....(1.9.1c)$$

FortheequivalentcircuitofFig.1.10(b),

$$IR_{Se} = E \qquad ....(1.9.2)$$

ComparingEq.(1.9.1c)and(1.9.2)wehave,

$$R_{Se} = (R_1 + R_2 + R_3)$$

Ingeneralfornresistancesinseries,

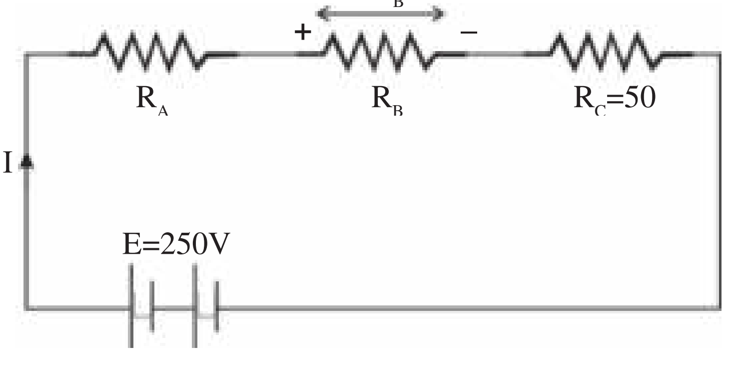
$$R_{Se} = \sum_{i=1}^{n} R_i \qquad ....(1.9.3)$$

Intermsofconductancesforresistancesinseries,

$$\frac{1}{G_{Se}} = \sum_{i=1}^{n} \frac{1}{G_i} \qquad ....(1.9.4)$$

Example1.6:

Fig.belowshowsthreeresistorsR_A,$R_B$and$R_C$connectedinseriestoa250Vsource;GivenR_C=50Λ,andV_B=80Voltswhenthecurrentis2Amperes,calculatethetotalresistances,$R_A$andR_B.



Solution:

Since I

$=2$Amperes

$V_B = IR_B$

$=80V$

$R_B = 40\Lambda$

Also, $I = \dfrac{E}{(R_A \; (c) \; R_B \; (d) \; R_C)}$

Therefore,

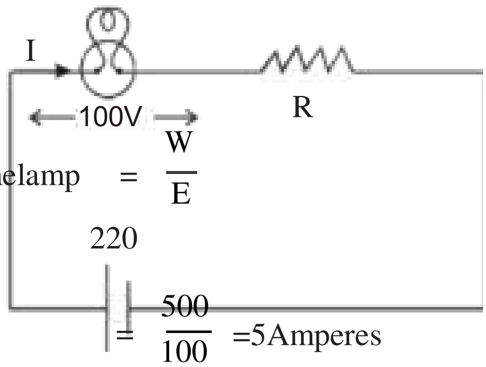
$$R_{Se} = R_A + R_B + R_C = \frac{E}{I} = \frac{250}{2} = 125\Lambda$$

Therefore, $R_A = R_{Se} - (R_B + R_C) = 35\Lambda$.

Example1.7:

Alamprated500W,100Vistobeoperatedfrom220Vsupply.Findthevalueof the resistor to be connected in series with the lamp. What is the power lost intheresistance.

Solution:



Currentinthelamp $= \dfrac{W}{E}$

$= \dfrac{500}{100} = 5$Amperes

SincetheVoltagedropacrossthelampis100V,Voltagetobedroppedintheseries resistoris120V.

Therefore, Valueofthe resistor $= \frac{120}{5}$

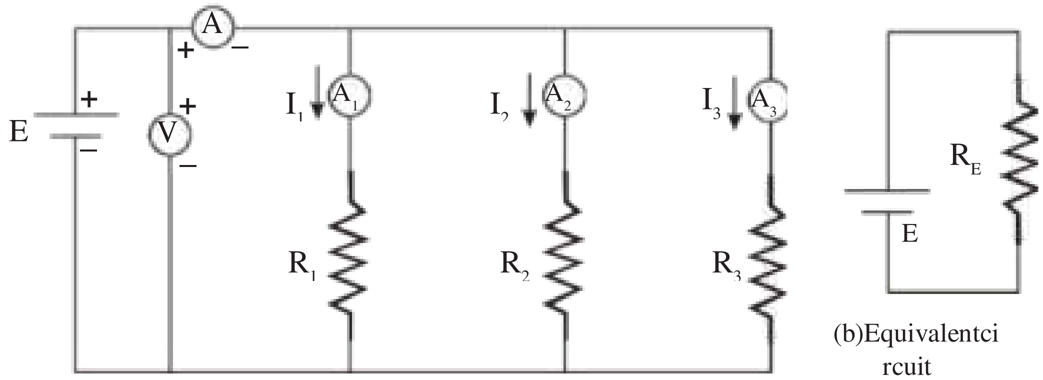
$=24\Lambda$

PowerLost in this resistor $=I^2R$

$= 5^2 \times 24 \quad =600W$

5.2. RESISTANCESINPARALLEL

If the starting terminal of two or more elements are connected together andthe ending terminals of these elements are connected together then the elements aresaidtobeconnectedinparallel.AparallelelementmayalsobeknownasaShunt Element.



(b)Equivalentci rcuit

(a)Parallelcirc uit

Fig.1.11*CircuitwithResistancesinParallel*

Thevoltageacrossalltheelementsthatareconnectedinparallelwillbesame.

InD.C.circuits,iftheelementsofthemetersortheequipmentswithpolarities marked are connected in parallel then terminals of the same polarities should beconnectedtogether.

In the parallel circuit given in the Fig. 1.11(a), applying Kirchoff's CurrentLawtothejunctionA,

$$I \quad =I_1+I_2+I_3 \quad \text{.......................} \quad (1.10.1)$$

ApplyingOhm'sLaw,

$$I = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3} \quad \text{..........(1.10.1a)}$$

FortheequivalentcircuitgiveninFig.1.14b,

$$I = \frac{E}{R_P} \quad \text{..........(1.10.2)}$$

ComparingEq.(1.16.2)and(1.16.1a)wehave,

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{..........(1.10.3)}$$

or Intermsofconductances,

$$G_P = G_1 + G_2 + G_3 \quad \text{..........(1.10.4)}$$

Ingeneralforparallelcircuitswithnresistancesinparallel,

$$\frac{1}{R_P} = \sum_{i=1}^{n} \frac{1}{R_i} \quad \text{..........(1.10.5)}$$

or

$$G_P = \sum_{i=1}^{n} G_i \quad \text{..........(1.10.6)}$$

IftworesistancesR$_1$andR$_2$areinparallel,

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} \quad \text{..........(1.10.7)}$$

or

$$R_P = \frac{R_1 R_2}{R_1 + R_2} \quad \text{..........(1.10.7a)}$$

Ifthetworesistancesareequalandinparalleli.

e., $R_1 = R_2 = R$

then,

$$R_P = \frac{R}{2} \qquad \text{..........(1.10.7b)}$$

IfthreeresistancesR_1,R_2andR_3areparallel,

$$\frac{1}{R_P} = \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3} \qquad \text{..........(1.10.8)}$$

or $$R_P = \frac{R_1R_2R_3}{R_1R_2+R_2R_3+R_3R_1} \qquad \text{..........(1.10.8a)}$$

Ifthreeresistancesareequal,i.e.,R_1=R_2=R_3=Rthen,

$$R_P = \frac{R}{3} \qquad \text{..........(1.10.9)}$$

Ingeneral,if nresistances,eachofvalueRareinparallelthe,

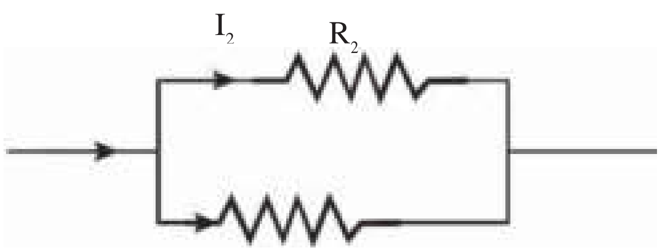
$$R_P = \frac{R}{n} \qquad \text{..........(1.10.10)}$$

1.10.1 DivisionofCurrentsinParallelCircuits

If two resistances R_1 and R_2 are connected in parallel and if the total currententering the parallel combination is I then this current I divides into two parts I_1flowingthroughR_1andI_2flowingthroughR_2.

Fig.1.12*DivisionofCurrentsinParallelCircuits*

TheVoltageDropacrosstheparallelcombinationwillbe



$$V_P = I\times R_P = I\times\left(\frac{R_1R_2}{R_1+R_2}\right) \text{ Volts}$$

The current I_1 flowingthroughR_1 willbegivenas,

$$I_1 = \frac{V_P}{R_1} = \frac{1}{R_1}\times I\times\left(\frac{R_1R_2}{R_1+R_2}\right) \text{ Amps}$$

$$I_1 = I\times\left(\frac{R_2}{R_1+R_2}\right) \text{ Amps} \quad \ldots\ldots\ldots\ldots (1.10.11)$$

WhentworesistancesR_1andR_2areinparallel,CurrentthroughR_1isgivenas,

$$I_1 = \text{TotalCurrent}\times\frac{\text{SecondResistance}}{\text{SumoftheTwoResistancesinParallel}}$$

..........(1.10.12)

ThisformisusedfrequentlyinElectronicCircuits.

Similarly,

$$I_2 = \frac{V_P}{R_2}$$

$$= \frac{1}{R_2}\times I\times\left(\frac{R_1R_2}{R_1+R_2}\right) \text{ Amps}$$

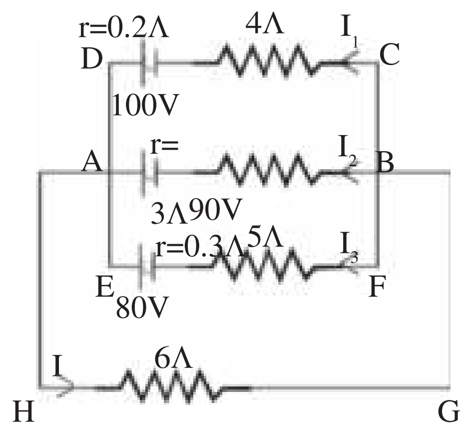
$$I_2 = I\times\left(\frac{R_1}{R_1+R_2}\right) \text{ Amps} \quad \ldots\ldots\ldots\ldots (1.10.13)$$

Also, $I_2=(I-I_1)$Amps

In general, *the current through any parallel path is given as the product of the totalcurrentandtheparallelequivalentresistancedividedbytheresistanceofthatpath* .

Example1.8:

Solvethe network showninthe figurefor the current through 6Λresistor.



Solution:

Letthecurrentflowingthroughvariousbranchesbeasmarkedinthefigure. ApplyingKirchoff'sVoltageLawtothefollowingclosedcircuits,

CircuitCDAHGBC,

$$-4I_1-0.2I_1+100-6(I_1+I_2+I_3) = 0$$

or $$10.2I_1+6I_2+6I_3=100 \quad \ldots\ldots(1)$$

CircuitBAHGB,

$$-3I_2-0.25I_2+90-6(I_1+I_2+I_3) = 0$$

or $$6I_1+9.25I_2+6I_3=90 \quad \ldots\ldots(2)$$

CircuitFEAHGBF,

$$-5I_3-0.3I_3+80-6(I_1+I_2+I_3) = 0$$

or $$6I_1+6I_2+11.3I_3=80 \quad \ldots\ldots(3)$$

Subtracting(2)from(1),weget,

$$4.2I_1-3.25I_2 =10 \quad \ldots\ldots(4)$$

Eqn.(2)x11.3 -Eqn.(3) x6gives

$$31.8I_1+68.525I_2=537 \quad \ldots\ldots(5)$$

Eqn.(5) x 4.2- Eqn.(4) x 31.8 gives

$$391.51I_2= 1937.4$$

$$I_2= 4.953A$$

FromEqn.(5)substitutingforI_2

I_1=6.21A

FromEqn.(3),substitutingforI_1

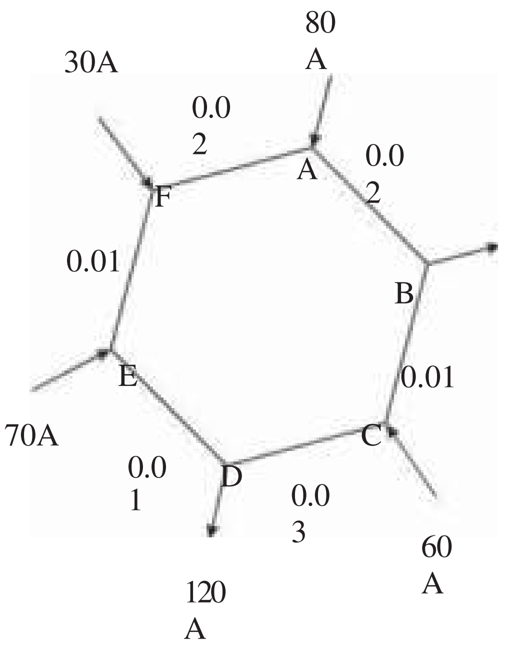
and$I_2$$I_3$=1.15A

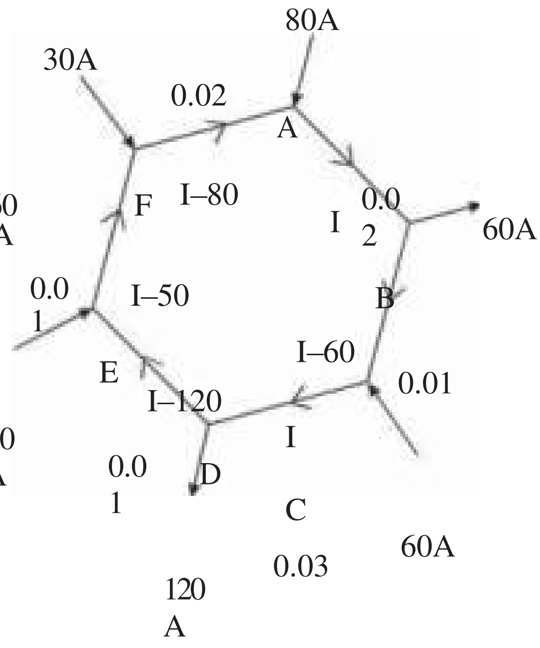
Currentin6Λresistor,

$$I = I_1+I_2+I_3$$
$$=6.21+4.953+1.15$$
$$=12.313A$$

Example1.9:

Find the magnitude and direction of the currents in all branches of the circuitshowninthefigureusingKirchoff'sLaws.AllresistancesareinOhms.





Solution:

Let current from A to B junctions be I Amps. Applying Kirchoff's First Law,letcurrentflowingthroughvariousbranchesbeasshowninthefigure.

ApplyingKirchoff'sCurrentLawtocurrentineachbranchandKirchoff'sVoltageLawtoaclosedloopABCDEFA,weget,

$$-0.02I-0.01(I-60)-0.03I-0.01(I-120)-0.01(I-50)$$
$$-0.02(I-80) \quad =0$$

or $0.02I+0.01I+0.03I+0.01I+0.01I+0.02I$

$$=0.6+1.2+0.5+1.6$$

or $0.1I = 3.9$

or $I = 39A$

Currentin various branches is as under :

I_{AB}	=	39A			(i.e.,AtoB)
I_{BC}	=	I–60	=	–21A	(i.e.,CtoB)
I_{CD}	=	I	=	39A	(i.e.,CtoD)
I_{DE}	=	I–120	=	–81A	(i.e.,EtoD)
I_{EF}	=	I–50	=	–11A	(i.e.,FtoE)
I_{FA}	=	I–80	=	–41A	(i.e.,AtoF)

- **SERIES-PARALLELRESISTANCES**

Inthecaseofseries-parallelresistances,theparallelequivalentoftheresistances in parallel are obtained first as a single resistance which will be in serieswith the other resistances, thus bringing the circuit into a single series circuit. Afterfinding the current flowing through this equivalent series circuit again the parallelequivalentresistancemaybereplacedwiththecorrespondingparallelcircuitandthecurrent in the parallel paths are calculated as given in the Section 1.10, *the currentthrough any parallel path is given as the product of the total current and theparallelequivalentresistancedividedbytheresistanceofthatpath.*

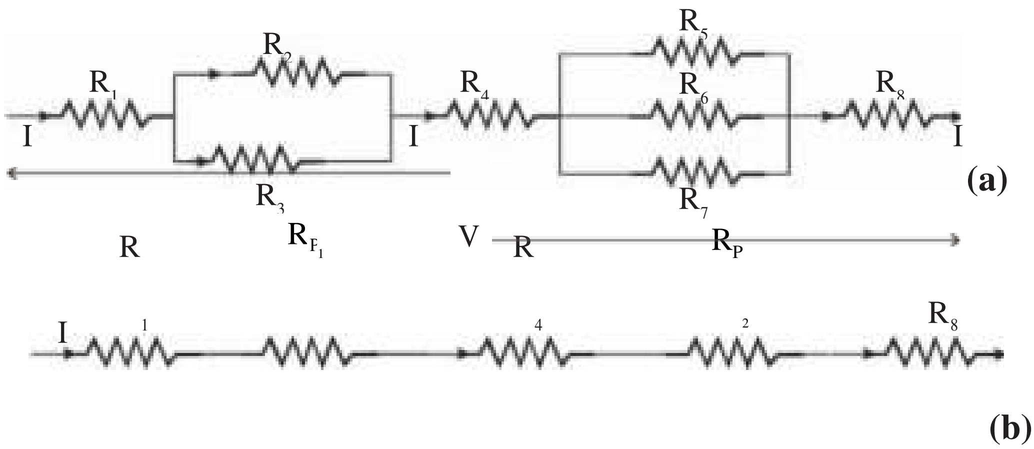


Fig.1.13*ResistanceinSeries-Parallel*

Typical values of currents are given below for the above circuit,

$$R_{P_1} = \left(\frac{R_2R_3}{R_2+R_3}\right)$$

$$R_{P_2} = \frac{R_5R_6R_7}{R_5R_6+R_6R_7+R_7R_5}$$

$$I = \frac{V}{R_1 + R_{P_1} + R_4 + R_{P_2} + R_8}$$

$$I_2 = I\times\left(\frac{R_3}{R_2+R_3}\right)$$

$$I_6 = \frac{I}{R_6}\left(\frac{R_5R_6R_7}{R_5R_6+R_6R_7+R_7R_5}\right)$$

Example 1.10:

A Wheatstone Bridge consists of AB=4Λ, BC=3Λ, CD=6Λ and DA=5Λ. A 2V Cell is connected between B and D and a Galvanometer of 10Λ resistance between A and C. Find the current through the Galvanometer.

Solution:

The circuit is shown in the figure. Applying Kirchoff's Current Law at junction B, A and C, the current in various branches is marked.

Applying Kirchoff's Voltage Law to various closed loops and considering loop BACB, we get,

$$-4I_1 - 10I_3 + 3I_2 = 0$$

or $\quad 4I_1 + 10I_3 - 3I_2 = 0$ ....(1)

Considering loop ADCA, we get

$$-5(I_1 - I_3) + 6(I_2 + I_3) + 10I_3 = 0$$

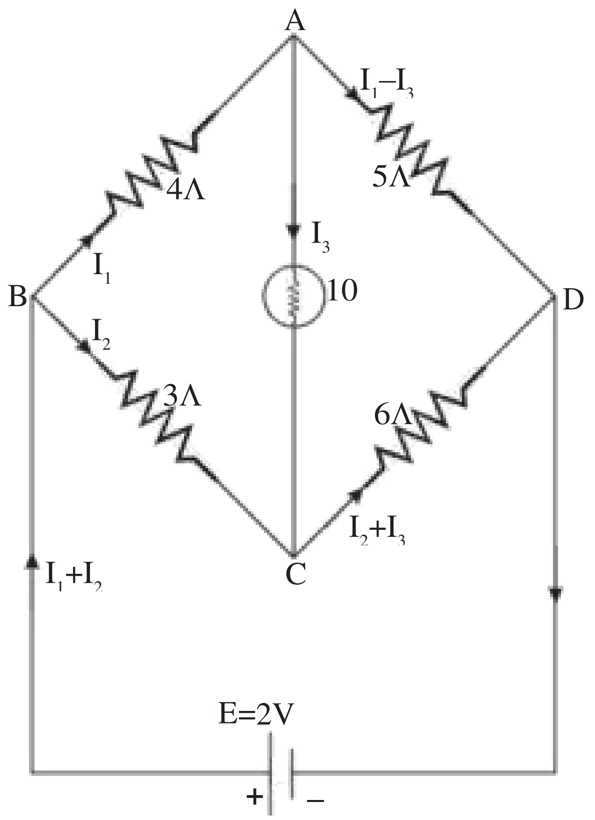
or $\quad 5I_1 - 6I_2 - 21I_3 = 0$ ....(2)

ConsideringloopBADEB,weget,

$$-4I_1 - 5(I_1 - I_3) + 2 = 0$$

or $\quad 4I_1 - 5I_1 + 5I_3 \quad = -2$ .... (3)

or $\quad 9I_1 - 5I_3 = \quad 2$



MultiplyingEq.(1)byEq.(2)andSubtractingfromEq.(2),weget,$5I_1 -$

$6I_2 - 21I_3$	$=0$
$8I_1 - 6I_2 + 20I_3$	$=0$
$-3I_1 \quad -41I_3$	$=0$

or $\quad I_1 = -\frac{41}{3}I_3$

SubstitutingthevalueofI_1inEq.(3),weget,

$$9\left(-\frac{41}{3}I_3\right)-5I_3 = 0$$

or $$-123I_3-5I_3 = 2$$

or $$I_3 = \text{(c) } \frac{1}{64}\text{A}$$

Example1.11:

Aresistanceof15ΛisconnectedinserieswithtworesistanceseachofΛ30arr angedinparallel.Avoltagesourceof30Visconnectedtothiscircuit.

(a) Whatisthecurrentdrawnfromthesource.

(b) Whatresistanceshouldbeplacedinshunt(parallel)withtheparallelcombinati oninorderthatthecurrentdrawnfromthesourceis1.2A.

Solution:

Thecircuitisasshowninthefiguregivenbelow.

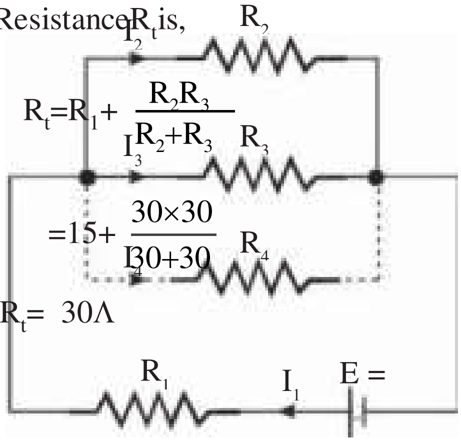
(a)R_1isinserieswiththeparallelcombinationofR_2andR_3.

Hence,TotalResistance$R_t$is,

$$R_t = R_1 + \frac{R_2R_3}{R_2+R_3}$$

$$= 15 + \frac{30\times30}{30+30}$$

$$R_t = 30\Lambda$$



Hencecurrent,

$$I_1 = \frac{E}{R_t}$$

$$I_1 = \frac{30}{30} = 1A$$

(b) WithI_1=1.2A,VoltageacrossR$_1$

$= I_1R_1 = 1.2 \times 15$

$= 18$ V

Voltage Drop across parallel combination of R_2, R_3 and

R_4 is,V_P $= 30 – 18$

V_P $= 12$ V

Hence, VoltageDropacrosseachresistorR_2,R_3,R_4is12V.

Hence, $I_2 = \frac{V_P}{R_2} = \frac{12}{30}$

$I_2 = 0.4A$

$$I_3 = \frac{V_P}{R_3} = \frac{12}{30}$$

$I_3 = 0.4A$

$I_4 = I_1 – (I_2 + I_3)$

$= 1.2 –$

$(0.4+0.4) I_4 = 0.4A$

$$I_4 = \frac{V_P}{R_4}$$

$0.4R_4 = 12$

Hence, $R_4 = \frac{12}{0.4}$

R_4 $= 30\Lambda$

UNIT IV

Network Theorems: Super Position Theorem – Thevenin's Theorem – Norton's Theorem – Thevenin to Norton Conversion (Theorem Statement and Simple problems)

INTRODUCTION:

Any complicated network i.e. several sources, multiple resistors are present if thesingle element response is desired then use the network theorems. Network theorems are also canbetermedas network reductiontechniques.Each andevery theorem gotits importanceofsolving network. Let us see some important theorems with DC and AC excitation with detailedprocedures.

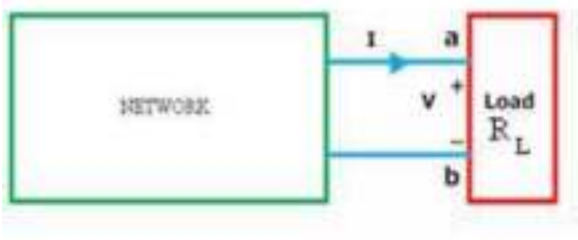
Thevenin'sTheoremandNorton'stheorem

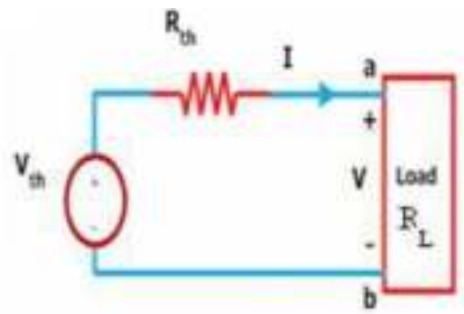
(Introduction) :

Thevenin's Theorem and Norton's theorem are two important theorems in solvingNetwork problems having many active and passive elements. Using these theorems the networkscan be reduced to simple equivalent circuits with one active source and one element. In circuitanalysis many a times the current through a branch is required to be found when it's value ischanged with all other element values remaining same. In such cases finding out every time thebranch current using the conventional mesh and node analysis methods is quite awkward andtimeconsuming.Butwiththesimpleequivalentcircuits(withoneactivesourceandoneelement) obtained using these two theorems the calculations becomevery simple. Thevenin'sandNorton'stheoremsaredualtheorems.

Thevenin'sTheoremStatement:

Anylinear,bilateraltwoterminalnetworkconsistingofsourcesandresistors(Impedance),can be replaced by an equivalent circuit consisting of a voltage source inserieswith aresistance(Impedance).Theequivalentvoltagesource**V_{Th}**istheopen circuitvoltage looking into the terminals(with concerned branch element removed) and the equivalentresistance **R_{Th}**while all sources are replaced by their internal resistors at ideal condition i.e.voltage source isshortcircuitandcurrentsource isopencircuit.





1- (b)

Figure (a)shows a simpleblockrepresentationof anetworkwithseveral active /passiveelements with the load resistance **R_L** connected across the terminals **'a & b'** and figure (b) showsthe **Theveninequivalentcircuit**with**V_{Th}**connectedacross**R_{Th}**&**R_L.**

MainstepstofindoutV$_{Th}$andR$_{Th}$:

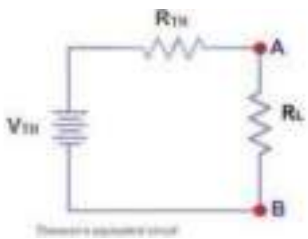
(ii) Theterminalsofthebranch/elementthroughwhichthecurrentistobefoundoutaremarkedassay**a&b**afterremovingthe concernedbranch/element.

(iii)Opencircuitvoltage**V$_{OC}$**acrossthesetwoterminalsisfoundoutusingtheconventionalnetworkmesh/node analysismethodsandthiswouldbe**V$_{Th}$.**

(iv) **TheveninresistanceR$_{Th}$**isfoundoutbythe methoddependinguponwhetherthenetworkcontains dependentsources ornot.

- Withdependentsources:**$R_{Th}=V_{oc}/I_{sc}$**
- Withoutdependentsources:**R_{Th}=Equivalentresistancelookingintotheconcerned terminals** with all voltage & current sources replaced by their internalimpedances (i.e. ideal voltage sources short circuited and ideal current sourcesopencircuited)

(v) ReplacethenetworkwithV**$_{Th}$**inserieswith**R$_{Th}$**and the concerned branchresistance**(or)** loadresistanceacrosstheloadterminals(A&B)asshowninbelowfig.



Example: Find V$_{TH}$, R$_{TH}$ and the load current and load voltage flowing through R$_L$ resistorasshowninfig.byusingThevenin'sTheorem?

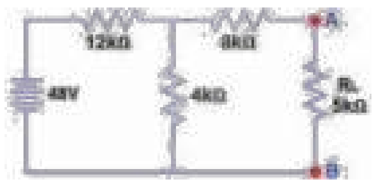


Fig.(a)

Solution:

Theresistance**R$_L$**isremovedandtheterminalsoftheresistance**R$_L$**aremarkedas**A&B**asshowninthefig.(1)

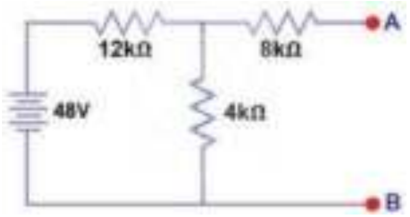
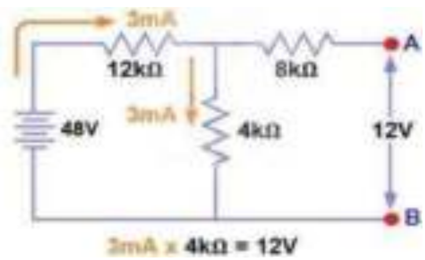


Fig.(1)

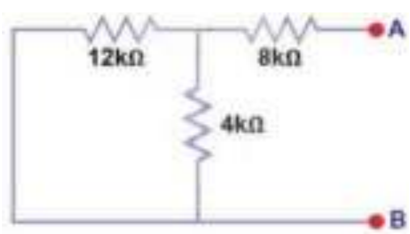
Calculate / measure the Open Circuit Voltage. This is the Thevenin Voltage (V_{TH}). We havealready removed the load resistor from fig.(a), so the circuit became an open circuit as shown infig (1). Now we have to calculate the Thevenin's Voltage. Since 3mA Current flows in both12kΩ and 4kΩ resistors as this is a series circuit because current will not flow in the 8kΩ resistoras itis open. So 12V (3mA x 4kΩ) will appear across the 4kΩ resistor. We also know thatcurrent is not flowing through the 8kΩ resistor as it is open circuit, but the 8kΩ resistor is inparallelwith4kresistor.Sothesamevoltage(i.e.12V)willappearacrossthe8kΩresistoras

4kΩresistor.Therefore12V willappearacrosstheABterminals.So,**V_{TH}=12V**



Fig(2)

All voltage & current sources replaced by their internal impedances (i.e. ideal voltage sourcesshort circuitedandidealcurrentsourcesopencircuited)asshown infig.(3)



Fig(3)

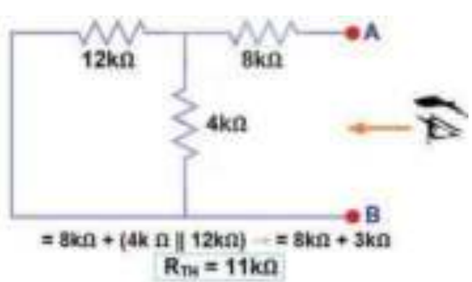
Calculate /measure the Open Circuit Resistance. This is the Thevenin Resistance (R_{TH})We haveReduced the 48V DC source to zero is equivalent to replace it with a short circuit as shown infigure (3) We can see that 8kΩ resistor is in series with a parallel connection of 4kΩ resistor and12kΩ resistor.i.e.:

8kΩ+ (4k Ω||12kΩ)…..(||=

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

(4kΩ + 12kΩ)]R_{TH}=8kΩ + 3kΩ

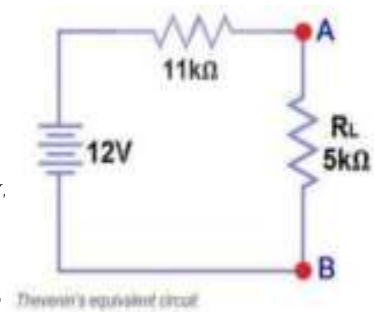
R_{TH}=11kΩ



Fig(4)

Connect the R_{TH} in series with Voltage Source $V_{TH}$and re-connect the load resistor across theload terminals(A&B) as shown in fig (5) i.e. Thevenin circuit with load resistor. This is theThevenin'sequivalentcircuit

V



RT H

Fig(5)

NowapplyOhm'slawandcalculatethetotalload

currentfromfig5.$I_L=V_{TH}/(R_{TH}+R_L)=12V/(11k\Omega+5k\Omega)=12/16k\Omega$

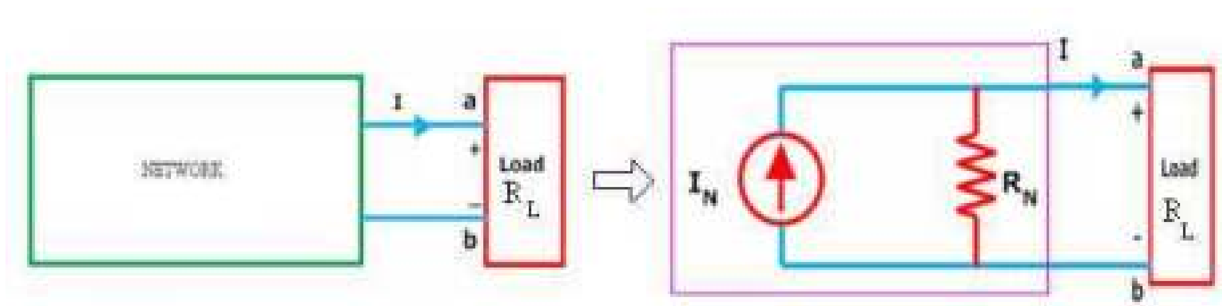
I_L=0.75mA

And$V_L= I_L x R_L= 0.75mA x 5k\Omega$

V_L=3.75V

Norton'sTheoremStatement:

Anylinear,bilateraltwoterminalnetworkconsistingofsourcesandresistors(Impedance),can be replaced by an equivalent circuit consisting of a current source inparallel with a resistance (Impedance),the current source being the short circuited current acrossthe load terminals and the resistance being the internal resistance of the source network lookingthroughtheopencircuitedloadterminals.



(a)

(b)

Figure (a)shows asimpleblockrepresentationof anetworkwithseveral active /passiveelements with the load resistance $\mathbf{R_L}$ connected across the terminals **'a & b'** and figure (b) showsthe **Nortonequivalentcircuit**with$\mathbf{I_N}$connectedacross $\mathbf{R_N}$&$\mathbf{R_L}$.

MainstepstofindoutI$_N$andR$_N$:

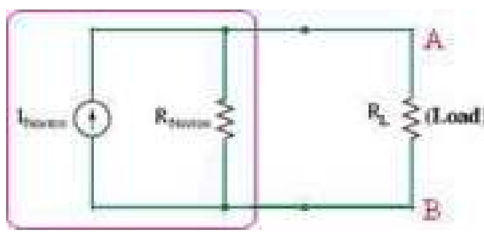
(iii) Theterminalsofthebranch/elementthroughwhichthecurrentistobefoundoutaremarkedassay**a &b**afterremovingthe concernedbranch/element.

(iv) Open circuit voltage **V_{OC}** across these two terminals and **I_{SC}** through these two terminalsare found out using the conventional network mesh/node analysis methods and they aresame aswhatweobtainedinThevenin'sequivalentcircuit**.**

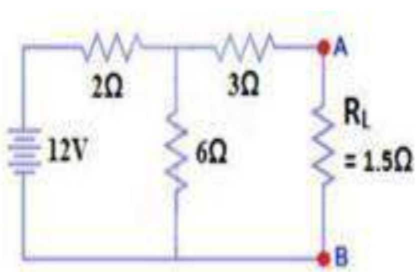
(v) Next **Norton resistance R_N**is found out depending upon whether the network containsdependentsourcesornot.

- Withdependentsources:**R_N=V_{oc}/I_{sc}**
- Withoutdependentsources:**R_N=**Equivalentresistancelookingintotheconcerned terminals with all voltage & current sources replaced by their internalimpedances (i.e. ideal voltage sources short circuited and ideal current sourcesopencircuited)

(vi) Replace the network with **I_N**in parallel with **R_N**and the concerned branch resistanceacrosstheloadterminals(A&B)asshowninbelowfig

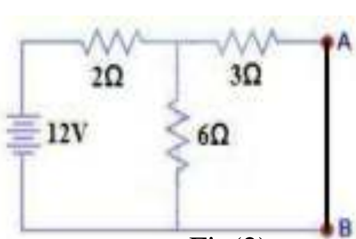


Example:FindthecurrentthroughtheresistanceR$_L$(1.5Ω)ofthecircuitshowninthefigure (a)belowusingNorton'sequivalentcircuit.?



Fig(a)

Solution: TofindouttheNorton'sequivalentcktwehavetofindout**I_N=I_{sc},R_N=V_{oc}/I_{sc}.**
Shortthe1.5Ωloadresistorasshownin(Fig2),andCalculate/measuretheShortCircuitCurrent.Thisis theNortonCurrent(I_N).



Fig(2)

We have shorted the AB terminals to determine the Norton current, I_N. The 6Ω and 3Ω are thenin parallel and this parallel combination of 6Ω and 3Ω are then in series with 2Ω.So the TotalResistance ofthecircuittothe Sourceis:-

2Ω+ (6Ω||3Ω)…..(|| = inparallelwith)R_T=2Ω + [(3Ω x6Ω)/(3Ω+6Ω)]

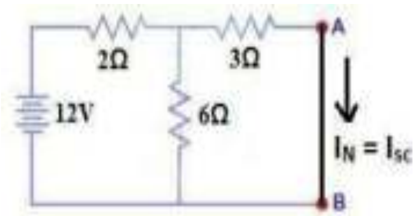
R_T=2Ω +2Ω

R_T= 4ΩI_T=V/R_T

I_T=12V /4Ω=3A..

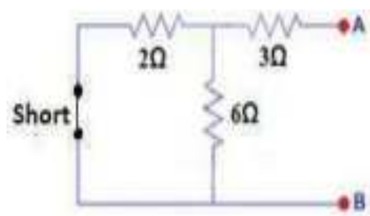
Now we have to find I_{SC} = I_N… Apply CDR… (Current Divider Rule)…I_{SC}=I_N=3Ax[(6Ω /(3Ω + 6Ω)]=2A.

I_{SC}=I_N=2A.



Fig(3)

All voltage & current sources replaced by their internal impedances (i.e. ideal voltage sourcesshort circuited and ideal current sources open circuited) and Open Load Resistor. as shown infig.(4)



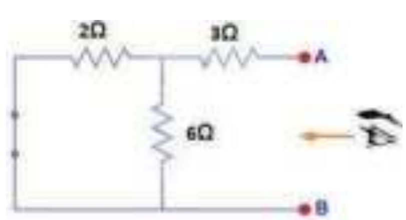
Fig(4)

Calculate /measure the Open Circuit Resistance. This is the Norton Resistance (R_N) We haveReduced the 12V DC source to zero is equivalent to replace it with a short circuit as shown infig(4), We can see that 3Ω resistor is in series with a parallel combination of 6Ω resistor and 2Ωresistor.i.e.:

3Ω+ (6Ω||2Ω)…..(|| = inparallelwith)R_N=3Ω+[(6Ω x2Ω)/(6Ω+2Ω)]

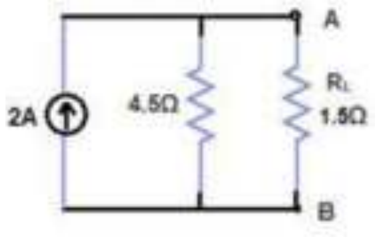
R_N= 3Ω+ 1.5Ω

R_N= 4.5Ω



Fig(5)

Connect the $R_N$in Parallel with Current Source I_N and re-connect the load resistor. This isshowninfig(6)i.e.NortonEquivalentcircuitwithloadresistor.



Fig(6)

Now apply the Ohm's Law and calculate the load current throughLoad resistance across theterminalsA&B.LoadCurrentthroughLoadResistoris

$I_L= I_N x[R_N/(R_N+R_L)]$

I_L=2Ax(4.5Ω/4.5Ω+1.5kΩ)I_L=1.5A

I_L=1.5A

SuperpositionTheorem:

The principle of superposition helps us to analyze a linear circuit with more thanone current or voltage sources sometimes it is easier to find out the voltage across or current in abranch of the circuit by considering the effect of one source at a time by replacing the othersourceswiththeiridealinternalresistances.

SuperpositionTheoremStatement:

Any linear, bilateral two terminal network consisting of more than one sources,The total current or voltage in any part of a network is equal to the algebraic sum of the currentsor voltages in the required branch with each source acting individually while other sources arereplaced by their ideal internal resistances. (i.e. Voltage sources by a short circuit and currentsources byopencircuit)

StepstoApplySuperpositionPrinciple:

1. Replaceallindependentsourceswiththeirinternalresistancesexceptonesource.Findtheoutput (voltage orcurrent)duetothatactive sourceusingnodalormeshanalysis.
2. Repeatstep1 foreachoftheotherindependentsources.
3. Findthetotalcontributionbyaddingalgebraicallyallthecontributionsduetotheindependentsources.

Example:ByUsingthesuperposition theoremfindIinthecircuit showninfigure?

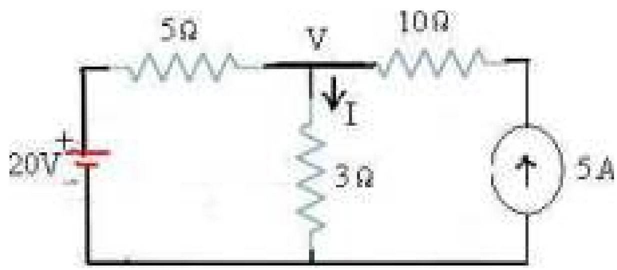


Fig.(a)

Solution: Applying the superposition theorem, the current $\mathbf{I_2}$ in the resistance of 3 Ω due to thevoltage source of 20V alone, with current source of 5A open circuited [as shown in the figure.1below]is givenby:

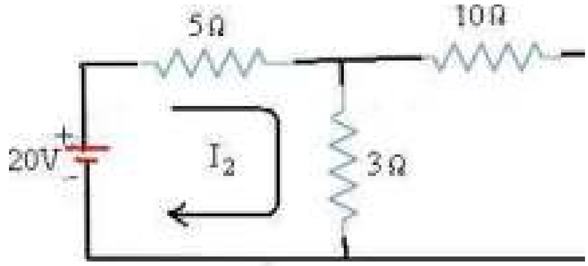


Fig1

I_2=20/(5+3) =2.5A

Similarly the currentI_5in the resistance of 3 Ω due to the current source of 5A alone withvoltagesourceof20V shortcircuited [asshown inthefigure.2below]isgivenby:

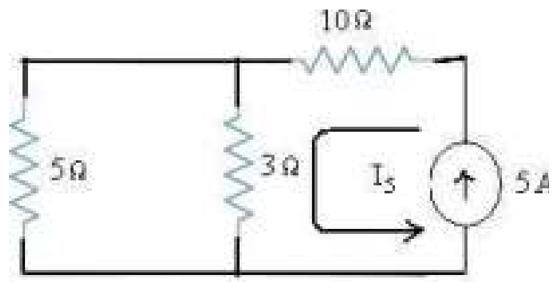


Fig.2

I_5=5x5/(3+5)=3.125A

Thetotalcurrentpassingthroughthe resistance of3Ωisthen=I_2+I_5= 2.5+ 3.125=**5.625A**

Let us verify the solution using the basic nodal analysis referring to the node marked with V infig.(a).Thenwe get:

$$\frac{V-20}{5}+\frac{V}{3}=5$$

3V-60+5V=15×5

8V-60=75

8V=135V=16.

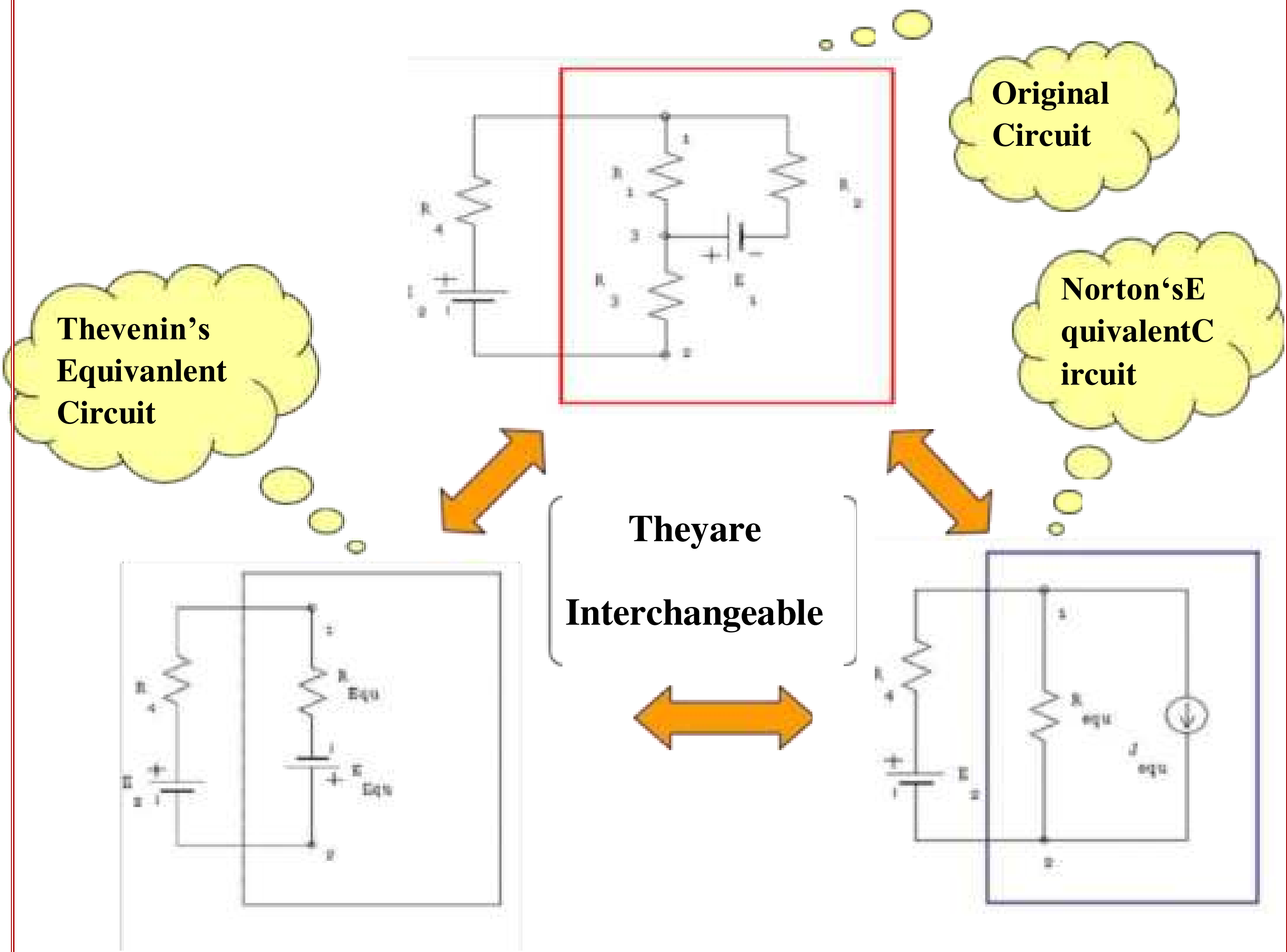
875

The current I passing through the resistance of 3Ω =V/3 = 16.875/3= **5.625 A .**

THEVENIN'SANDNORTON'SEQUIVALENTCIRCUITTUTORIAL.(BYKIM,EUNG)

Thevenin's Theorem states that we can replace entire network by an equivalent circuit thatcontainsonlyanindependentvoltagesourceinserieswithanimpedance(resistor)suchthatthecurrent-voltagerelationshipattheloadisunchanged.

Norton'sThereomisidenticaltoThevenin'sTheoremexceptthattheequivalentcircuitisanindependent current source in parallel with an impedance (resistor). Therefore, the Nortonequivalentcircuitisasourcetransformationof theTheveninequivalentcircuit.



HowtofindThevenin'sEquivalentCircuit?

If thecircuit contains	Youshoulddo
Resistors and independentsources	1) Connectanopencircuitbetweenaandb. 2) FindthevoltageacrosstheopencircuitwhichisVoc.Voc =Vth. 3) Deactivate the independent sources.Voltage source ➔ open circuitCurrentsource ➔shortcircuit 4) FindRthbycircuitresistancereduction
Resistors and dependent sourcesor independentshorces	1) Connectanopencircuitbetweenaandb. 2) FindthevoltageacrosstheopencircuitwhichisVoc.Voc =Vth. Iftherearebothdependentandindependentsources. 3) Connect a shortcircuit between a and b. 4) Determinethe current betweena and b. 5) Rth=Voc/Iab Ifthereareonlydependentsources. 3) Connect1Amperecurrentsourceflowingfromter minalb to a. It = 1 [A] 4) ThenRth=Voc/It=Voc/1

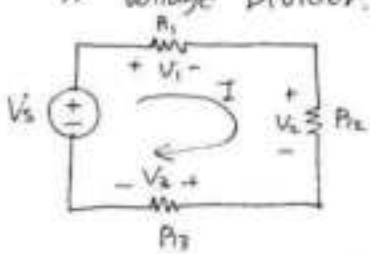
Note: When there are only dependent sources, the equivalent network is merely R_{Th}, that is, nocurrentorvoltagesources.

Norton'sEquivalentCircuit?

If thecircuit contains	Youshoulddo
Resistors and independentsources	- Deactivatetheindependentsources. Voltage source ➔ open circuitCurrentsource➔shortcircuit - FindRtbycircuitresistance reduction - Connect anshort circuit between a and b. - Findthecurrentacrosstheshortcircuitwhichis Isc.
Resistors and dependent sourcesor Independentsources	6 Connect a shortcircuit between a and b. 7Find the current across the short circuit which is Isc.Isc = In. Ifthearebothdependentandindependentsources. 8 Connect a opencircuit between a and b. 9 Determinethevoltagebetweenaandb.Voc=Vab 10 Rn=Voc/Isc Iftherearonlydependentsources. 2Connect1Amperecurrentsourceflowingfromterminalb to a. It = 1 [A] 3 ThenRn=Voc/It=Voc/1

Note: When there are only dependent sources, the equivalent network is merely R_{Th}, that is, nocurrentorvoltagesources.

* Voltage Divider



When you have multiple resistors in a single loop, the source voltage will be divided according to KVL.

$V_s = V_1 + V_2 + V_3$

And since there exists only one loop, the current flowing through each resistor is the same as I.

$$\begin{pmatrix} V_1 = I \cdot R_1 \\ V_2 = I \cdot R_2 \\ V_3 = I \cdot R_3 \end{pmatrix} \text{ therefore } \begin{aligned} V_s &= V_1 + V_2 + V_3 \\ &= I \cdot R_1 + I \cdot R_2 + I \cdot R_3 \\ &= I (R_1 + R_2 + R_3) \end{aligned}$$

$$\therefore I = \frac{V_s}{R_1 + R_2 + R_3}$$

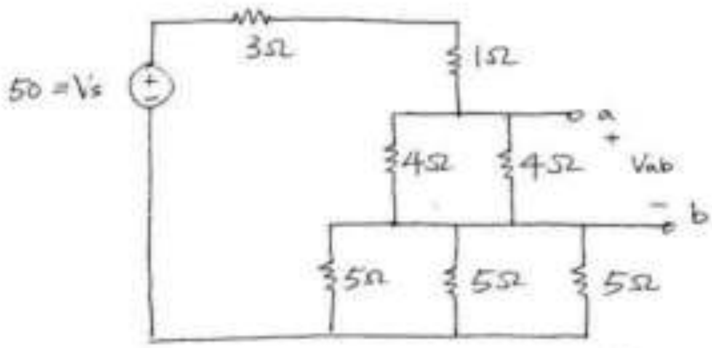
Thus, the voltage across the n-th resistor R_n can be found as

$$V_n = I \cdot R_n = \left(\frac{V_s}{R_1 + R_2 + R_3} \right) \cdot R_n$$

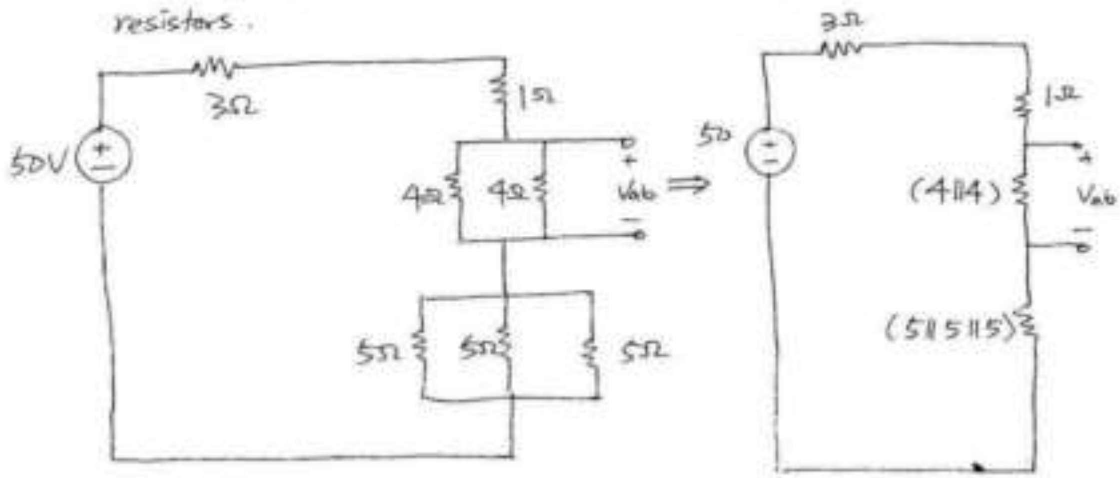
In general, we may repeat the voltage divider principle by

$$V_n = \left(\frac{V_s}{\sum_{i=1}^{n} R_i} \right) \cdot R_n$$

example 1)

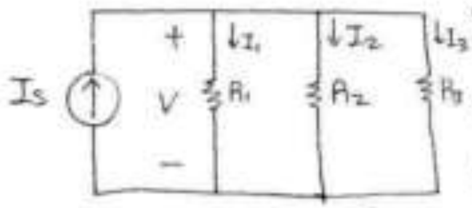


We can seperate the resistors into some groups of parallel-connected resistors.



$$\therefore V_{ab} = \frac{50}{3+1+(4\|4)+(5\|5\|5)} \cdot (4\|4)$$

* Current Divider:



When we have multiple resistors in parallel connection, the source current will be divided into each parallel branch according to KCL

$$I_s = I_1 + I_2 + I_3$$

Since parallel-connected resistors can be simplified as one single resistor as $(R_1 \parallel R_2 \parallel R_3)$, the voltage across each resistor is the same as V.

$$\left(\begin{array}{l} I_1 = \frac{V}{R_1} \\ I_2 = \frac{V}{R_2} \\ I_3 = \frac{V}{R_3} \end{array} \right) \text{ therefore } \quad I_s = I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$= V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\therefore V = \frac{I_s}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}$$

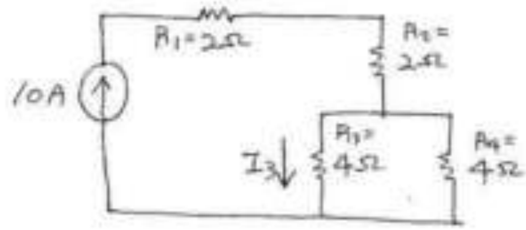
Thus, the current flowing through n-th resistor R_n can be found as

$$I_n = \frac{V}{R_n} = \frac{I_s}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)} \cdot \frac{1}{R_n}$$

In general, we can repeat the current divider principle by

$$I_n = \frac{I_s}{\sum_{i=1}^{n} G_n} \cdot G_n \qquad \left(\begin{array}{c} G \text{ is conductance} \\ G_n = \frac{1}{R_n} \end{array} \right)$$

example 1)

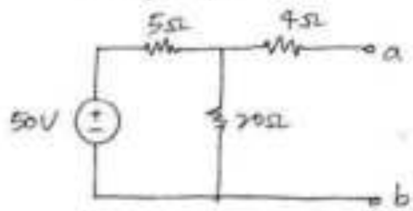


R1 and R2 is series-connected to the current source, therefore the current flowing across R1 and R2 is just the same as 10A. However R3 and R4 are parallel-connected, so the current will be divided into two branches.

$$I_3 = \frac{10}{\left(\frac{1}{4}+\frac{1}{4}\right)}\cdot\left(\frac{1}{4}\right)$$

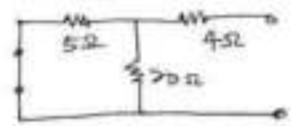
* Thevenin's and Norton's Equivalent Circuits

example 1).

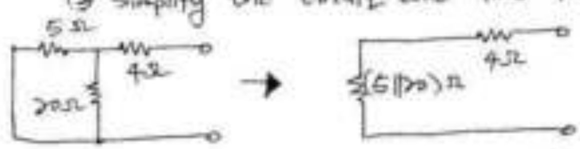


sol) ① deactivate voltage source

(voltage source ⇒ short circuit).



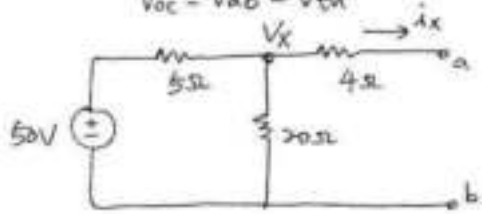
② Simplify the circuit and find R_{th}.



$\therefore R_{th} = (5\|20) + 4 = 8\Omega$

③ Find open-circuit voltage across ab

$V_{oc} = V_{ab} = V_{th}$

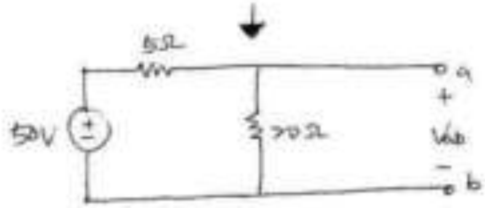


$i_x = 0$ since node a is open.

Therefore $V_x = V_a$.

(no voltage drop across 4Ω resistor).

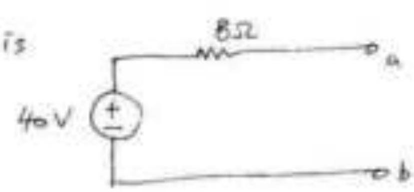
We can remove 4Ω resistor from the circuit.



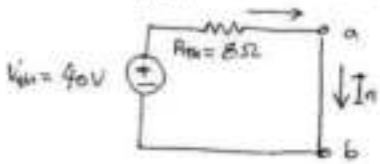
$$V_{ab} = V_{th} = 50 \times \frac{20}{20+5} = 40\,V$$

Thevenin's Circuit is

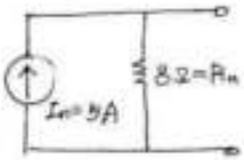
$\therefore$



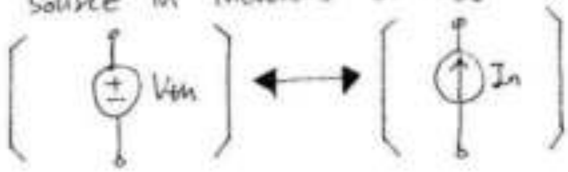
This Thevenin's Circuit can be converted to Norton's Circuit as



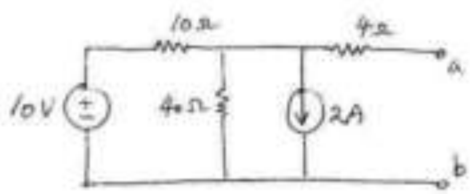
$$\left(\begin{array}{l} I_n = \dfrac{40V}{8\Omega} = 5A \\ R_{th} = R_n \end{array} \right. \Rightarrow$$



note: when you convert Thevenin's Circuit to Norton's Circuit, the direction of current flow of the current source in Norton's Circuit should be matched with the voltage source in Thevenin's Circuit.

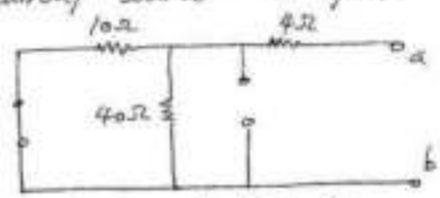


example 2).

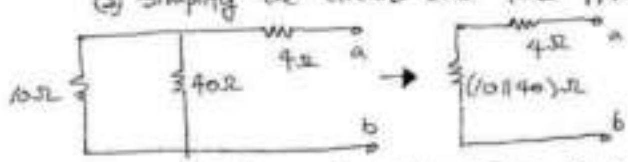


① deactivate independent sources

(Voltage Source $\longrightarrow$ short
(Current source $\longrightarrow$ open.

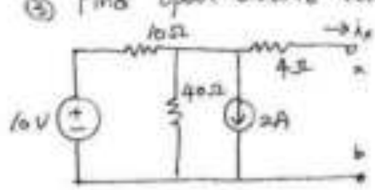


② Simplify the circuit and find R_{th}.

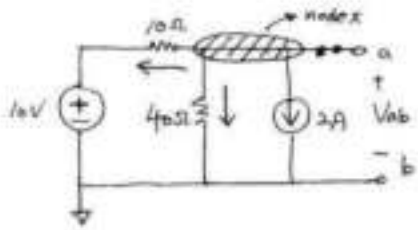


$\therefore R_{th} = (10 \| 40) + 4 = 12\,\Omega$

③ Find open-circuit voltage across ab



$i_x = 0$ since node a is open,
no voltage drop across 4Ω resistor.
We can ignore 4Ω resistor.

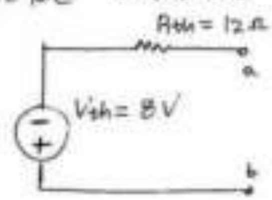


If we set the minus terminal of the voltage source as ground, then the voltage of node-x is V_{ab}. Apply KCL to node-x.

$$\frac{V_{ab}-10}{10}+\frac{V_{ab}}{40}+2=0$$

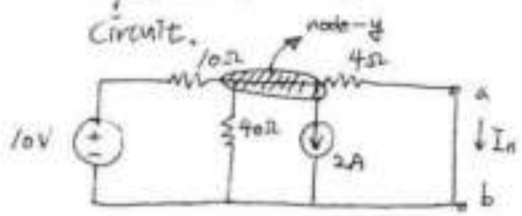
$$\therefore V_{ab}=-8\,V=V_{th}.$$

Therefore Thevenin's Circuit is



(The polarity of the voltage source is reversed since Thevenin voltage source is minus value.)

As you know, the impedence in Thevenin's Circuit is the same as the impedence in Norton's Circuit. So, if you find short-circuit current across ab at ③ instead of open-circuit voltage across ab, you can find Norton's Equivalent Circuit.

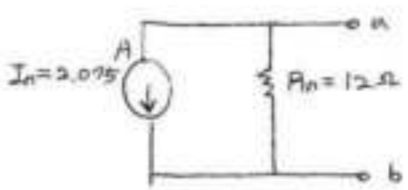


Let's set the voltage at node-y as V_y. Apply KCL to node-y

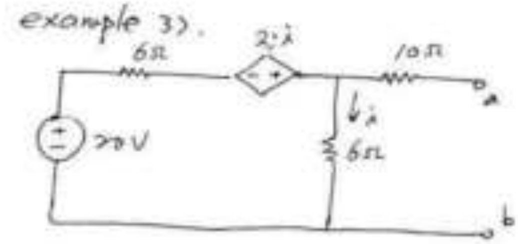
$$\frac{V_y-10}{10}+\frac{V_y}{40}+2+\frac{V_y}{4}=0$$

$$\therefore V_y=-8.3\,V$$

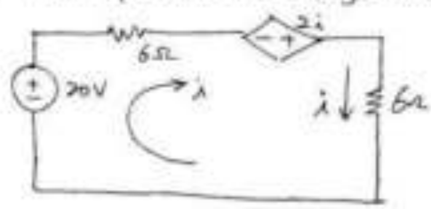
$$\therefore I_n=\frac{V_y}{4\Omega}=\frac{-8.3V}{4\Omega}=-2.075\,A$$



example 3).



① Find open-circuit voltage across ab.



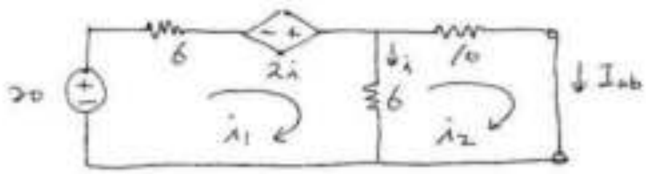
10Ω resistor can be ignored since node a is open.

Apply KVL. $6i - 2i + 6i - 20 = 0$

$\therefore i = 2A$

Therefore $V_{ab} = 6i = 12V$

② Find short-circuit current across ab.



Using two mesh currents, we have

$$\begin{cases} -20 + 6i_1 - 2i + 6(i_1 - i_2) = 0 \\ 6(i_2 - i_1) + 10i_2 = 0 \\ i = i_1 - i_2 \end{cases}$$

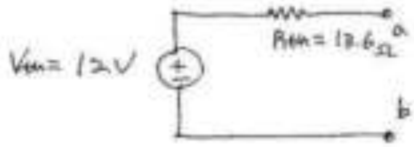
From these three equations, we obtain

$i_2 = \frac{120}{136} A = I_{ab}$

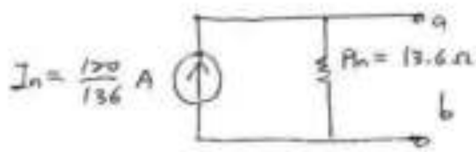
③ From V_{ab} (open-circuit) and I_{ab} (short-circuit), find R_{th}

$$R_{th} = \frac{V_{ab}}{I_{ab}} = \frac{12}{120/136} = 13.6\,\Omega$$

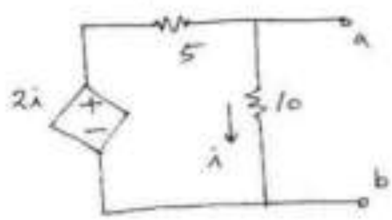
Therefore Thevenin's Equivalent Circuit is



Norton's Equivalent Circuit is

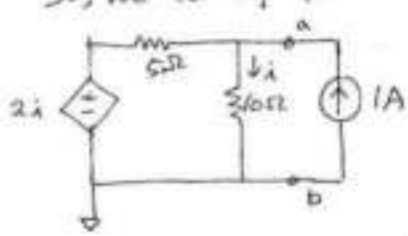


example 4).



* Since the circuit has no independent source, $i=0$ when we connect an open circuit to ab.
Therefore $\underset{(open)}{V_{ab}}=0$ and $\underset{(close)}{I_{ab}}=0$.
So, we can not use $R_{th}=\frac{V_{ab}}{I_{ab}}$ like example 3)

So, we connect 1A test current source to ab. Then we can say



$R_{th}=\frac{V_{ab}}{1\,A}$

Let's set the minus node of the voltage source as ground for reference.

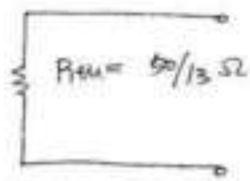
Apply KCL to node a.

$$\begin{cases} \frac{V_{ab}-2i}{5}+\frac{V_{ab}}{10}-1=0 \\ \text{and} \quad i=\frac{V_{ab}}{10} \end{cases}$$

Therefore $\frac{V_{ab}-2\left(\frac{V_{ab}}{10}\right)}{5}+\frac{V_{ab}}{10}-1=0 \quad \therefore V_{ab}=\frac{50}{13}\,V$

$\therefore R_{th}=\frac{V_{ab}}{1}=\frac{50}{13}\,\Omega.$

∴ Thevenin's Equivalent Circuit is



Norton's Equivalent Circuit is the same as Thevenin's Circuit.

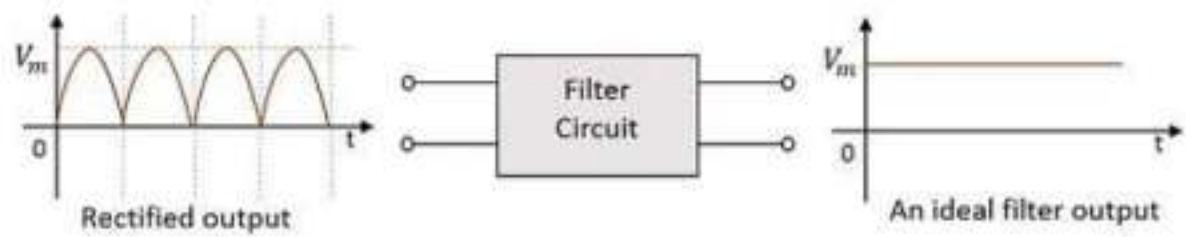
UNIT 5

Filters

The ripple in the signal denotes the presence of some AC component. This ac component has to be completely removed in order to get pure dc output. So, we need a circuit that **smoothens** the rectified output into a pure dc signal.

A **filter circuit** is one which removes the ac component present in the rectified output and allows the dc component to reach the load.

The following figure shows the functionality of a filter circuit.



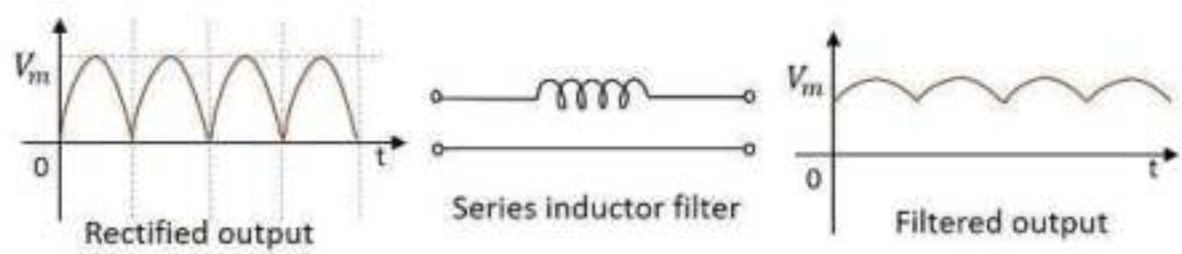
A filter circuit is constructed using two main components, inductor and capacitor. We have already studied in Basic Electronics tutorial that

- An inductor allows **dc** and blocks **ac**.
- A capacitor allows **ac** and blocks **dc**.

Let us try to construct a few filters, using these two components.

Series Inductor Filter

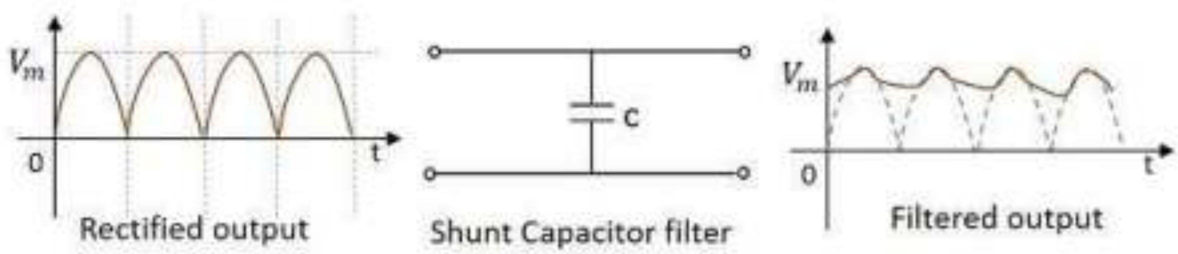
As an inductor allows dc and blocks ac, a filter called **Series Inductor Filter** can be constructed by connecting the inductor in series, between the rectifier and the load. The figure below shows the circuit of a series inductor filter.



The rectified output when passed through this filter, the inductor blocks the ac components that are present in the signal, in order to provide a pure dc. This is a simple primary filter.

Shunt Capacitor Filter

As a capacitor allows ac through it and blocks dc, a filter called **Shunt Capacitor Filter** can be constructed using a capacitor, connected in shunt, as shown in the following figure.

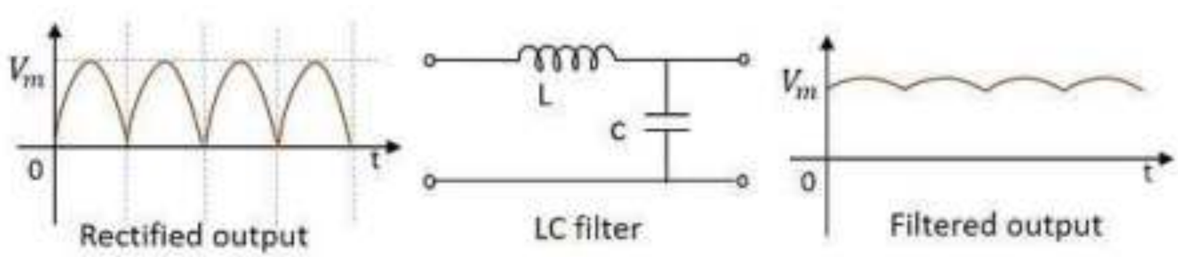


The rectified output when passed through this filter, the ac components present in the signal are grounded through the capacitor which allows ac components. The remaining dc components present in the signal are collected at the output.

The above filter types discussed are constructed using an inductor or a capacitor. Now, let's try to use both of them to make a better filter. These are combinational filters.

L-C Filter

A filter circuit can be constructed using both inductor and capacitor in order to obtain a better output where the efficiencies of both inductor and capacitor can be used. The figure below shows the circuit diagram of a LC filter.



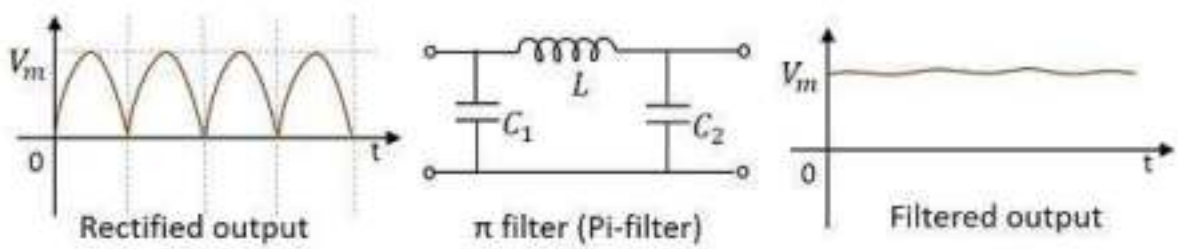
The rectified output when given to this circuit, the inductor allows dc components to pass through it, blocking the ac components in the signal. Now, from that signal, few more ac components if any present are grounded so that we get a pure dc output.

This filter is also called as a **Choke Input Filter** as the input signal first enters the inductor. The output of this filter is a better one than the previous ones.

Π- Filter PifilterPifilter

This is another type of filter circuit which is very commonly used. It has capacitor at its input and hence it is also called as a **Capacitor Input Filter**. Here, two capacitors and one inductor are connected in the form of π shaped network. A capacitor in parallel, then an inductor in series, followed by another capacitor in parallel makes this circuit.

If needed, several identical sections can also be added to this, according to the requirement. The figure below shows a circuit for ππ filter Pi−filterPi−filter.



Working of a Pi filter

In this circuit, we have a capacitor in parallel, then an inductor in series, followed by another capacitor in parallel.

- **Capacitor C_1** − This filter capacitor offers high reactance to dc and low reactance to ac signal. After grounding the ac components present in the signal, the signal passes to the inductor for further filtration.
- **Inductor L** − This inductor offers low reactance to dc components, while blocking the ac components if any got managed to pass, through the capacitor C_1.
- **Capacitor C_2** − Now the signal is further smoothened using this capacitor so that it allows any ac component present in the signal, which the inductor has failed to block.

Thus we, get the desired pure dc output at the load.

Pure Resistive AC Circuit

The circuit containing only a pure resistance of R ohms in the AC circuit is known as **Pure Resistive AC Circuit**. The presence of inductance and capacitance does not exist in a purely resistive circuit. The alternating current and voltage both move forward as well as backwards in both the direction of the circuit. Hence, the alternating current and voltage follows a shape of the Sine wave or known as the sinusoidal waveform.

In the purely resistive circuit, the power is dissipated by the resistors and the phase of the voltage and current remains same i.e., both the voltage and current reach their maximum value at the same time. The resistor is the passive device which neither produce nor consume electric power. It converts the **electrical energy into heat**.

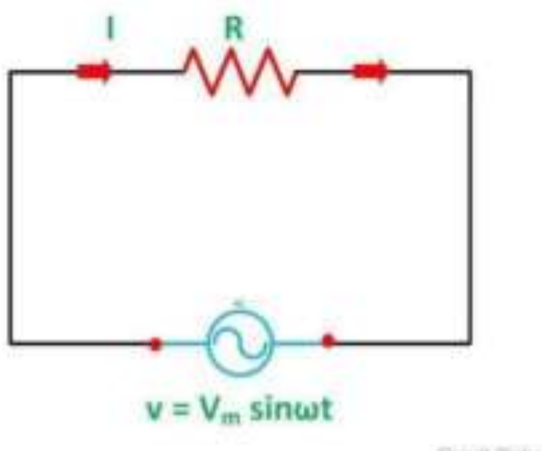
Explanation of Resistive Circuit

In an AC circuit, the ratio of voltage to current depends upon the supply frequency, phase angle, and phase difference. In an AC resistive circuit, the value of resistance of the resistor will be same irrespective of the supply frequency.

Let the alternating voltage applied across the circuit be given by the equation

$$v = V_m \mathrm{Sin}\omega t \,\ldots\ldots\ldots\ldots\ldots (1)$$

Then the instantaneous value of current flowing through the resistor shown in the figure below will be:



$$i = \frac{v}{R} = \frac{V_m}{R} \sin\omega t \ldots\ldots\ldots (2)$$

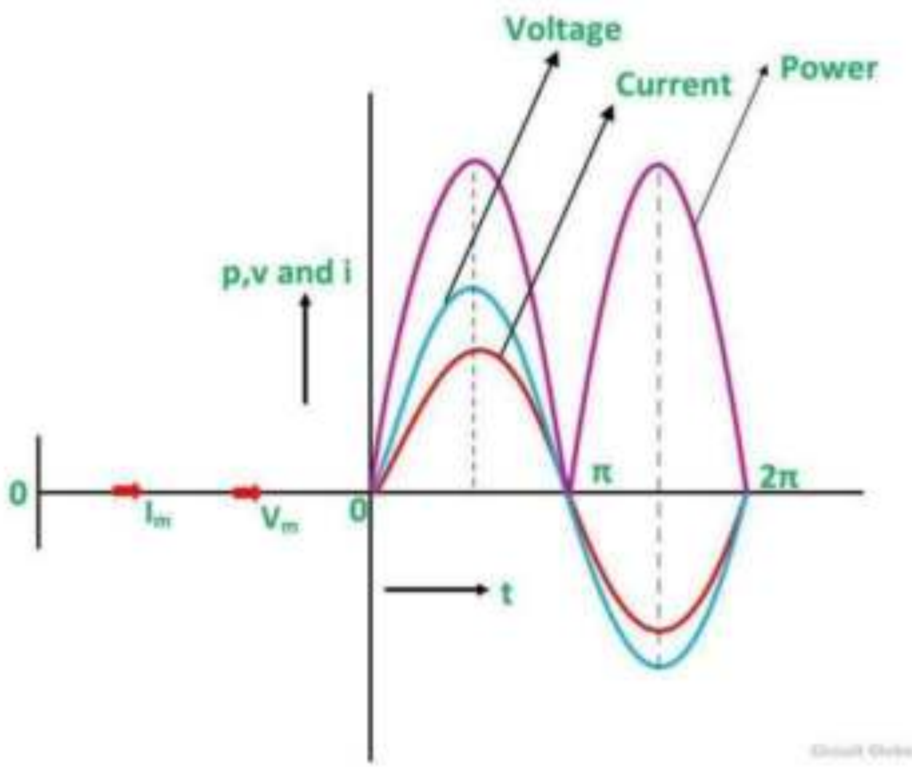
The value of current will be maximum when ωt= 90° or sinωt = 1

Putting the value of sinωt in equation (2) we will get

$$i = I_m \sin\omega t \ldots\ldots\ldots(3)$$

Phase Angle and Waveform of Resistive Circuit

From equation (1) and (3), it is clear that there is no phase difference between the applied voltage and the current flowing through a purely resistive circuit, i.e. phase angle between voltage and current is **zero**. Hence, in an AC circuit containing pure resistance, the current is in phase with the voltage as shown in the waveform figure below.



Waveform and Phasor Diagram of Pure Resistive Circuit

Power in Pure Resistive Circuit

The three colours red, blue and pink shown in the power curve or the waveform indicate the curve for current, voltage and power respectively. From the phasor diagram, it is clear that the current and voltage are in phase with each other that means the value of current and voltage attains its peak at the same instant of time, and the power curve is always positive for all the values of current and voltage.

As in DC supply circuit, the product of voltage and current is known as the Power in the circuit. Similarly, the power is the same in the AC circuit also, the only difference is that in the AC circuit the instantaneous value of voltage and current is taken into consideration.

Therefore, the instantaneous power in a purely resistive circuit is given by the equation shown below:

Instantaneous power, p= vi

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

$$p = \frac{V_m I_m}{2} 2\sin^2\omega t = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} (1 - \cos 2\omega t)$$

$$p = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} - \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos 2\omega t$$

The average power consumed in the circuit over a complete cycle is given by

$$P = \text{average of } \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} - \text{ average of } \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos\omega t \ldots\ldots(4)$$

As the valve of cosωt is zero.

So, putting the value of cosωt in equation (4) the value of power will be given by

$$P = V_{r.m.s} I_{r.m.s} - 0$$

- P – average power
- $V_{r.m.s}$ – root mean square value of supply voltage
- $I_{r.m.s}$ – root mean square value of the current

Hence, the power in a purely resistive circuit is given by:

$$P = VI$$

The voltage and the current in the purely resistive circuit are in phase with each other having **no phase difference** with phase angle zero. The alternating quantity reaches their peak value at the interval of the same time period that is the rise and fall of the voltage and current occurs at the same time.

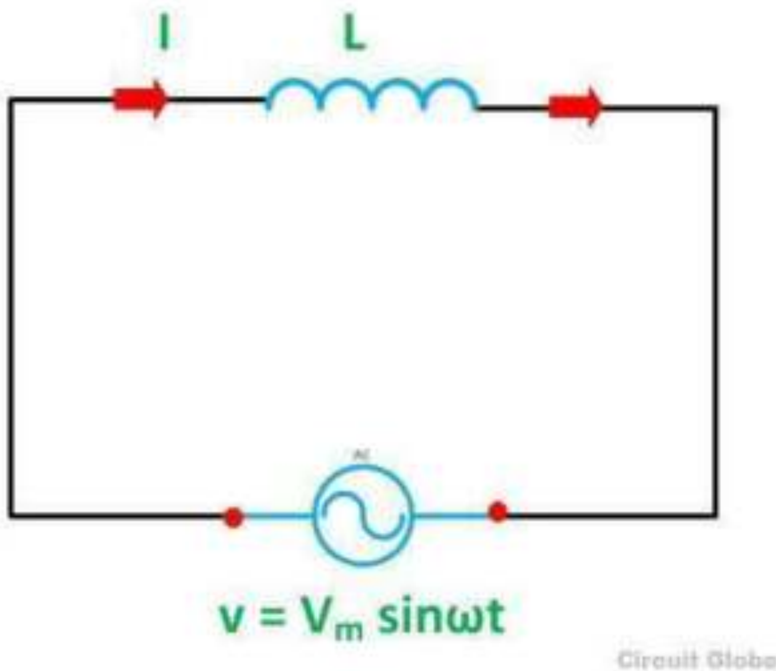
Pure inductive Circuit

The circuit which contains only inductance (L) and not any other quantities like resistance and capacitance in the circuit is called a **Pure inductive circuit.** In this type of circuit, the current lags behind the voltage by an angle of 90 degrees.

The inductor is a type of coil which reserves electrical energy in the magnetic field when the current flow through it. The inductor is made up of wire which is wound in the form of a coil. When the current flowing through inductor changes then time-varying magnetic field causes emf which obstruct the flow of current.The inductance is measured in **Henry**.The opposition of flow of current is known as the **inductive reactance**.

Explanation and Derivation of Inductive Circuit

The circuit containing pure inductance is shown below:



Let the alternating voltage applied to the circuit is given by the equation:

$$v = V_m \text{Sin}\omega t \ldots\ldots\ldots\ldots\ldots(1)$$

As a result, an alternating current i flows through the inductance which induces an emf in it. The equation is shown below:

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

The emf which is induced in the circuit is equal and opposite to the applied voltage. Hence, the equation becomes,

$$v = -e \ \ldots\ldots\ldots..(2)$$

Putting the value of e in equation (2) we will get the equation as

$$v = -\left(-L\frac{di}{dt}\right) \quad \text{or}$$

$$V_m \text{Sin}\omega t = L\frac{di}{dt} \quad \text{or}$$

$$di = \frac{V_m}{L}\sin\omega t\, dt \quad \dots\dots\dots\dots (3)$$

Integrating both sides of the equation (3), we will get

$$\int di = \int \frac{V_m}{L}\sin\omega t\, dt \quad \text{or}$$

$$i = \frac{V_m}{\omega L}(-\cos\omega t) \quad \text{or}$$

$$i = \frac{V_m}{\omega L}\sin\left(\omega t - {}^{\pi}/_{2}\right) = \frac{V_m}{X_L}\sin\left(\omega t - {}^{\pi}/_{2}\right) \quad \dots\dots\dots..(4)$$

where, $X_L = \omega L$ is the opposition offered to the flow of alternating current by a pure inductance and is called inductive reactance.

The value of current will be maximum when $\sin(\omega t - \pi/2) = 1$

Therefore,

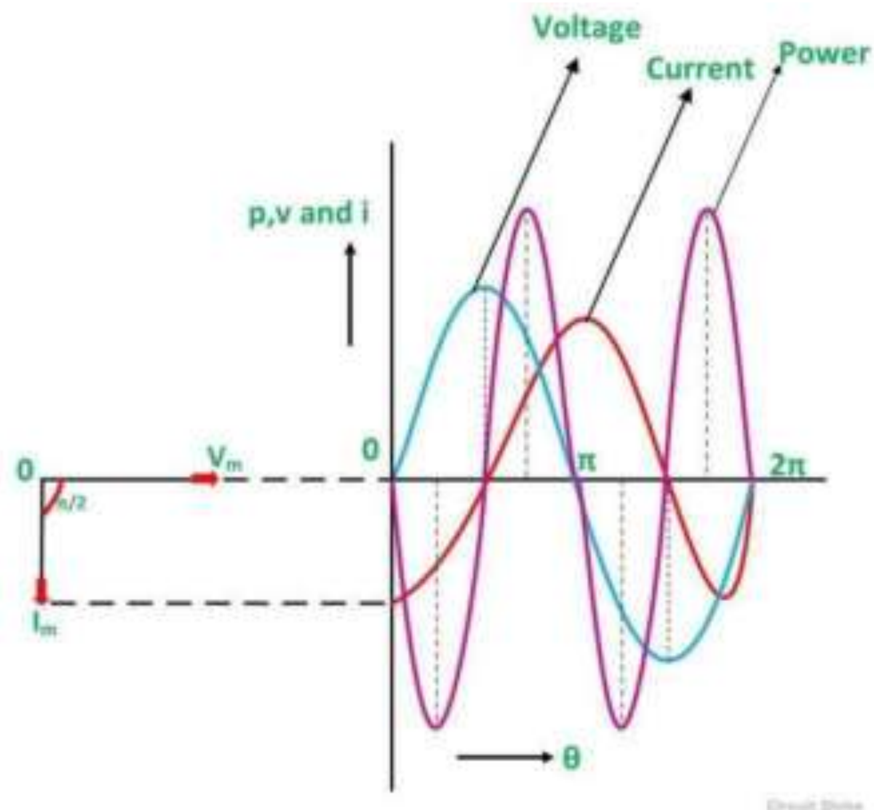
$$I_m = \frac{V_m}{X_L} \dots\dots\dots\dots (5)$$

Substituting this value in I_m from the equation (5) and putting it in equation (4) we will get

$$i = I_m \sin(\omega t - \pi/2)$$

Phasor Diagram and Power Curve of Inductive Circuit

The current in the pure inductive AC circuit lags the voltage by 90 degrees. The waveform, power curve and phasor diagram of a purely inductive circuit is shown below



The voltage, current and power waveform are shown in blue, red and pink colours respectively. When the values of voltage and current are at its peak as a positive value, the power is also positive and similarly, when the voltage and current give negative waveform the power will also become negative. This is because of the phase difference between voltage and current.

When the voltage drops, the value of the current changes. When the value of current is at its maximum or peak value of the voltage at that instance of time will be zero, and therefore, the voltage and current are out of phase with each other by an angle of 90 degrees.

The phasor diagram is also shown on the left-hand side of the waveform where current (I_m) lag voltage (V_m) by an angle of π/2.

Power in Pure Inductive Circuit

Instantaneous power in the inductive circuit is given by

$$p = vi$$

$$P = (V_m \sin\omega t)(I_m \sin(\omega t + \pi/2)$$

$$P = V_m I_m \sin\omega t \cos\omega t$$

$$P = \frac{V_m I_m}{2} 2 \sin\omega t \cos\omega t$$

$$P = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \sin 2\omega t \ \text{ or}$$

$$P = 0$$

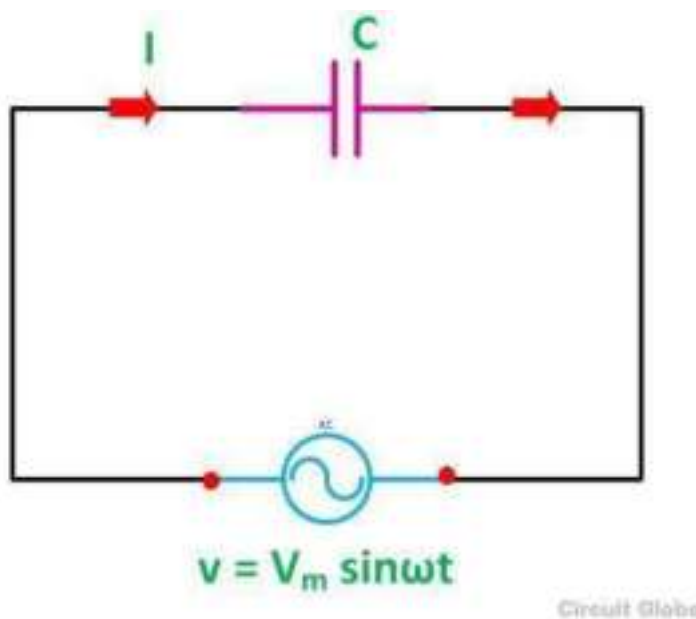
Hence, the average power consumed in a purely inductive circuit is zero.The average power in one alteration, i.e., in a half cycle is zero, as the negative and positive loop is under power curve is the same.In the purely inductive circuit, during the first quarter cycle, the power supplied by the source, is stored in the magnetic field set up around the coil. In the next quarter cycle, the magnetic field diminishes and the power that was stored in the first quarter cycle is returned to the source.This process continues in every cycle, and thus, no power is consumed in the circuit.

Pure Capacitor Circuit

The circuit containing only a pure capacitor of capacitance C farads is known as a **Pure Capacitor Circuit**. The capacitors stores electrical power in the electric field, their effect is known as the capacitance. It is also called the **condenser**.The capacitor consists of two conductive plates which are separated by the dielectric medium. The dielectric material is made up of glass, paper, mica, oxide layers, etc. In pure AC capacitor circuit, the current leads the voltage by an angle of 90 degrees.When the voltage is applied across the capacitor, then the electric field is developed across the plates of the capacitor and no current flow between them. If the variable voltage source is applied across the capacitor plates then the ongoing current flows through the source due to the charging and discharging of the capacitor.

Explanation and derivation of Capacitor Circuit

A capacitor consists of two insulating plates which are separated by a dielectric medium. It stores energy in electrical form. The capacitor works as a storage device, and it gets charged when the supply in **ON** and gets discharged when the supply is **OFF**. If it is connected to the direct supply, it gets charged equal to the value of the applied voltage.



Let the alternating voltage applied to the circuit is given by the equation:

$$v = V_m \text{Sin}\omega t \ldots\ldots\ldots\ldots\ldots(1)$$

Charge of the capacitor at any instant of time is given as: $q = Cv \ldots\ldots\ldots\ldots (2)$

Current flowing through the circuit is given by the equation: $i = \frac{d}{dt} q$

Putting the value of q from the equation (2) in equation (3) we will get

$$i = \frac{d}{dt}(Cv) \ldots\ldots\ldots\ldots(3)$$

Now, putting the value of v from the equation (1) in the equation (3) we will get

$$i = \frac{d}{dt} C\, V_m \text{Sin}\omega t = C\, V_m \frac{d}{dt} \sin\omega t \quad \text{or}$$

$$i = \omega\, C\, V_m \cos\omega t = \frac{V_m}{1/\omega C} \sin\left(\omega t + \pi/2\right) \quad \text{or}$$

$$i = \frac{V_m}{X_C} \sin\left(\omega t + \pi/2\right) \ldots\ldots\ldots\ldots(4)$$

Where Xc = 1/ωC is the opposition offered to the flow of alternating current by a pure capacitor and is called **Capacitive Reactance.**

The value of current will be maximum when sin(ωt + π/2) = 1. Therefore, the value of maximum current I_m will be given as:

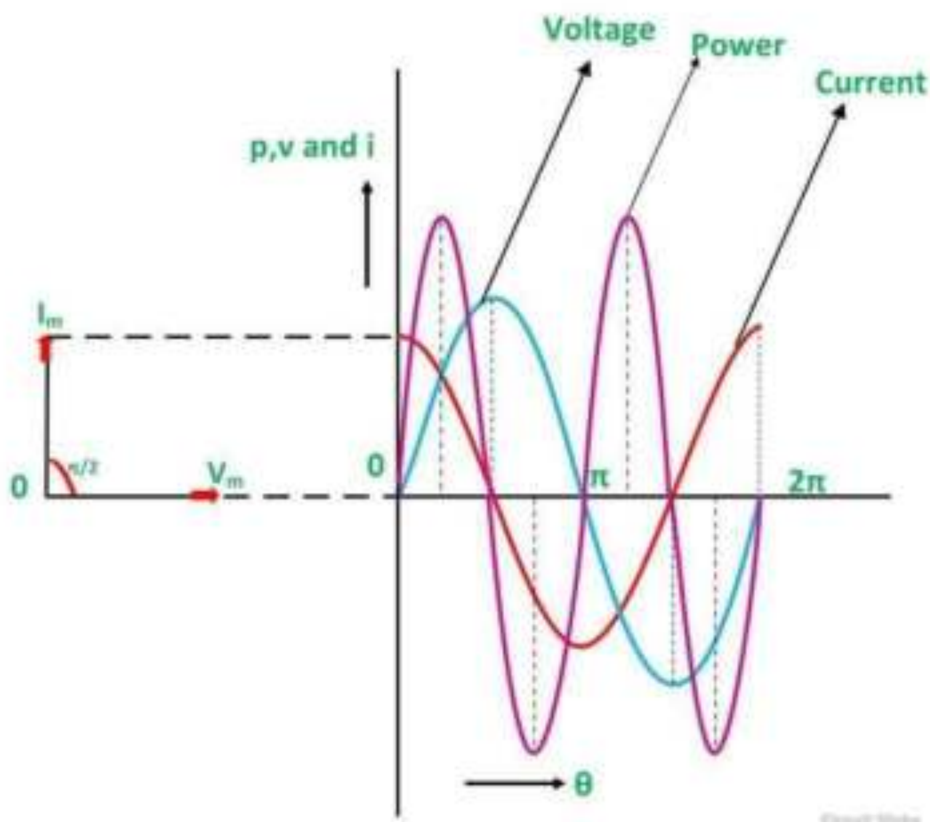
$$I_m = \frac{V_m}{X_C}$$

Substituting the value of I_m in the equation (4) we will get:

$$i = I_m \sin(\omega t + {}^{\pi}/_{2})$$

Phasor Diagram and Power Curve

In the pure capacitor circuit, the current flowing through the capacitor leads the voltage by an angle of 90 degrees. The phasor diagram and the waveform of voltage, current and power are shown below:



The red colour shows current, blue colour is for voltage curve, and the pink colour indicates a power curve in the above waveform.

When the voltage is increased, the capacitor gets charged and reaches or attains its maximum value and, therefore, a positive half cycle is obtained. Further when the voltage level decreases the capacitor gets discharged, and the negative half cycle is formed.

If you examine the curve carefully, you will notice that when the voltage attains its maximum value, the value of the current is zero that means there is no flow of current at that time.

When the value of voltage is decreased and reaches a value π, the value of voltage starts getting negative, and the current attains its peak value. As a result, the capacitor starts discharging. This cycle of charging and discharging of the capacitor continues.

The values of voltage and current are not maximised at the same time because of the phase difference as they are out of phase with each other by an angle of 90 degrees.

The phasor diagram is also shown in the waveform indicating that the current (I_m) leads the voltage (V_m) by an angle of π/2.

Power in Pure Capacitor Circuit

Instantaneous power is given by p = vi

$$P = (V_m \sin\omega t)(I_m \sin(\omega t + {}^{\pi}/_{2})$$

$$P = V_m I_m \sin\omega t \cos\omega t$$

$$P = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \sin 2\,\omega t \quad \text{or}$$

$$P = 0$$

Hence, from the above equation, it is clear that the average power in the capacitive circuit is zero.The average power in a half cycle is zero as the positive and negative loop area in the waveform shown are same.

In the first quarter cycle, the power which is supplied by the source is stored in the electric field set up between the capacitor plates. In the another or next quarter cycle, the electric field diminishes, and thus the power stored in the field is returned to the source. This process is repeated continuously and, therefore, no power is consumed by the capacitor circuit.

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