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|---|---|
| Subject: EEE | Unit No: 01 |
| Faculty: Sudhakar. A | Lecture No: 01 |
| Topic: Basic Definitions (Introduction) | Link to Session Planner (SP): S.No.... of SP |
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# Class Notes

## Voltage:

potential difference in electrical terminology is known as voltage, and is denoted by 'v' (or) V.

The difference in potential energy of the charges is called potential difference. All opposite charges possess a certain amount of potential energy because of the seperation between them.

Voltage is expressed in terms of energy (W) per unit charge (Q).

$$\therefore V = \frac{W}{Q} \text{ (or) } v = \frac{dw}{dq}.$$

where 'dw' is the small change in energy

dq is the small change in charge.

where energy expressed in Joules (J)

charge (Q) expressed in coulombs (C)

voltage expressed in volts (V)

Ex: If 70J of energy is available for every 30C charge what is the voltage?

Ans: given $W = 70J$, $Q = 30C$, $V = \frac{W}{Q} = \frac{70 \text{ Joule}}{30 \text{ coulombs}} = 2.33V$.

## Current:

Current is defined as the rate of flow of electrons in a conductive (or) semiconductive material. It's measured by the number of electrons that flow past a point in unit time.

Current is expressed as rate of change of electrons per unit time, and it is expressed as $I = \frac{Q}{t}$ (or) $i = \frac{dq}{dt}$.

where '$dq$' is the small change in charge, and '$dt$' is the small change in time.

Current can be measured in Amperes and denoted by A.

**Note:** one Ampere is equal to one Coulomb per second.

one coulomb is the charge carried by $6.25 \times 10^{18}$ electrons.

**Ex:** Five coulombs of charge flow past a given point in a wire in 2s. How many amperes of current is flowing?

**Ans:** $I = \frac{Q}{t} = \frac{5}{2} = 2.5$ Amps.

## Power:

Power is the rate of change of Energy. and it is denoted by either P (or) p. If certain amount of Energy is used ~~to overcome~~ over a certain length of time, Then $\text{power}(P) = \frac{\text{Energy}}{\text{time}} = \frac{W}{t}$ (or) $p = \frac{dw}{dt}$.

Where 'dw' is the change in energy and 'dt' is the change in time.

We can also write $p = \frac{dw}{dt} = \frac{dw}{dq} \times \frac{dq}{dt}$

$p = v \times i = vi$ (Watts)

Where energy can be measured in Joules (J), time measured in seconds (s), power measured in watts (W)

Note: ① The number of Joules consumed in one ~~Watt~~ second is always equal to the number of Watts.

② Amounts of power less than one Watt are usually expressed in fraction of Watts in the field of electronics i.e mW and μW (Milli, micro)

③ In the field of electrical Kilowatts (kW) and megaWatts (MW)

④ In the field of Radio & Television stations also use large Amount of power to transmit signals.

Ex: What is the power in Watts if energy is equal to 50J is used in 2.5 s?

Ans:- $p = \frac{\text{Energy}}{\text{time}} = \frac{50}{2.5} = 20\,W$.

## Energy:

Energy is the capacity for doing work. i.e. energy is nothing but stored work. Energy may exist in many forms such as mechanical, chemical, Electrical and so on.

## Network:

Interconnection of two or more simple circuit's elements (i.e voltage sources, resistors, capacitors, inductors) is called an electric network.

## Circuit:

If a Network contains atleast one closed path, it is called an electric circuit.

Electric circuit consists of three parts.

(1) Energy source (Battery or generator)

(2) the load (or) sink (lamp, motor)

(3) Connecting Wires.

**Note:** The purpose of the circuit is to transfer Energy from source (battery) to the load (lamp).

## closed circuit:

It's a circuit in which the current has a complete path to flow.

**open circuit:** when the current path is broken so that current can't flow, that circuit is [illegible]

**Class Notes**

Subject: EEE
Faculty: Sudhakar. Ajmera
Topic: ohms law

Unit No: 01
Lecture No: 2
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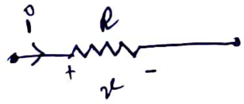
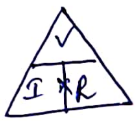
Def: ohms Law:-

ohms law states that the amount of Electric current through a metal conductor is directly proportional to the voltage across it and inversely proportional to the total Resistance of the circuit for any given temperature.




$$I = \frac{V}{R} \text{ (or) } i = \frac{v}{R}.$$




we can write above eqn in terms of charge as follows $v = iR \Rightarrow \boxed{V = R \cdot \frac{dq}{dt}}$ (or) $\boxed{i = \frac{v}{R} = Gv}$

where G is the conductance of a conductor.

the unit of resistance is $\Omega$ (ohm) & conductance is $\mho$ (mho).

Note:

When current flows through any resistive material, heat is generated by the collision of Electrons with other atomic particles. the power absorbed by the resistor is converted to heat.

The power absorbed by the resistor is given by.

$$p = vi = (iR)i = i^2R$$

Where $i$ is the current in the resistor in amps, and $v$ is the voltage across the resistor in volts.

Energy lost in a resistance in time $t$ is given by

$$w = \int_0^t p\,dt = pt = i^2Rt = \frac{v^2}{R}t.$$

where $v$ is the volts

$R$ is in ohms

$t$ is in seconds and

$W$ is in joules.

Example:

A $10\Omega$ resistor is connected across a 12V battery, How much current flows through the resistor?

Ans:- $V = IR$

$$I = \frac{V}{R} = \frac{12}{10} = 1.2 \text{ Amps.}$$

## Class Notes

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Subject: EEE
Faculty: Sudhakar Ajmera
Topic: Kirchoffs laws. (KVL & KCL)

Def: Kirchoffs Laws

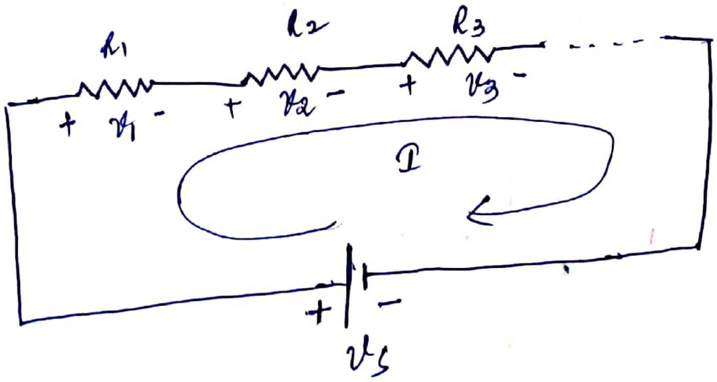
Kirchhoff laws can help you to understand current & voltage in a circuit & also be used to analyze complex circuit's that cant be reduced to one equivalent resistance these are Two Types.

(1) Kirchhoffs Voltage law (KVL)

(2) Kirchhoffs current law (KCL)

Kirchhoffs voltage law (KVL) :-

KVL states that the algebraic sum of all branch voltages around any closed path in a circuit is always zero at all instants of time.




According to definition applied voltage is $V_s$.
all branch voltages are $v_1, v_2, v_3 \ldots$

$$V_s - V_1 - V_2 - V_3 \ldots = 0$$

$$\boxed{V_s = V_1 + V_2 + V_3 + \ldots}$$

As the current passes through the circuit is same across all the resistors (series connected)

The sum of the voltage drop around the loop is equal to the Total voltage in that loop (Applied voltage)

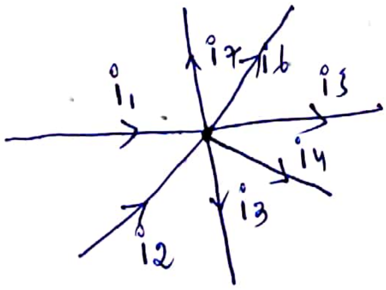
Note:

→ When the current passes through a resistor, there is a loss of energy and hence a voltage drop

→ In any element, a current flows from higher potential to lower potential.

## Kirchoffs current law (KCL) :-

KCL states that the sum of the currents entering into any node is equal to the sum of the currents leaving that node.




Here $\boxed{i_1 + i_2 = i_3 + i_4 + i_5 + i_6 + i_7}$ where $i_1, i_2$ are entering currents & $i_3\ i_4\ i_5\ i_6\ i_7$ are leaving currents. from the above eqn

$$\boxed{i_1 + i_2 - i_3 - i_4 - i_5 - i_6 - i_7 = 0}$$

**Class Notes**

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| Unit No: 01 | |
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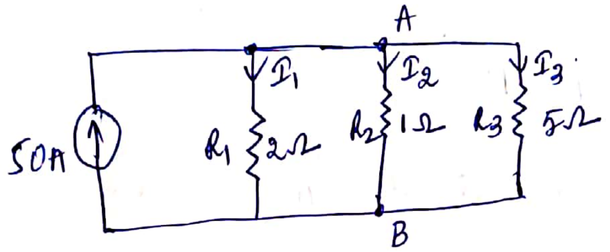
Subject: EEE
Faculty: Sudhakar Ajmera
Topic: problems on Ohms law & Kirchoffs laws)

Ex: ① Determine the current in all resistors in the circuit shown in below figure.




Sol: Assume at node A voltage is $v$ wrt to B.

According to KCL

$$50 = I_1 + I_2 + I_3$$

$$50 = \frac{V}{2} + \frac{V}{1} + \frac{V}{5} \Rightarrow 50 = V(0.5 + 1 + 0.2)$$

$$50 = V(1.7) \Rightarrow V = \frac{50}{1.7} = 29.41$$

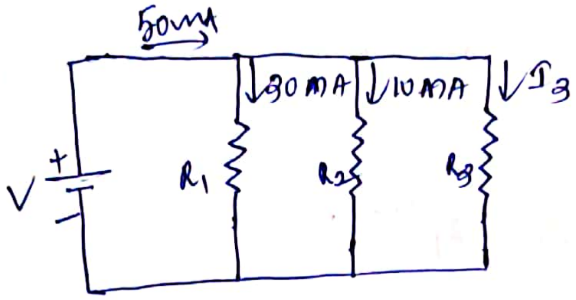
Now voltage at node A is $v = 29.41$

Now $I_1 = \frac{V}{2} = \frac{29.41}{2} = 14.7$ Amps

$I_2 = \frac{V}{1} = \frac{29.41}{1} = 29.41$ Amps

$I_3 = \frac{V}{5} = \frac{29.41}{1} = 5.88$ Amps.

Ex ②: Determine the current through resistance $R_3$ in the circuit shown

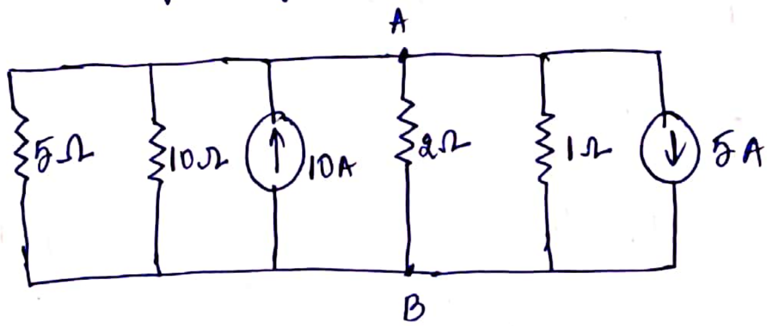



According to Kirchoffs law $50mA = (30+10+I_3)\ mA$

$$I_3 = (50-40)\ mA$$

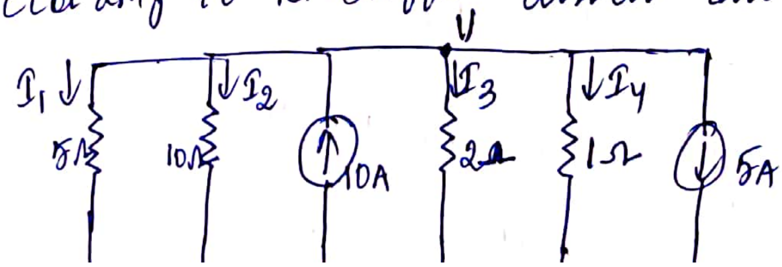
$$\boxed{I_3 = 10mA}$$

Ex: 3 : Find the voltage across the $10\Omega$ resistor and current passing through it.




The circuit shown above is parallel circuit, & consists of a single node A. By assuming voltage V at the node A wrt B.

According to Kirchoffs current law $I_1+I_2+I_3+I_4+5=10$



**Class Notes**

Subject: EEE
Faculty: Sudhakar Ajmera
Topic: Types of Elements

Unit No: 01
Lecture No: 5
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## Types of elements

Networks elements may be classified into four groups

1. Active (or) passive
2. Unilateral (or) Bilateral
3. Linear (or) non-linear
4. Lumped (or) distributed.

### 1. Active (or) passive elements:

→ Energy sources (voltage or current sources) are Active Elements, capable of delivering power to some external device.

→ passive elements are those which are capable of receiving power

→ passive elements like inductors, capacitors are capable of storing a finite amount of energy and return it later to an external element.

→ An Active element is capable of delivering an average power greater than zero to some external device over an infinite time interval. Ideal sources are Active Elements.

A passive element is defined as one that cannot supply average power that is greater than zero over an infinite time interval. Resistors, capacitors, and inductors fall into this category.

2. Bilateral and Unilateral

In the bilateral element, voltage-current relation is the same for current flowing in either direction. whereas Unilateral element has different relations between voltage and current for the two possible directions of current.

Examples of Bilateral elements are elements made up of high conductivity materials in general.

Vaccum Diodes, silicon Diodes, and metal Rectifiers are examples of Unilateral Elements.

3. Linear & Non linear Elements.

An Element is said to be linear if its V-I characteri-stics is all times a straight line through the origin

→ A linear element which satisfy the principle of superposition i.e; the principle of homogeneity and additivity. An element which doesnot satisfy the above principle is called a non-linear element.

## 4. Lumped & Distributed :

→ Lumped Elements are those elements which are very small in size and in which simultaneous actions takes place for given cause at the same instant of time.

→ Typical lumped elements are capacitors, resistors & Inductors & transformers.

→ Lumped elements are very small in size compared to wavelength of the applied signal.

→ Distributed Elements, on the other hand, are those which are not electrically seperable for analytical purposes.

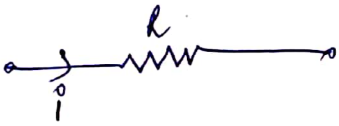
Ex: A Transmission line which has Distributed resistance, inductance and capacitance along its length over hundreds of miles.

## Basic elements :

Resistance:-

It's a two terminal Device which opposes the flow of electrons through it.

Symbol :




$V = IR$ (according to ohms law)

$I = \frac{V}{R}$ (or) $v = R \cdot \frac{dq}{dt}$ (or) $i = \frac{v}{R} = Gv$

$P = vi = (iR)i = i^2R$, $W = i^2Rt = \frac{v^2}{R}t$.

$V$ = volts, $i$ = amperes, $t$ = seconds, $W$ = Joules, $R$ = ohms.

It's the property of a material to restrict the flow of electrons is called Resistance and it's denoted by 'R'.

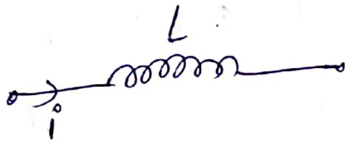
The unit of resistance is ohm($\Omega$)

*** Note: Resistor Dissipates energy in the form of Heat.

## Inductance:

A wire of certain length, when Twisted into a coil becomes a basic inductor. It's a two terminal Device.

If current is made pass through an inductor, an electro-magnetic field is formed. A change in the magnitude of the current, changes the electromagnetic field.

Symbol: 

The unit of Inductance is Henry. denoted by H.

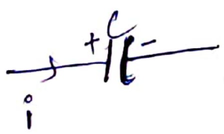
$W = \frac{1}{2} L i^2$, $v = L \cdot \frac{di}{dt}$, $i(t) = \frac{1}{L} \int_0^t v\,dt + i(0)$, $P = vi = Li\frac{di}{dt}$ watts.

***Note: Inductance stores Energy in the form of magnetic field

## Capacitance:

Any two conducting surfaces seperated by an insulating medium exhibits the property of capacitor. It's a two terminal Device.

The conducting surfaces are called electrodes, and the insulating medium is called dielectric.

Symbol: 

The unit of capacitance is Farads.

$C = \frac{Q}{V}$ (or) $C = \frac{q}{v}$, $i = C \cdot \frac{dv}{dt}$, $v(t) = \frac{1}{C} \int_0^t i\,dt + v(0)$

$P = vi = Cv\frac{dv}{dt}$, $W = \frac{1}{2} C v^2$

***Note: Capacitor stores Energy in the form of electric field.

## Class Notes

Subject: EEE
Faculty: Sudhakar · Ajmeera
Topic: Types of Sources.

Unit No: 01
Lecture No: 6
Link to Session Planner (SP): S.No.... of SP
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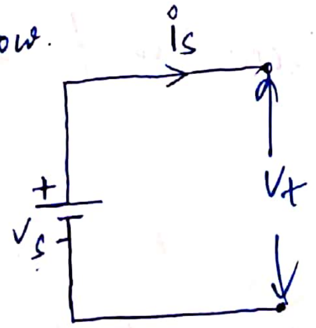
Page No: 8

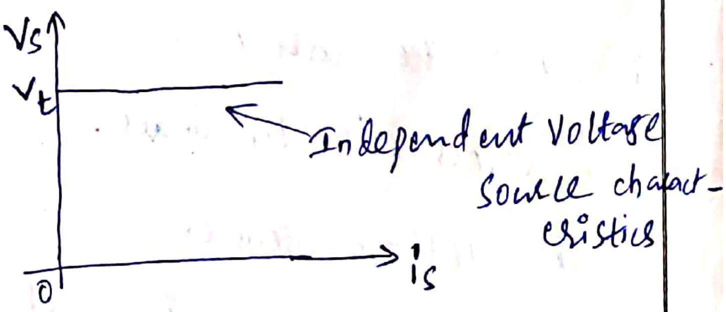
According to V-I characteristics, Electrical Energy sources are categorised into ideal voltage sources and ideal current sources.

Further they can be categorised into independent and dependent sources.

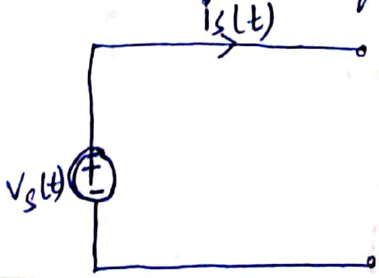
### Ideal voltage source :-

It's a two terminal Element in which the voltage ($V_s$) is completely independent of the current ($i_s$) through it's terminals. Representation of ideal constant voltage source as below.

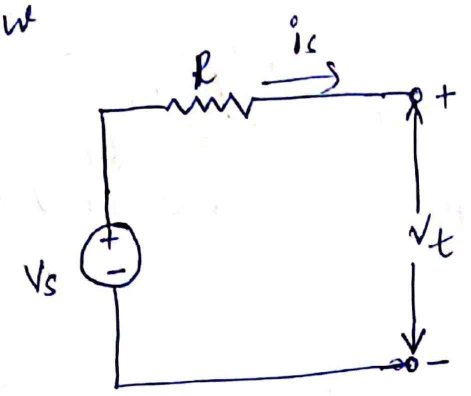


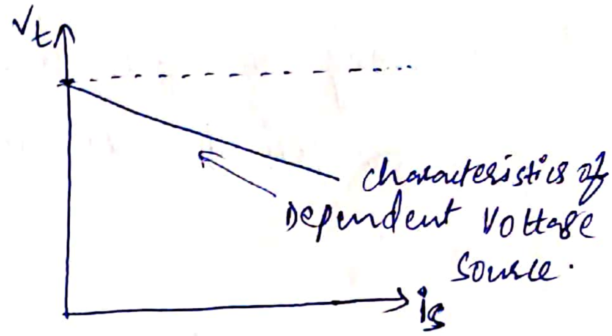




voltage sources need not have constant magnitude. in many cases the specified voltage may be time-dependent like a sinusoidal waveform. it may be represented as below



In many practical voltage sources, the internal resistance is represented in series with the source. it's shown as below




Here the terminal voltage $V_t$ depends on the source current as shown in above figure ($V_t$ vs $i_s$)

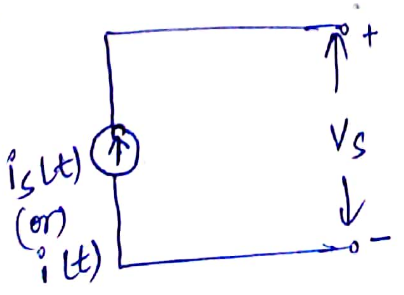
$$V_t = V_s - i_s R.$$

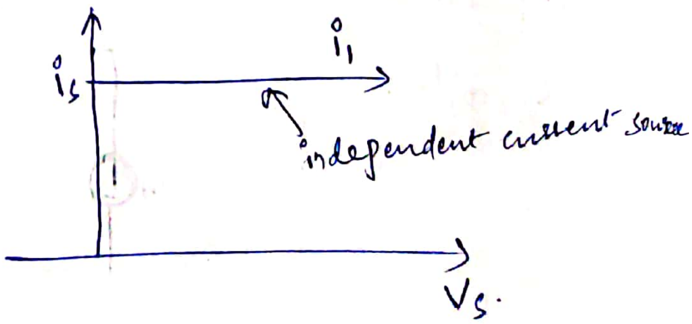
## Ideal current source:

An Ideal constant current source is a two terminal Element in which the current '$i_s$' completely independent of the voltage '$V_s$' across it's terminals.

like voltage sources we can have current sources of constant magnitude '$i_s$' and sources whose current varies with time $i_s(t)$.

The Representation of an ideal current source is shown below.



# Class Notes

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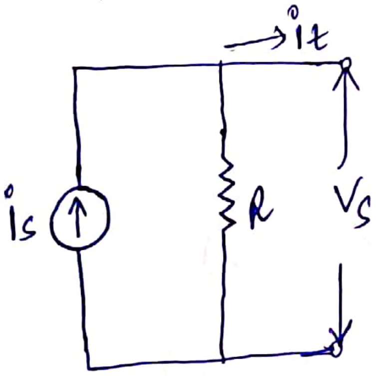
Subject: EEE

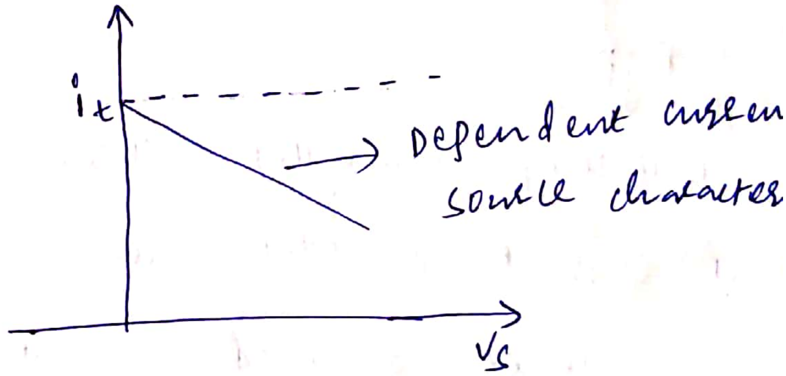
Faculty: Sudhakar Ajmera

Topic: Types of sources

if we see from above figure V-I characteristics of ideal current source, at any time current '$i_s$' is constan with respect to the voltage across it.

- But in many practical current source the resistance is in parallel with a source.




- <u>Note</u>: The terminal current is given by $i_t = i_s - (V_s/R)$.

where R is the internal resistance of the current source.

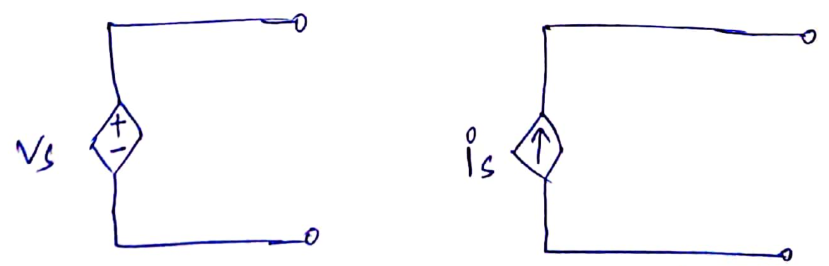
There are two types of sources for which voltage & currents are independent means not affected by other parts of circuit in independent sources.

Whereas dependent sources, the source voltage or source current is not fixed, but it's dependent on the voltage or current existing at some other location in the circuit.

Dependent (or) controlled sources are of the following Types

(i) Voltage controlled Voltage source (VCVS)
(ii) current controlled current source (CCCS)
(iii) Voltage controlled current source (VCCS)
(iv) current controlled voltage source (CCVS)

These sources are denoted (or) Represented as below Diagram.



Class Notes

Subject: EEE
Faculty: Sudhakar Ajmera
Topic: Resistive Networks.

Unit No: 01
Lecture No: 7
Link to Session
Planner (SP): S.No.... of SP
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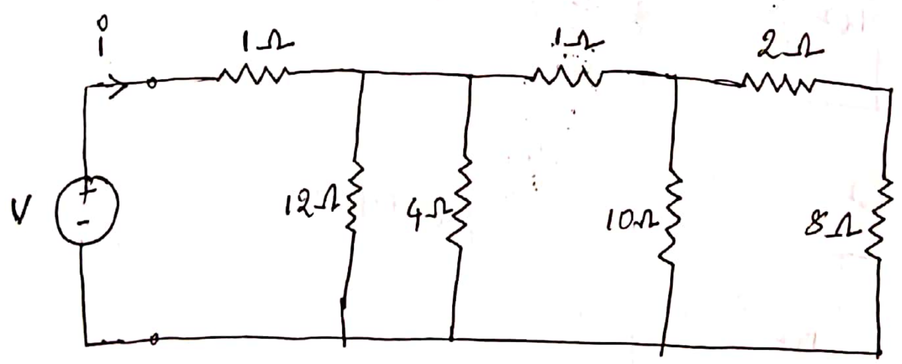
A resistive network containing only resistors, ideal current sources, and ideal voltage sources. If the sources are constant (DC) sources, the result is a DC circuit.

Analysis of a circuit consists of solving for the voltages and current present in the circuit.

Ex: Resistor circuits that combine series and parallel resistors networks together are generally known as Resistor combination or mixed resistor circuit.




Complicated resistor networks can be simplified by identifying series and parallel resistors ~~and~~

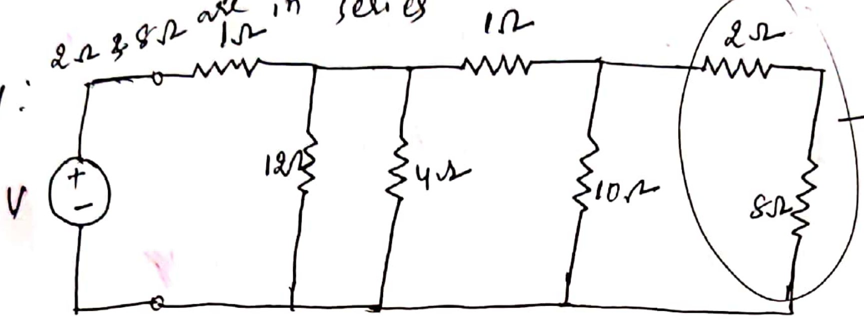
strategy for simplifying a resistor networks.

① Begin as far away as possible from the voltage source applied location.

(2) Replace all series or parallel resisters with their equivalent resisters

(3) Continue, moving left until a single equivalent resister represents the entire resister Networks.

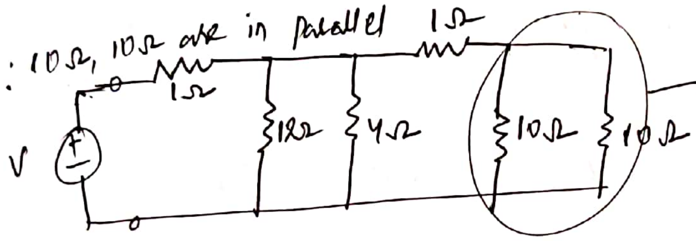
Step1 : 2Ω & 8Ω are in series




→ series resisters.

equivalent = 2+8 = 10Ω

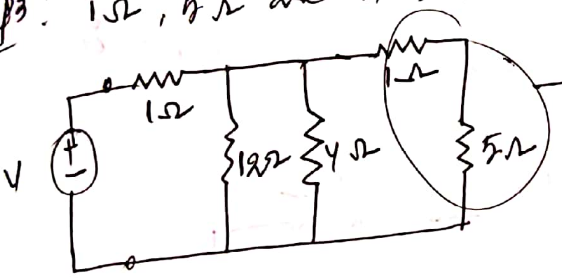
Step2 : 10Ω, 10Ω are in parallel




→ parallel resister.

equivalent = $\frac{10 \times 10}{10+10} = \frac{100}{20} = 5\Omega$

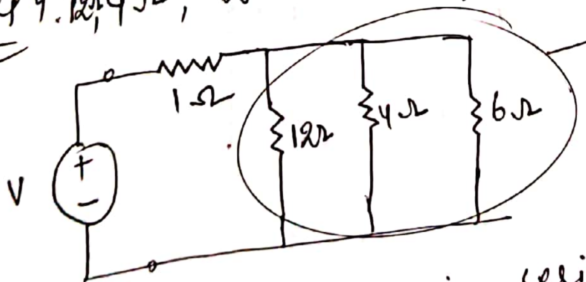
Step3 : 1Ω, 5Ω are in series.




→ series Resisters

equivalent = 1+5 = 6Ω

Step4 : 12Ω, 4Ω, 6Ω are in parallel.

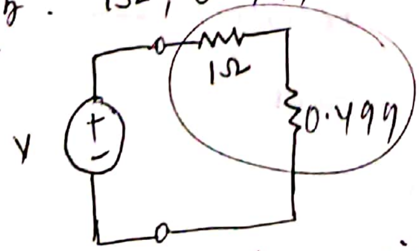



→ parallel resisters.

equivalent = $\frac{1}{12} + \frac{1}{4} + \frac{1}{6}$ = 0.0833 + 0.25 + 0.166

= 0.499

Step5 : 1Ω, 0.499 are in series

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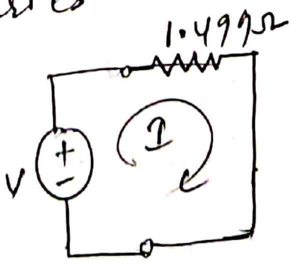


Step6 : current in a circuit $I = \frac{V}{1.499\Omega}$, V is applied voltage here.

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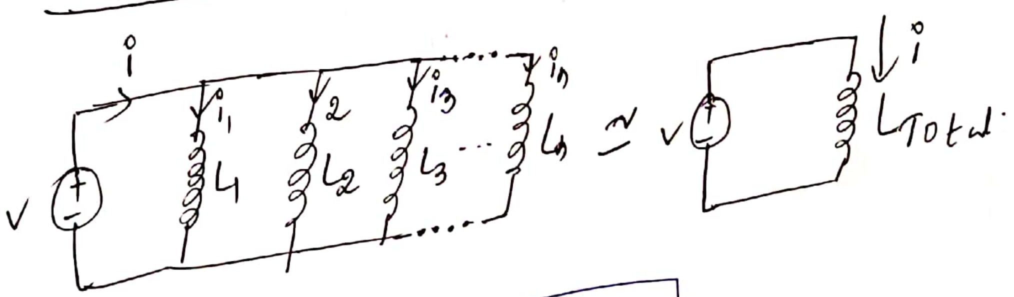
Collection of Inductors is called inductive network.

This Inductive Networks some time includes voltage sources & current sources.

Ex: Inductive circuit that consists of series and parallel networks together are generally known as Inductive Network.

Inductors connected in parallel :-




$$\boxed{V = L \cdot \frac{di}{dt}}$$

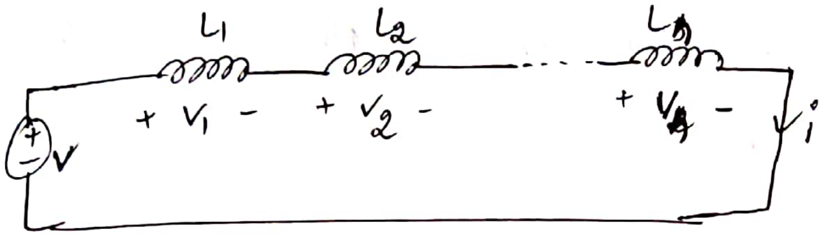
$$i = i_1 + i_2 + i_3 + \cdots i_n$$

$$\frac{di}{dt} = \frac{di_1}{dt} + \frac{di_2}{dt} + \cdots \frac{di_n}{dt}$$

$$\frac{V}{L_{Total}} = \frac{V}{L_1} + \frac{V}{L_2} + \cdots \frac{V}{L_n} \Rightarrow \boxed{\frac{1}{L_{Total}} = \frac{1}{L_1} + \frac{1}{L_2} + \cdots \frac{1}{L_n}}$$

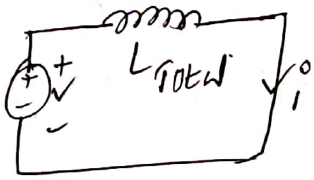
$$\boxed{\frac{1}{L_{Total}} = \sum_{j=1}^{n} \frac{1}{L_j}}$$

## Inductors Connected in series.




$$V = V_1 + V_2 + \cdots + V_n$$

=




$$\Rightarrow L_{Total}\frac{di}{dt} = L_1\frac{di}{dt} + L_2\frac{di}{dt} + \cdots L_n\frac{di}{dt}$$

$$\Rightarrow L_{Total} = L_1 + L_2 + \cdots L_n$$

$$\Rightarrow \boxed{L_{Total} = \sum_{j=1}^{n} L_j}$$

# Class Notes

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Subject: EEE

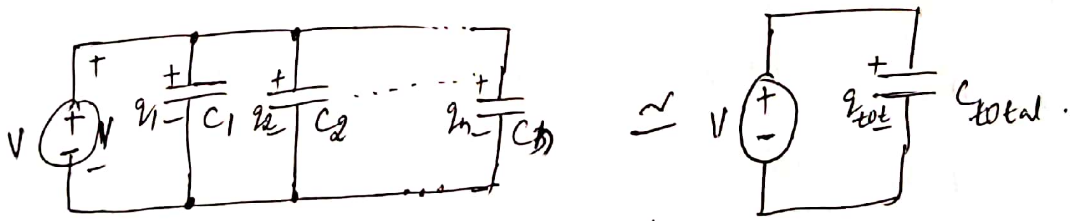
Faculty: Sudhakar Ajmera

Topic: Capacitive Networks

A collection of capacitors is called a capacitive networks. This capacitive network some time includes voltage sources and current sources.

Ex: Capacitive circuit that combine series and parallel capacitors networks together are generally known as capacitive combination.

Capacitors connected in parallel :-



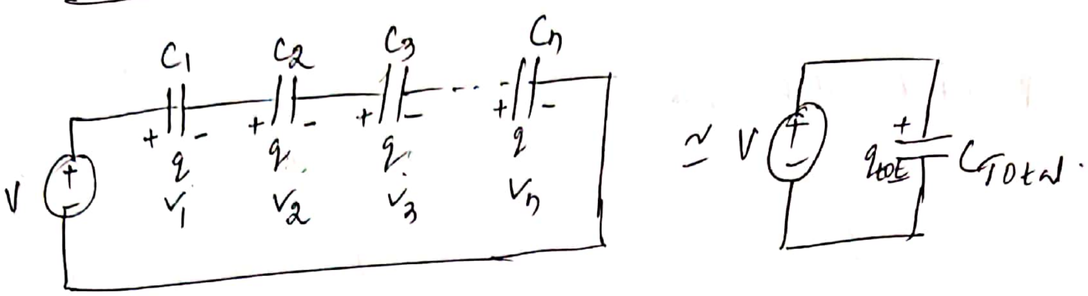

$$q_1 + q_2 + \cdots q_n = q_{total}$$

$$C_1V + C_2V + \cdots C_nV = C_{Total} \cdot V$$

$$(C_1 + C_2 + \cdots C_n)\cancel{V} = C_{Total} \cdot \cancel{V}$$

$$\boxed{C_{Total} = C_1 + C_2 + C_3 \cdots C_n} \quad (\text{or}) \quad \boxed{\sum_{i=1}^{n} C_i = C_{Total}}$$

## Capacitors connected in series :-




$$V = V_1 + V_2 + V_3 + \cdots V_n$$

$$V_1 = \frac{q}{C_1}, \quad V_2 = \frac{q}{C_2}, \quad \cdots V_n = \frac{q}{C_n}.$$

$$\frac{q}{C_{Tot}} = \frac{q}{C_1} + \frac{q}{C_2} + \cdots \frac{q}{C_n}$$

$$\frac{1}{C_{Tot}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots \frac{1}{C_n} \Rightarrow \boxed{\frac{1}{C_{Tot}} = \sum_{i=1}^{n} \frac{1}{C_i}}$$

**Note:** For series connection, Total capacitance of the circuit would be smaller than any individual capacitance.

→ For series connection, charge across all the capacitors is same but for parallel connection charge across all the capacitors are different.

## Class Notes

Subject: EEE

Faculty: Sudhakar Ajmera

Topic: problems.

Unit No: 01
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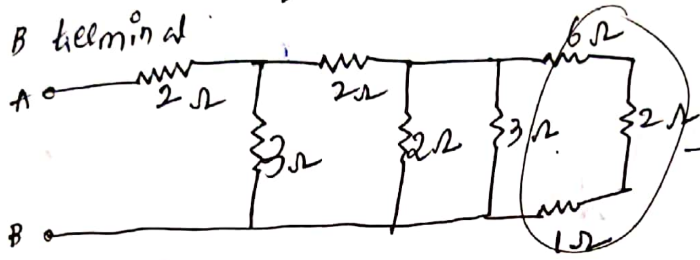
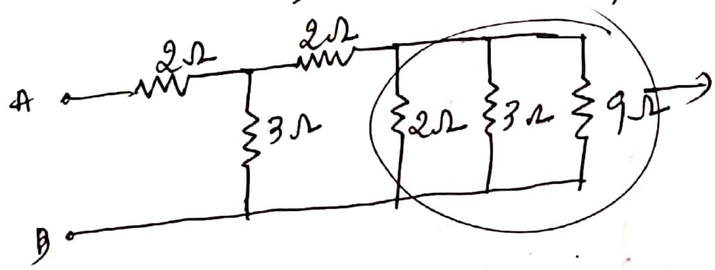
① What is the equivalent Resister of below Network b/w A & B terminal



→ series.

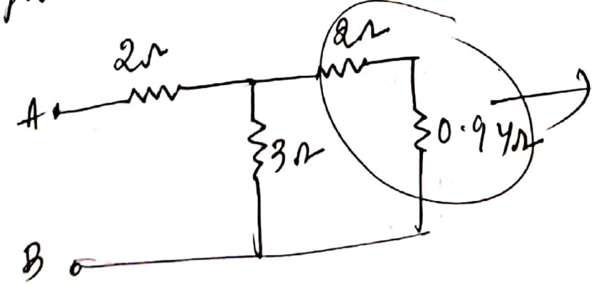
Ans:- from above Network 6, 2, 1Ω are connected in series.

so $6+2+1 = 9\Omega$



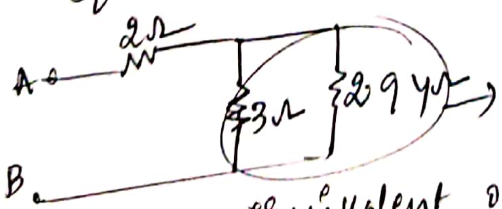
→ parallel Connected.

from above Network 2Ω, 3Ω, 9Ω are connected in parallel so equivalent Resistor $= \frac{1}{2\Omega} + \frac{1}{3\Omega} + \frac{1}{9\Omega} = 0.94\Omega$



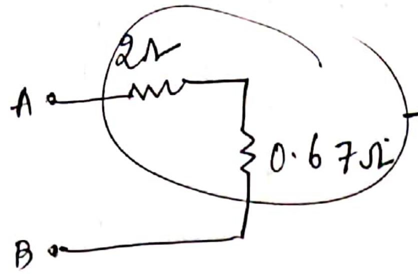
→ series connected

equivalent of 2Ω, 0.94Ω ⇒ $2 + 0.94 = 2.94\Omega$

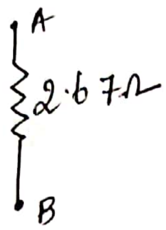


→ parallel connected

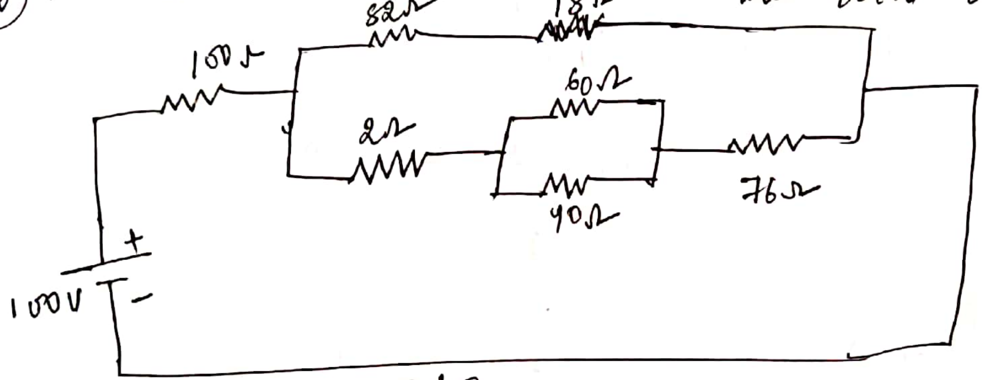
equivalent of parallel connected 3Ω, 2.94Ω = 0.67Ω



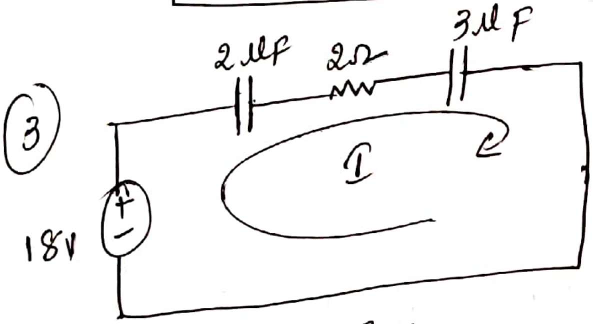

series connected



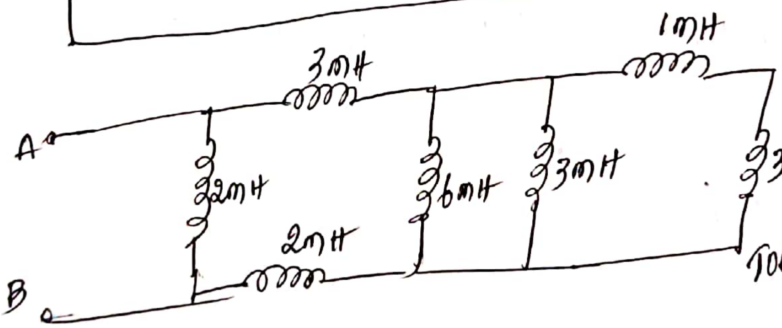

(2) For the circuit shown. Find the total current.



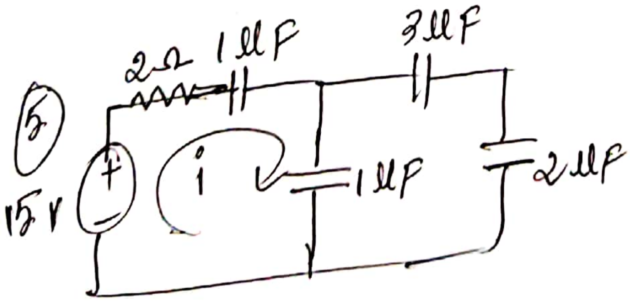

(3) Find the Total current I




(4) find terminal AB Total Inductance.




(5) Find total circuit current due to 15V supply.



## Class Notes

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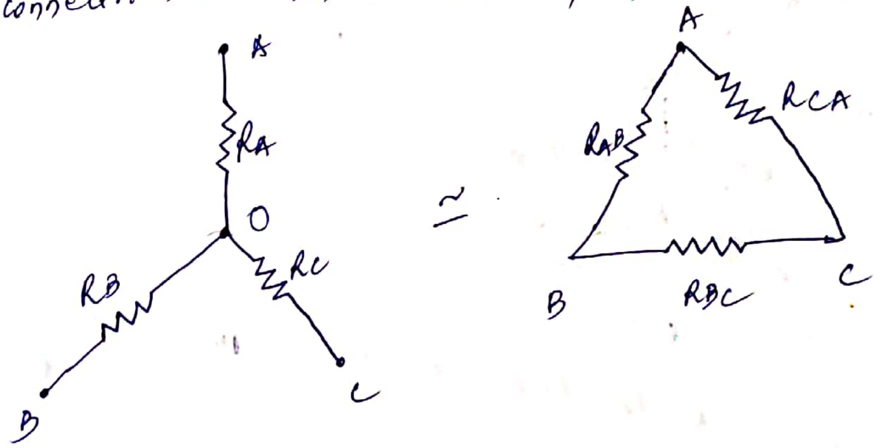
Subject: EEE

Faculty: Sudhakar Ajmera

Topic: Star to Delta Transformation.

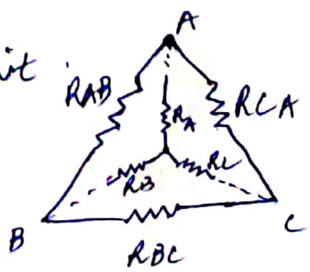
The star to delta transformation is another technique useful in solving complex networks.

Basically any three elements resistive, Inductive or capacitive may be connected in star connection (Y connection) or otherway of connecting elements is called the delta ($\Delta$) connection. Here star connections are known values & delta connections are unknown values




for star to delta connection conversion RA, RB, RC are known values and RAB, RBC, RCA are unknown values.

to findout unknown values RAB, RBC, RCA We need to place star circuit in delta circuit & We can directly write unknown values of RAB. RBC & RCA as below.

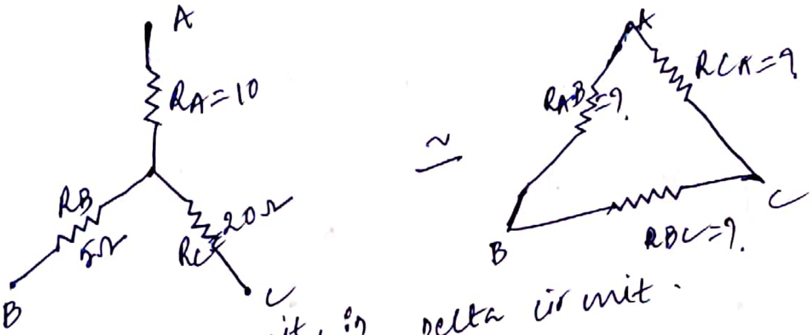


$$\boxed{R_{AB} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_C}}$$

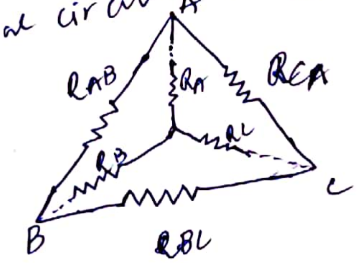
$$\boxed{R_{BC} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_A}}$$

$$\boxed{R_{CA} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_B}}$$

Ex: convert below star connected circuit to delta connected circuit.




Ans: Insert star circuit in delta circuit.

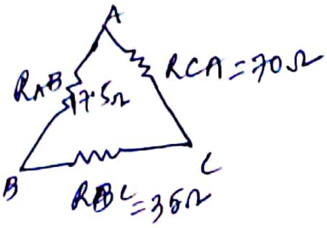



Now $R_{AB} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_C} = \frac{10\times5 + 5\times20 + 20\times10}{20} = \frac{50+100+200}{20} = \frac{350}{20} = 17.5$

$R_{BC} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_A} = \frac{10\times5 + 5\times20 + 20\times10}{10} = 35\Omega$

$R_{CA} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_B} = \frac{10\times5 + 5\times20 + 20\times10}{5} = 70\Omega$

Now $\Delta$ Network (unknown) as shown below.



Subject: EEE

**Class Notes**

Faculty: Sudhakar. Ajmeera.

Topic: Delta to Star conversion.

Unit No: 01
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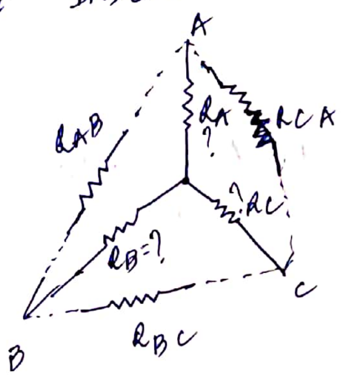
Delta to star is another technique in solving complex networks. Basically any three Resistive, Inductive and capacitive may be connected in delta (Δ) connection.

In this Δ to Y conversion; Delta circuit's ~~has~~ known values & Y circuit's ~~has~~ unknown values.

To find out Insert star into delta.



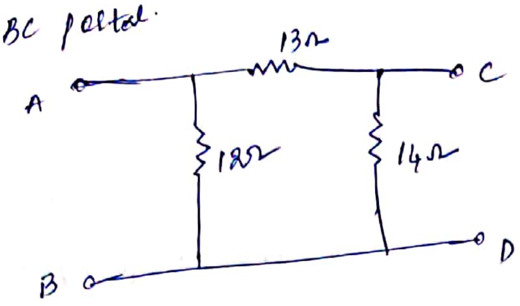

Now we can directly write

$$\boxed{R_A = \frac{R_{AB} * R_{CA}}{R_{AB} + R_{BC} + R_{CA}}}$$

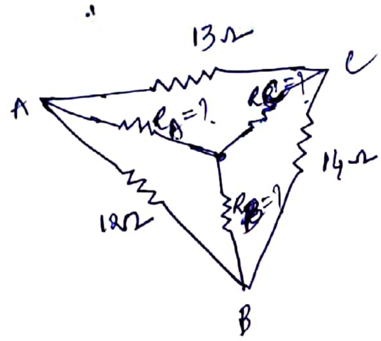
$$\boxed{R_B = \frac{R_{AB} \times R_{BC}}{R_{AB} + R_{BC} + R_{CA}}}$$

$$\boxed{R_C = \frac{R_{BC} * R_{CA}}{R_{AB} + R_{BC} + R_{CA}}}$$

Ex: Convert below Delta to star circuit, which is connected across AB & BC portal.

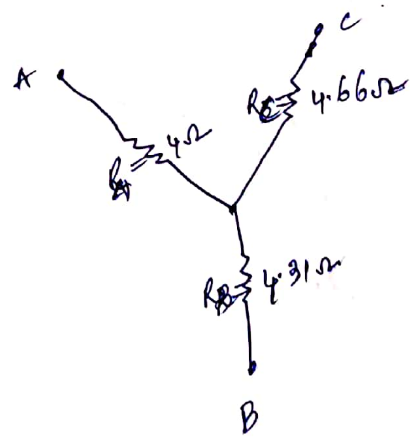



Ans: We can re-write above circuit as shown in figure below.




$$R_A = \frac{13 \times 12}{13+12+14} = 4\Omega \qquad R_B = \frac{12 \times 14}{12+14+13} = 4.31\Omega \qquad R_C = \frac{13 \times 14}{13+12+14} = 4.66\Omega$$

Now star circuit



**Class Notes**

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Subject: EEE

Faculty: Sudhakar. Ajmera.

Topic: Y to Δ & Δ to Y problems.

① Delta to Star Transformation

② Star to Delta Transformation problems

① obtain Δ circuit when the 9Ω resister each connected in star

② obtain star circuit when 3Ω resister each connected in Δ

③ What is the equivalent Delta(Δ) circuit, when connected in star of each resistor 4Ω

④ What is the equivalent of Delta (Δ) circuit, when connected in star of each resistor 5Ω

⑤ What is the equivalent of star (Y) circuit, when each resistor of values 3Ω connected in Delta(Δ)

Subject: EEE

Faculty: Sudhakar Ajmera

Topic: Introduction to DC machines & Working principle of D.C machine.

**Class Notes**

Unit No: 02.
Lecture No: 17.
Link to Session Planner (SP):S.No.... of SP
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## Introduction to D.C machine:-

A D.C machine is an Electromechanical energy conversion device. It requires magnetic flux, conductors and the relative motion ~~of~~ for the energy conversion.

## Working principle of D.C. machine:-

D.C machine can be categorized as DC motors and D.C generators

## Working principle of DC motor:-

DC motor is a D.C machine to which electrical energy is given as input and mechanical energy is obtained as output. DC motor works on the principle of Faraday's laws of Electromagnetic induction. i.e., whenever a current carrying conductor is placed in a magnetic field, it experience a mechanical force.

The magnitude of mechanical force Experienced as

$$F = BIl \text{ newton}.$$

where $B$ = flux density (web/m$^2$ (or) Tesla)

$I$ = current flowing through conductor (Ampere)

$l$ = the length of the conductor (meters)

The direction of force is given by flemings left hand rule.

## Working principle of DC generator :-

DC Generator is a DC machine, which takes mechanical energy as input and converts it into Electrical energy as output. DC Generator works on the principle of Faraday's laws of electromagnetic induction i.e., whenever a moving conductor is placed in a magnetic field, dynamically induced e.m.f is produced in the conductor or whenever a conductor cuts the magnetic flux dynamically, e.m.f is produced. As a result, this e.m.f causes a current to flow in the conductor circuit is closed.

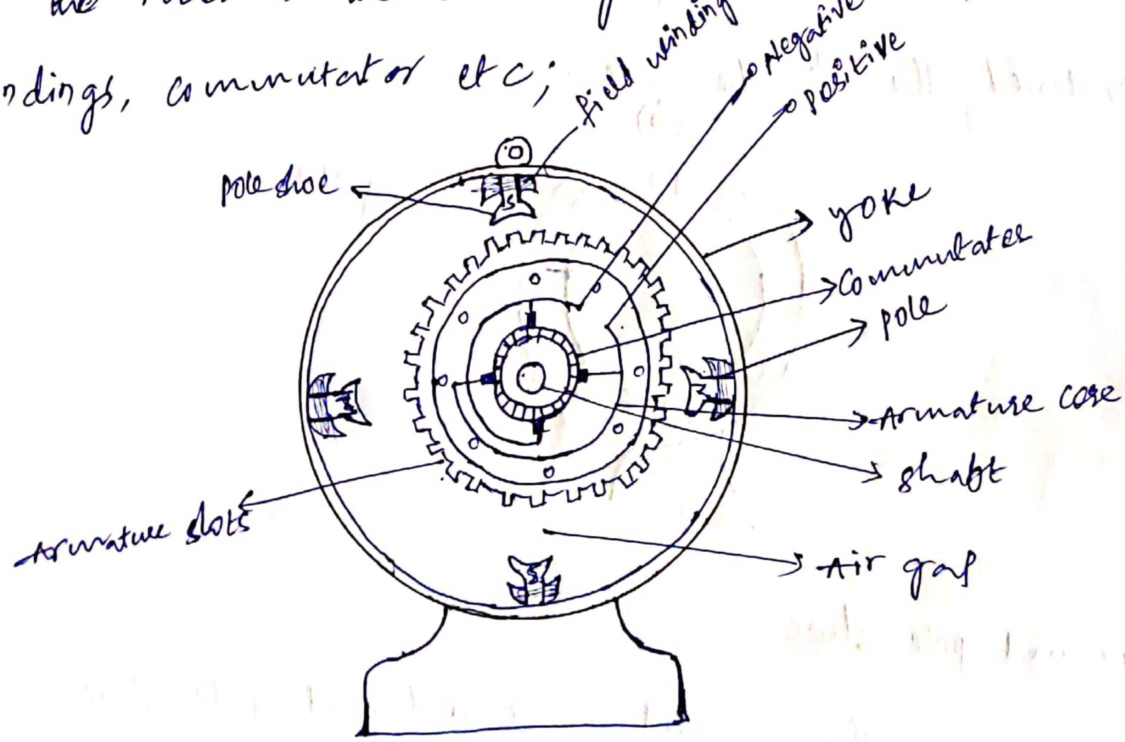
Therefore, for a machine operating as a generator, external driving force is given as input and a D.C output is obtained.

| | |
|---|---|
| Subject: EEE<br>Faculty: Sudhakar Ajmera.<br>Topic: Construction Details of DC machine. | Unit No: 02<br>Lecture No: 18<br>Link to Session Planner (SP): S.No.... of SP<br>Book Reference:<br>Date Conducted:<br>Page No: 02 |

**Class Notes**

A Direct current (D.C) machine is an Energy conversion device. It converts Electrical Energy to mechanical while working as a motor and mechanical Energy to Electrical Energy while working as a generator. Hence it is known as Electromechanical Energy Conversion Device. It consists of stator and rotor.

Stator is the assembly of main parts like yoke, main poles, pole shoe, interpoles, field windings etc., and the rotor is the assembly of armature, armature windings, commutator etc;



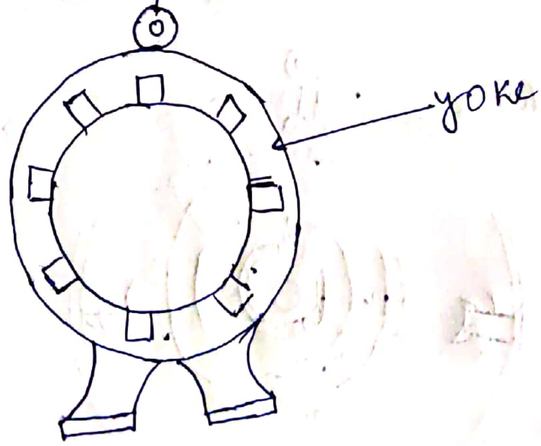
D.C machine parts

- Stator
  - yoke
  - pole core (or) pole shoe
  - Interpoles
  - field windings
  - Brush and Brush holders
- Rotor
  - Armature core
  - Armature windings
  - Commutator.

**Stator:-** stator is generally a stationary part.

**YOKE:-**

yoke is the outer cover of the machine supporting and protecting the internal parts. It is made up of low reluctance material like silicon steel ~~or~~ cast iron. since it has to carry the magnetic flux i.e; to provide the closed path for the flux produced through the poles.




**pole core and pole shoe:**

pole core is generally a solid material and pole shoe is a laminated one in small machines but both pole shoe and

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**Class Notes**

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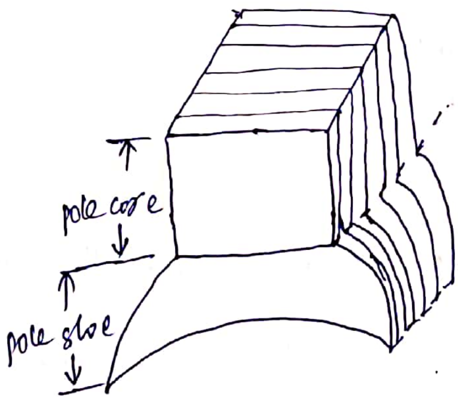
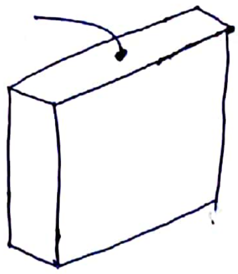
pole core are laminated in modern days. The purpose of the pole core is to provide flux and to support the field windings, whereas the pole shoe is stretched so as to provide uniform air gap along the armature core and also to provide uniform flux distribution in the air gap.




Brush and Brush Holders.

Brushes are the structures placed on the rotating commutator through which the unidirectional current is to be collected. Generally, it is made of carbon which can give smooth surface at the contacts so as to reduce the sparks and wear and tear of the commutator bars. These are fixed to the stator core (yoke) by means of brush holders

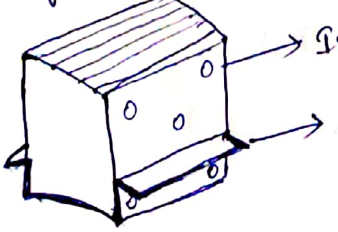



## Field windings:

The field windings are wound initially on a wooden former and then installed into the pole core. These are generally made of low resistivity materials like copper (or) alluminium. There are two ways of connecting the field winding to the armature in case of self excited machine. They can be connected in series or shunt.

## Interpoles:

These are the pole structures generally smaller than main poles and is placed in between the main poles. The windings of the interpoles are of less turns since it is connected in series with armature windings. The main purpose of these interpoles is to reduce the armature reaction, thereby reducing the sparks at the brush contacts. The polarity of the interpole is made same as that of the main pole ahead of it in the direction of rotation.




Interpole & support to coil.

Subject: EEE
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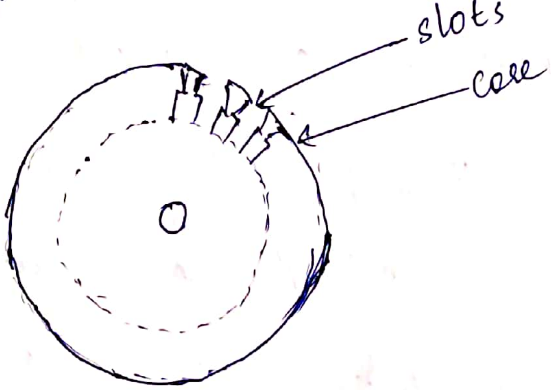
## Rotor :-

The rotor is generally a rotating part which carries the armature, armature windings and the commutator on the same shaft.

## Armature core :-

The armature core is made up of laminated silicon steel. The main purpose is to hold the armature windings and the to provide low reluctance path for the flux




## Armature windings :-

The windings placed in the armature is called the armature windings and is generally connected in two ways.

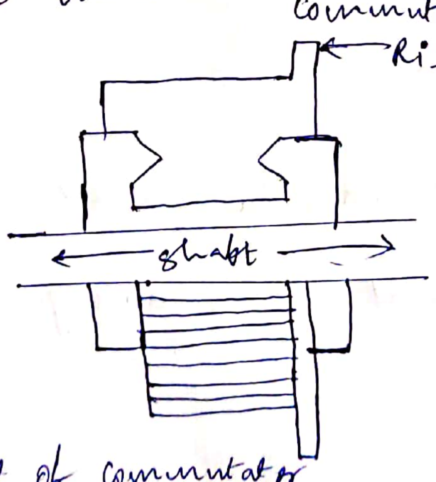
(i) Lap windings
(ii) Wave windings

Lap windings are preferred for higher currents and low voltages whereas as wave windings are preferred for higher voltages and lower currents.

## Commutator :-

Commutator is a split rings of larger size with large number of splits (commutator segments). It is called a mechanical rectifier in generator and an inverter in motor. The connections to the commutator depends upon the type of armature windings. These are made of hard copper so as to withstand the brush forces which are placed upon the commutator segments.

The position of the brushes is generally based on the windings. A fan is connected to the shaft of the motor so as to cool the armature.




Front view of commutator

Subject: EEE
Faculty: Sudhakar. Ajmera.
Topic: Types of DC machines

# Class Notes

Unit No: 02
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A DC machine is an Electromechanical energy conversion device. It requires magnetic flux, conductors and the relative motion for the energy conversion. Based on the production of magnetic flux (i.e excitation of the field windings), the D.C. machines are classified into two types.

(1) permanent magnet
(2) electro magnet

D.C machines
- permanent magnet
- Electromagnet
  - seperately excited
  - self excited
    - shunt
    - series
    - compound
      - short shunt
      - long shunt

## Permanent magnet:-

These type of machines are of low rating and consists of the magnetic poles fixed in the inner periphery and the armature coils feeds (or) being fed by the supply in case of generator and motor respectively.

In this permanent magnet type machine, field is fixed and it can't varied

## Electromagnet machines :-

Here Electro magnet DC machines can be Either Generator (or) motor.

## → Types of DC Generator :-

DC Generators are of two Types:

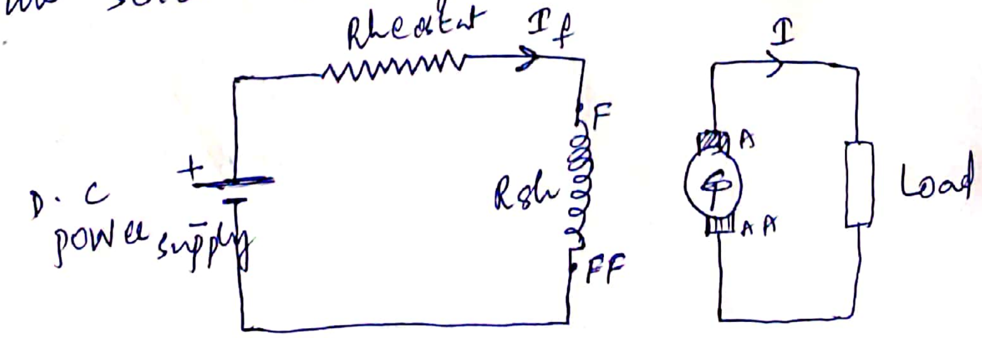
(1) self excited DC Generators.

(2) seperately Excited DC Generators.

### (1) seperately excited DC Generators.

In a seperately excited DC Generator, the field windings is excited from a seperate external D.C source.

The schematic diagram as shown below



The armature and the field circuits are independent of each other and hence the armature current I is independent of the field current $I_f$. In order to get the desired excitation D.C voltage source can be designed conveniently without any effect on armature current.

## Self excited D.C Generators:-

In a self excited D.C Generator, the field winding is excited by the armature current. Hence, there is a strong interconnection between the armature and field currents.

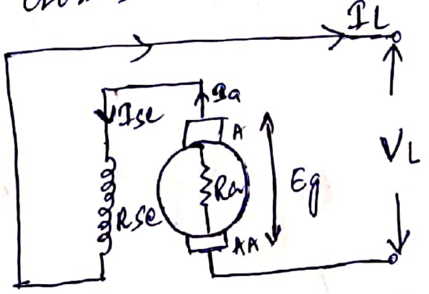
In this type of generators, the field poles should always contain some residual magnetism. Due to the residual magnetism, the poles always contain some flux. When the armature is rotated, some e.m.f is induced. The current produced passes through field coils to strengthen the flux. This in turn increases the induced voltage and hence the current in the field. It results in to the build up of voltage.

Depending upon the position of the field winding with respect to the armature winding, self excited generators are classified into three types. They are

(i) self excited series generator
(ii) self excited shunt generator
(iii) self excited compound generators.

## Self excited series Generator:-

In this type generator, the field coils are connected in series with the armature terminals and the conductors would be of higher cross-section and with lesser number of turns.



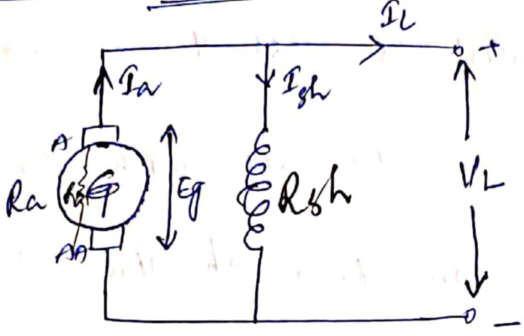

The current flowing through the coil would be the same as that of the armature current. So it is made more cross-sections

$I_L$ = line current = series field current = Armature current

i.e $\Rightarrow I_L = I_{se} = I_a$

$\therefore$ Generated e.m.f $E_g = V_L + I_a R_a + I_a R_{se}$
$= V_L + I_a (R_a + R_{se})$

## Self excited shunt Generators:




If the field winding is connected across the armature winding then the machine is called the shunt machine. In the shunt generator, as the shunt winding has to overcome the generated voltage it is made with higher turns of lower cross-sectional conductors. They have higher resistance as compared to the series coils, but the current is less.

Here line current = Armature current - Shunt field current

$$I_L = I_a - I_{sh}$$

$\therefore$ Generated e.m.f ($E_g$) = Terminal voltage + Armature Resistance drop

$\Rightarrow$ $\boxed{E_g = V_L + I_a R_a}$, where $I_a$ = Armature current
$I_L$ = Line current
$R_a$ = Armature resistance

## Self excited compound generator:-

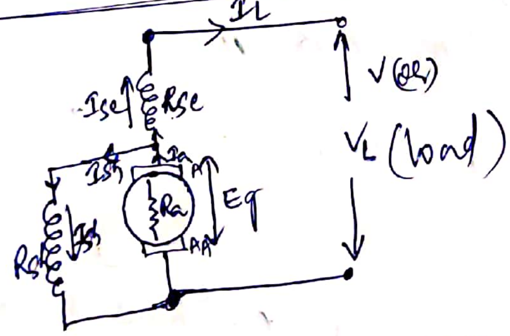
The combination of two windings i.e series & shunt field winding is connected to a compound generator. In the compound generator, normally the field of the shunt will be more than the series field and will be less than the individual shunt machine. The same is the case with the series field also.

Based on the type of connection of the shunt field to the armature and series field, it is divided as

(1) short shunt generator

(2) Long shunt generator.

### Short shunt generator



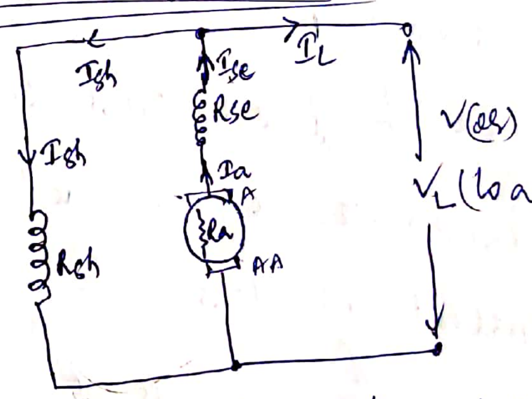

In this type of machine, the series field current is made same as that of the line current, the connection of shunt field is done first & then series field connections are made.

Terminal voltage (V) (or) load voltage $(V_L) = E_g - I_a R_a - I_{se} R_{se}$

shunt field voltage $(V_{sh}) = E_g - I_a R_a$

Armature current $(I_a) = I_{sh} + [I_{se} \text{ (or) } I_L]$

### Long shunt generator.




In this type of machine, the series current and the armature current are made same and the shunt connection is made after the series connection is done

series field current = Armature current

$I_a = I_{se} = I_L + I_{sh}$

$V_L = V_{sh} = E_g - I_a R_a - I_{se} R_{se}$
$= E_g - I_a (R_a + R_{se})$

Subject: EEE

Faculty: Sudhakar Ajmera

Topic: Types of DC motors:-

**Class Notes**

Unit No: 02
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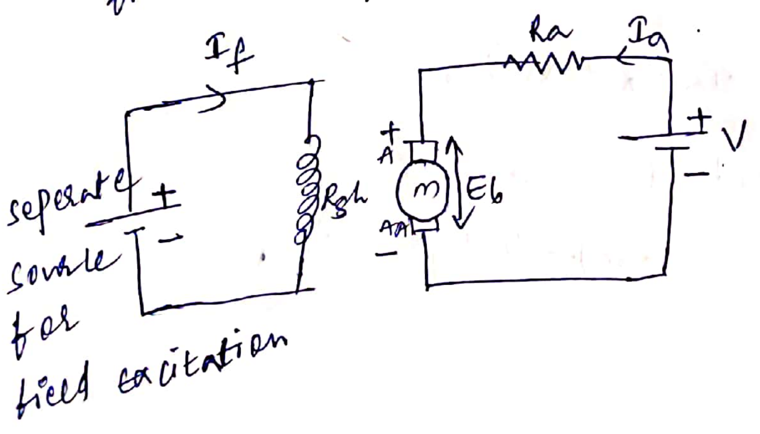
Based on the excitation the D.C motors are mainly classified into two types. They are

1. seperately excited D.C motors
2. self excited D.C. motors.

## Seperately excited D.C. motors:-

The field coil and armature of these motors are supplied from a seperate supply source.

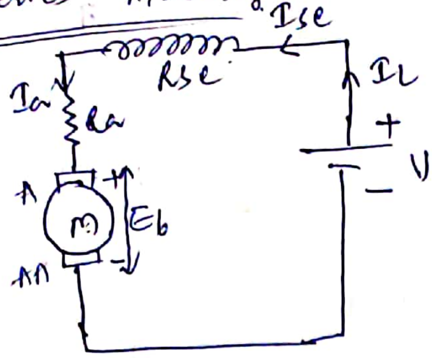



## self excited D.C motors:

The field coils of these motors are supplied from the armature. The different types of self excited D.C motors are

(1) shunt motors
(2) series motors
(3) compound motors.

## DC Series motor :-




For the series motor field winding is series connected with motor Armature.

Here $\boxed{I_L = I_{se} = I_a}$ means load current = field winding current = Armature current.

Terminal voltage $\boxed{V = E_b + I_a R_a + I_{se} R_{se}}$

$= E_b + I_a R_a + I_a R_{se}$

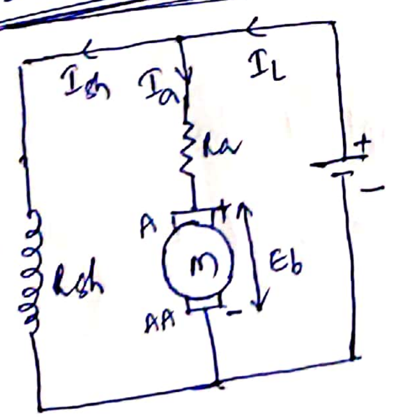
$= E_b + I_a (R_a + R_{se})$

Back e.m.f $\boxed{E_b = V - I_a (R_a + R_{se})}$

If voltage drop is considered then we get

$\boxed{E_b = V - I_a (R_a + R_{se}) - \text{voltage drop}}$

## DC shunt motor :-




For the shunt motor field windings are parallel to the motor armature.

Here $\boxed{I_L = I_a + I_{sh}}$ ; $\boxed{I_a = I_L - I_{sh}}$

Terminal voltage $\boxed{V = I_a R_a + E_b}$

$\boxed{V = I_{sh} R_{sh}}$

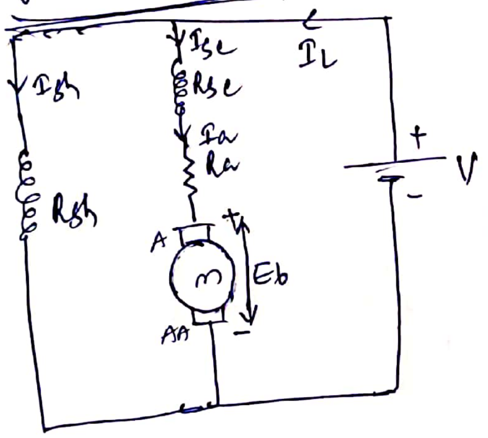
$\boxed{I_{sh} R_{sh} = I_a R_a + E_b}$

## DC compound motor:-

based on series field & shunt field winding connection to the armature it's again divided into 2 types.

(1) long shunt motor (2) short shunt motor.

### (1) long shunt DC compound motor:-




$$V = I_{se} R_{se} + I_a R_a + E_b.$$

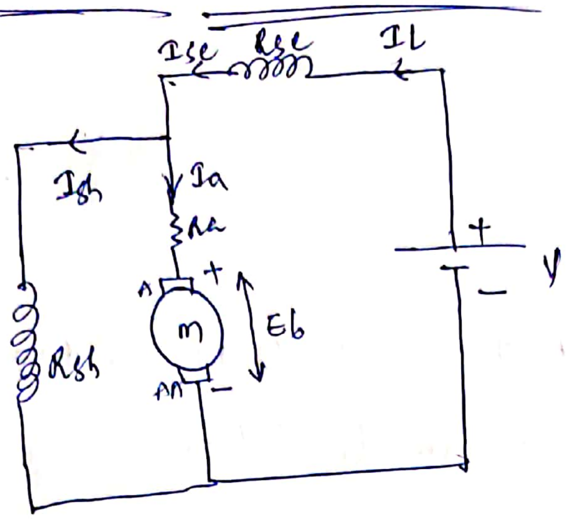
$$= I_a R_{se} + I_a R_a + E_b \quad [\because I_a = I_{se}]$$

$$\boxed{V = E_b + I_a (R_a + R_{se})} \quad \text{(or)} \quad \boxed{V = E_b + I_{se}(R_a + R_{se})}$$

$$\boxed{V = I_{sh} R_{sh}}$$

$$\boxed{I_{sh} R_{sh} = E_b + I_a (R_a + R_{se})}$$

## Short shunt D.C Compound motors :-




Here $\boxed{V = I_{se}R_{se} + I_{sh}R_{sh}}$

$$I_L \text{ (or) } I_{se} = I_{sh} + I_a$$

$$\boxed{I_a = I_{se} - I_{sh}}$$

$$\boxed{I_a = I_L - I_{sh}}$$

$$\boxed{I_{sh}R_{sh} = I_aR_a + E_b}$$

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Subject: EEE

Faculty: Sudhakar Ajmera

Topic: Working principle of DC Generator.

→ D.C Generator is a DC machine to which Mechanical Energy given as input and Electrical energy is obtained

→ DC Generator works on the principle of Faradays law of Electromagnetic induction i.e whenever a Rotating conductor cuts a magnetic field an e.m.f is induced in it.

The magnitude of induced e.m.f is given by Eg

$$\boxed{E_g = N \cdot \frac{d\phi}{dt}}$$

The direction of induced e.m.f is given by Flemmings right hand rule.

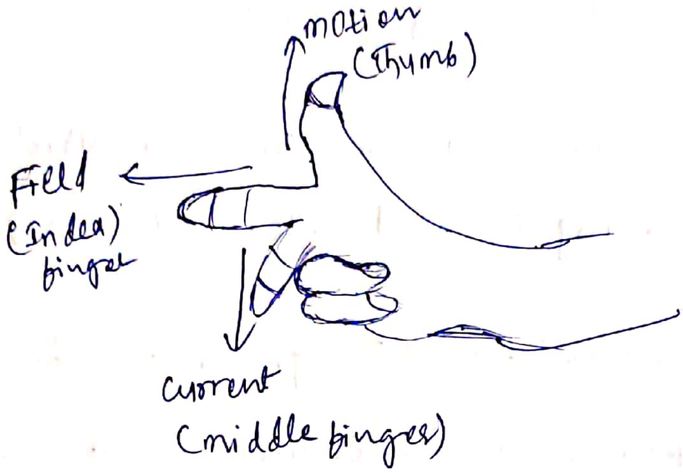
## Flemmings Right Hand rule :-

→ Flemmings Right-hand Rule states that the direction of induced current is shown by middle finger, and

→ The first finger (index finger) is pointed in the direction of the magnetic field and

→ The Thumb is pointed in the direction of the motion (Force) of the conductor (relative to the magnetic field)

Here The Right hand thumb, index finger and middle finger mutually perpendicular to each other




Applications of DC Generator:-

① DC Generators are used in power-generating stations to serve as an Excitation source for large alternators.

② These generators are also used in series are lighting, charging of batteries and They serve as auxiliary and Emergency power supplies.

Topic: Working principle of D.C. motor.

→ DC motor is a D.C Machine to which electrical Energy is given as input and mechanical energy is obtained as output.

→ D.C Motor works on the principle of Faradays Laws of electromagnetic induction i.e whenever a current carrying conductor is placed in a magnetic field it experience a mechanical force.

The magnitude of mechanical force experienced is given as

$$\boxed{F = BIL} \text{ Newton}$$

where B is the flux density (Wb/m² or Tesla)

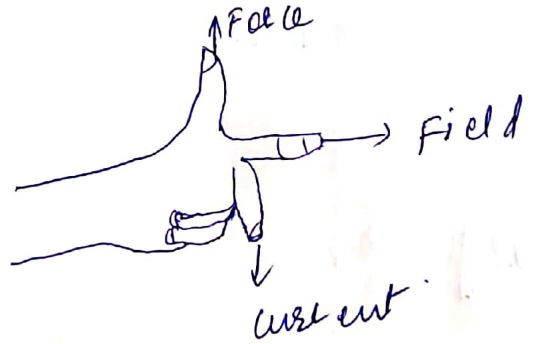
I is the current flowing through the conductor (Amps)

'l' is the length of the conductor (meters)

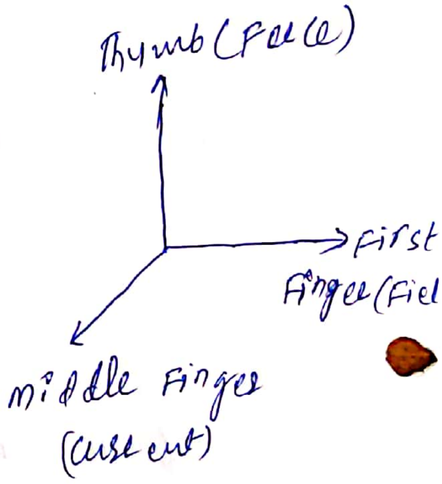
Also the direction of force experienced is given by Flemmings left hand rule.

Flemmings left hand rule.

Flemmings left hand rule states that "If the first three fingers of the left hand are held mutually at right angles(90) to each other and if the index finger indicates the direction of original field, and if the middle finger indicates the direction of current flowing through the conductor, then the thumb indicates the direction of force exerted on the conductor.




(or)




Applications of DC motor.

① DC motors are used for driving trains, cranes, Excavators etc

② These motors are used in industries where wide range of speed control is required such as lathes, centrifugal pumps, fans, blowers conveyors etc.

Subject: EEE
Faculty: Sudhakar. Ajmeera
Topic: problems on DC motor.

**Class Notes**

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① A 440V, shunt motor has armature resistance of $0.8\Omega$ and field resistance of $200\Omega$. Determine the back e.m.f when giving an output of 7.46KW at 85 percent efficiency.

Ans:- Motor input power $= 7.46\times10^3/0.85$ W

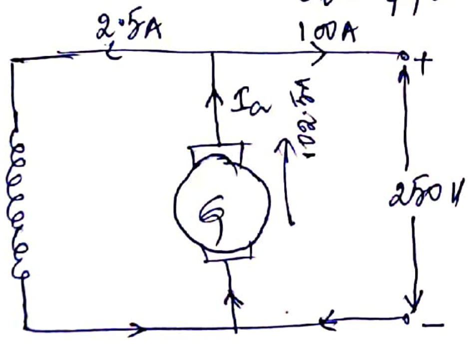
Motor input current $= \frac{7460}{0.85} \times 440 = 19.95$ Amps.

$I_{sh} = 440/220 = 2.2$ A

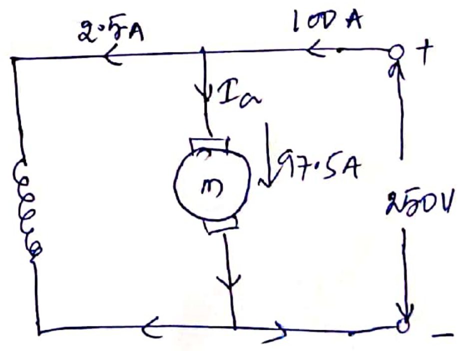
$I_a = 19.95 - 2.2 = 17.75$ Amps,

Now $E_b = V - I_a R_a$

$E_b = 440 - (17.75\times0.8) = 425.8$ V.




Generator.




motor.

② A 25KW, 250-V, d.c shunt generator has armature and field resistances of $0.06\Omega$ and $100\Omega$ respectively. Determine the total armature power developed when working

(i) as Generating delivering 25KW output and

(ii) as a motor taking 25KW input.

Subject: EEE
Faculty: Sudhakar Ajmera
Topic: Losses in a DC motor

**Class Notes**

Unit No: 02
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In case of motors electrical power is input. Therefore, when current flows copper losses take place. These copper losses take place before the conversion of electrical form into mechanical form whereas iron and friction losses take place after the conversion.

Powerflow of DC motor:-

Electrical input power = $VI_L$ ⇒ copper losses ⇒ Electrical power converted to mechanical = $E_bI_a$ ⇒ Iron & Friction ⇒ motor useful output power.

① copper or electrical losses:-

ⓐ Armature copper losses:

These losses are given by $I_a^2 Ra$, where $Ra$ → Armature resistance and brush contact resistance. This loss is about 30-40% of F.L. losses.

ⓑ Field copper loss:.

This loss is further classified into three. They are,

(i) shunt field copper loss:

$I^2_{sh} R_{sh}$ (or) $V I_{sh}$ and is practically constant which occurs in shunt and compound motors.

(ii) series field copper loss

$I^2_{se} R_{se}$ which occurs only in series and compound motors.

(iii) Interpole loss

$I_a^2 R_i$, where $R_i$ - Interpole field resistance.

These losses are about 20-30% of F.L losses.

(2) magnetic (or) Iron losses:

These are also called as core losses and are present in any part of machine which is made up of iron and subjected to variations of flux. Iron loss consists of

(a) Hysteresis losses.

The Hysteresis loss depends upon the volume and grade of Iron, $B_{max}$ and frequency of magnetic reversals. According to steinmetz formula, it is given as

$$W_h = \eta B_{max}^{1.6} f V \text{ Watt.}$$

where $\eta$ - steinmetz hysteresis coefficient which is $502\ J/m^3$ for dynamo sheet steel and $191\ J/m^3$ for silicon steel.

$V$ - volume of core in $m^3$, $f$ - frequency of magnetic reversals $= PN/120$, $B_{max}$ - maximum flux density.

Subject: EEE
Faculty: Sudhakar Ajmera.
Topic:

**Class Notes**

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## (b) Eddy current losses:

When the armature core rotates, it also cuts the magnetic flux. Hence e.m.f is generated. This e.m.f though small, sets up huge current in the core due to it's small resistance. This current is also known as eddy current. The power loss due to the flow of this current is known as eddy current loss. [∵ $R = \frac{\rho l}{A}$. If core is made of solid piece the area of cross-section is large hence R is small and eddy current is high]

Instead of a solid piece of the core is made up of laminations [area of cross-section decreases thus resistance increases and hence eddy current is low and thus eddy current loss decreases].

The eddy current loss is given as,

$$W_e = K_e B_m^2 f^2 V t^2$$

where $K_e$ = constant depending upon the electrical resistance of magnetic material, $B_m$ = maximum flux density,
t = thickness of lamination, V = volume of core, f = frequency of magnet.

the core losses are approximately constant in a machine whose flux and speed are constant as in the case of a shunt wound D.C machine but are variable in case of D.C series wound machine

They constitute 20-30% of F.L losses.

(c) mechanical losses.

These losses consists of power losses due to friction of the bearings, air friction or windage caused by the motion of moving parts through surrounding medium and friction between brushes and commutators rings.

These losses are approximately constant and are 10-20% of full-load losses.

[Rotational] stray losses = magnetic losses + mechanical losses

Constant losses = stray losses + shunt field copper losses

standing losses = magnetic losses + mechanical. losses + shunt field copper losses.

[∵ All three losses are constant]

∴ Total losses = Armature copper losses + constant losses.

Total losses = variable losses + constant losses.

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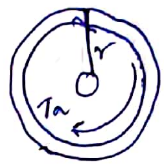
Subject: EEE

Faculty: Sudhakar Ajmera

Topic: Torque equation of a D.C. motor.

## Torque :

Torque is the twisting movement produced across the armature.




let N - speed of armature in r.p.m, F = Force in Newton

$\frac{N}{60}$ - speed in rpm, r = Radius of Armature in meter

Ta = Armature torque in N-m, S = circumferential distance.

$dt = \frac{60}{N}$ - Time taken for one revolution, Ta = Armature

mechanical work done per second = $\frac{F \times \text{circumferential distance}}{\text{Time}}$

$$= \frac{F \times S}{60/N} = F \times 2\pi r \frac{N}{60} \quad [\because S = 2\pi r]$$

$$= F \times r \times \frac{2\pi N}{60} \quad [\because T_a = F \times r]$$

Mechanical workdone per second $= T_a \times \frac{2\pi N}{60}$ N-m/sec. —— (2)

The electrical work done per second, $= E_b \times I_a$

workdone per second $= \frac{\phi P N}{60} \times \frac{Z}{A} I_a \quad [\because E_b = \frac{\phi P N}{60} \times \frac{Z}{A}]$ —— (1)

As Mechanical work = electrical work

As 1N-m/sec = 1 Watt

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

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

$$\Rightarrow T_a = \frac{1}{2\pi} \cdot \frac{\phi P Z I_a}{A}$$

$$T_a = \frac{0.159 \phi P Z I_a}{A} \text{ N-m (SI unit)}$$

$$T_a = \frac{0.159}{9.81} \cdot \frac{\phi P Z I_a}{A}$$

$$T_a = \frac{0.0162 \phi P Z I_a}{A} \text{ Kg-m (MKS unit)}$$

Where $\phi$ = Flux/pole in Wb, $P$ = Number of poles.

$Z$ = Number of armature conductors, $A$ = Number of armature paths, $I_a$ = Armature current.

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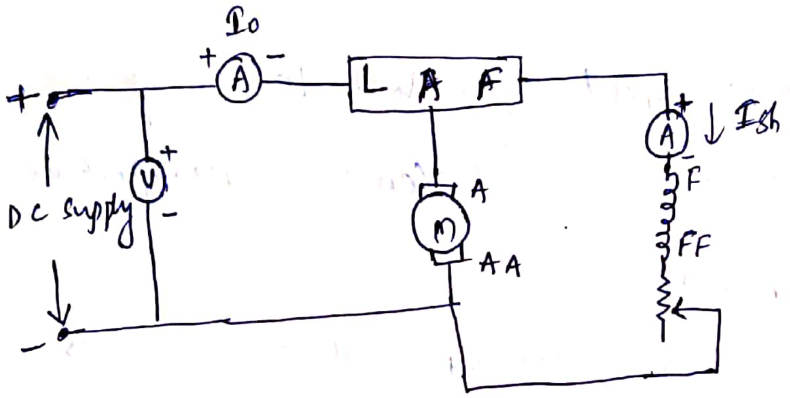
Subject: EEE

Faculty: Sudhakar Ajmera

Topic: Efficiency of D.C. machine

The circuit diagram for determining the no-load losses of a D.C shunt machine




Let supply voltage be V which is measured by voltmeter.

'$I_0$' is the input motor current which is measured by ammeter

'$I_{sh}$' is the shunt field current.

Input power = output power + losses

Input power = losses [∵ output power = 0]

From the above equation, it is clear that no-load input power is used to supply internal losses in the machine that is shunt field copper loss, armature copper loss, stray losses in shunt machine. whereas in compound machine the machine input is used to supply series field copper loss in addition to above losses.

power input $= VI_0$.

shunt field copper loss $= VI_{sh}$

Armature copper loss $= I_{ao}^2 Ra = (I - I_{sh})^2 Ra$ where $Ra$ = Armature resi

$\therefore$ power input = Total losses.

$VI_0 = VI_{sh} + I_{ao}^2 Ra +$ stray losses where

Stray losses $= VI_0 - VI_{sh} - (I_0 - I_{sh})^2 Ra$.

If we add shunt field copper loss to stray loss we get constant loss which remains constant irrespective of the load on the machine.

$\therefore$ Constant losses = stray losses + shunt copper losses

$= VI_0 - (I_0 - I_{sh})^2 Ra$.

## Efficiency when Running as Generator:

Generator output $= VI$ watts.

Total losses = Armature copper loss + Field copper loss + stray losses.

$= I_a^2 Ra + Wc$.

$= (I + I_{sh})^2 Ra + Wc$.

Input = output + losses

$= VI + (I + I_{sh})^2 Ra + Wc$

Efficiency $= \dfrac{\text{output}}{\text{Input}} = \dfrac{\text{output}}{\text{output} + \text{losses}} = \dfrac{VI}{VI + (I + I_{sh})^2 Ra + Wc}$

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## Class Notes

Subject: EEE

Faculty: Sudhakar Ajmera

Topic: Efficiency of DC motor

### Efficiency when running as motor.

Motor Input power $= VI_L$.

Total losses = Armature copper loss + $W_c$

$= I_a^2 R_a + W_c$

$= (I - I_{sh})^2 R_a + W_c$

Motor output power = Input − Losses.

$= VI_L - (I_L - I_{sh})^2 R_a - W_c$.

$\therefore$ Efficiency of motor $= \dfrac{\text{output power}}{\text{Input power}}$

$= \dfrac{\text{Input power} - \text{losses}}{\text{Input power}}$

$$\boxed{\%\eta = \frac{VI_L - (I_L - I_{sh})^2 R_a - W_c}{VI_L}}$$

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Subject: EEE

Faculty: Sudhakar Ajmera

Topic: problems on efficiency & losses of DC machine.

(1) A 220V shunt motor takes a total current of 80A and runs at 800 r.p.m shunt field resistance and armature resistance are 50Ω and 0.1Ω respectively. If iron and friction losses amount to 1600W. Find.

(1) copper losses
(2) Armature torque
(3) shaft torque
(4) Efficiency

Ans:-

Given that voltage $V = 220V$, current $I_L = 80A$, speed, $N = 800$ r.p.m, shunt field resistance $R_{sh} = 50\Omega$, armature resistance $R_a = 0.1\Omega$, Iron & friction losses $P_c = 1600W$

To Determine:

(1) copper losses, $P_c = ?$
(2) Armature torque, $T_a = ?$
(3) shaft torque, $T_{sh} = ?$
(4) Efficiency, $\eta = ?$

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Now, the shunt field current is given as

$$I_{sh} = \frac{V}{R_{sh}}$$

$$\Rightarrow I_{sh} = \frac{220}{50} = 4.4 \text{ Amps.}$$

And also, the Armature current is given as,

$$\Rightarrow I_a = I_L - I_{sh} \quad [\because I_L = I_a + I_{sh}]$$

$$\Rightarrow I_a = 80 - 4.4 = 75.6 \text{ Amps.}$$

We know that, the back emf of a rotor is given as

$$E_b = V - I_a R_a.$$

substituting all the values, we get.

$$E_b = 220 - [75.6 \times 0.1]$$

$$= 220 - 7.56 = 212.44 \text{ V.}$$

And also, the input power is given as

$$P_i = V \times I_L$$

$$P_i = 220 \times 80 = 17,600 \text{ Watts.}$$

therefore the power developed in an Armature is given as

power developed in Armature,

$$P_{ow} = E_b \times I_a$$

$$= 212.44 \times 75.6$$

$$= 16060.464 \text{ Watts.}$$

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# Class Notes

Subject: EEE

Faculty: Sudhakar Ajmera

Topic:

(i) copper losses:-

the copper losses is given as

copper loss, $P_{cu} = P_i -$ power developed in Armature

$= 17600 - 16060.464$

$= \boxed{1539.536 \text{ Watts}}$

(ii) Armature Torque:-

the Armature Torque is given by

$$T_a = 9.55 \times \frac{E_b I_a}{N}$$

substituting All the values, we get

$$T_a = 9.55 \times \frac{212.44 \times 75.6}{800} = 191.72 \text{ Nm}$$

(iii) shaft Torque

The shaft torque is given as

$$T_{sh} = 9.55 \times \frac{\text{output power}}{N}$$

$$= 9.55 \times \frac{P_{out} - P_c}{N}$$

substituting All the values, we get

$$\Rightarrow T_{sh} = 9.55 \times \left[\frac{16060.464 - 1600}{800}\right]$$

$$\Rightarrow T_{sh} = 9.55 \times \frac{14460.464}{800} \Rightarrow 172.623 \text{ Nm}.$$

(iv) Efficiency:-

The efficiency is given as

$$\eta = \frac{P_{out}}{P_{in}} \times 100$$

$$\eta = \frac{16060.464}{17600} \times 100 = 91.253\%.$$

(2) A 200V, 14.92KW, D.C shunt motor when tested by Swinburne's method gave the following test results.

Running light: Armature current of 6.5A and field current 2.2A

with armature locked, $I_a = 70A$ when potential difference of 3V was applied to the brushes. Estimate efficiency of motor when working under full load.

# Class Notes

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Subject: EEE

Faculty: Sudhakar Ajmera

Topic: E.m.f. equation of a D.C machine.

let $\phi$ = flux per pole in webers

$Z$ = total Number of armature conductors.

= Number of slots × Number of conductor per slot.

$P$ = Number of poles

$A$ = Number of parallel paths in armature

$N$ = Armature rotation in r.p.m

$E$ = e.m.f. induced in any parallel path in armature.

→ As per Faraday's law of Electromagnetic induction.

Average e.m.f generated per conductor $= \frac{d\phi}{dt}$ volts ($\because n=1$) —— (1)

→ During one revolution of armature in a 'p' pole generator, each armature conductor cuts the magnetic flux 'p' times so that flux cut per one conductor in one revolution is

$$\boxed{d\phi = \phi P \text{ web}} \quad \text{—— (2)}$$

→ Armature Rotates $\frac{60}{N}$ times in one second. therefore, the time required by it for one revolution is $dt$

i.e $\boxed{dt = \frac{60}{N} \text{ seconds.}}$ —— (3)

Substitute equation (2) and equation (3) in equation (1), we get

i.e e.m.f generated/conductor $= \frac{d\phi}{dt}$

$$= \frac{\phi P N}{60} \text{ volts.}$$

The total Number of Armature Conductors per parallel path $= \frac{Z}{A}$

$\therefore$ Total e.m.f generated/path $= \frac{\phi P N}{60} \times \frac{Z}{A}$

$$\therefore E = \frac{\phi P N Z}{60 A} \text{ volts.}$$

where $A = 2$ for wave winding

$A = 1$ for lap winding.

# Class Notes

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Subject: EEE

Faculty: Sudhakar Ajmera

Topic: problems on D.C machine [emf eqn]

(1) An 8-pole lap wound generator armature has 960 conductors, a flux of 40 mwb and a speed of 400 rpm. calculate the e.m.f generated on open circuit, if the same armature is wave wound, at what speed must it be driven to generate 400 volts.

Ans:- Given that,

Number of poles $P = 8$

Number of conductors, $Z = 960$

Speed of Generator, $N = 400$ r.p.m.

flux per pole, $\phi = 40 \times 10^{-3}$ wb

E.m.f. Generated $E = ?$

When Armature is wave connected and generates 400 V, speed $N_1 = ?$

(i) E.m.f. Generated (E)

For lap winding, Number of parallel paths $A = P$

Induced e.m.f is given by $E = \frac{\phi Z N}{60} (P/A)$

$$\frac{40\times10^{-3}\times 960\times 400}{60}\left(\frac{8}{8}\right) = 256\,V$$

$\therefore$ EMF generated, $E = 256\,V$.

(ii) Speed (N)

Generated e.m.f, $E = 400\,V$

For wave winding, Number of parallel paths $A = 2$

Induced e.m.f is given by

$$E = \frac{\phi Z N_1}{60}\left(\frac{P}{A}\right)$$

$$\Rightarrow \text{speed, } N_1 = \frac{60\times E\times A}{\phi Z P}$$

$$= \frac{60\times 400\times 2}{40\times10^{-3}\times 960\times 8} = 156.25\,rpm$$

~~Result~~:

(2) A 6 pole lap wound D.C generator has 600 conductors on its armature. The flux per pole is 0.02 Wb. Calculate

(i) The speed at which the generator must be run to generate 300V?

(ii) What would be the speed if the generator were wave wound?

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Subject: EEE

Faculty: Sudhakar Ajmera

Topic: principle operation of 1 $\phi$ transformer.

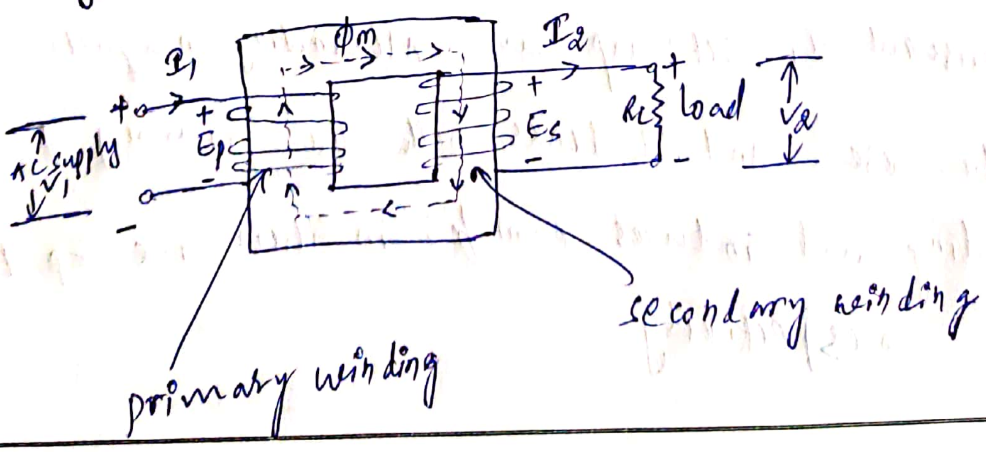
## Transformer :-

A transformer is a static device which will step-up or step-down the voltage without change in frequency. The energy is transferred to another circuit by the magnetic field.

The side where we give the supply is called "primary winding". The other side where the load should be connected is called "secondary-winding".

## Working principle of a transformer:-

Let us consider a core type transformer which is electrically isolated, but magnetically linked as shown below



where $P$ = primary winding

$S$ = secondary winding

$E_p$ = Induced e.m.f in primary winding

$E_s$ = Induced e.m.f in secondary winding

$V_1$ = A.C supply voltage, $V_2$ = load voltage

$I_1$ = primary current, $I_2$ = secondary current

$\phi_m$ = mutual flux.

→ the first coil has $N_1$ turns and it's known as primary winding

→ the second coil has $N_2$ turns and it's known as secondary winding.

→ AC supply voltage $V_1$ is given to the primary winding, which causes an Alternating current $I_1$ to circulate through the primary winding and load is connected to the secondary winding as shown in fig.

→ According to Faradays law of Electromagnetic induction, this current $I_1$ sets up an Alternating magnetic flux in the core. And it links both the primary & secondary winding and induces e.m.f's in them i.e $E_p$ & $E_s$ respectively.

Subject: EEE
Faculty: Sudhakar Ajmera.
Topic:

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→ The magnitude of the induced e.m.f's is proportional to the rate of change of flux linkage

→ As load is connected to the secondary winding, a current $I_2$ will flow in the secondary circuit.

→ According to Lenz's law, this current $I_2$ produces an m.m.f (magneto motive force) in the secondary winding in opposition to the main primary flux $\phi_m$, which acts to reduce the flux in the core.

Therefore, the secondary ampere-turns ($N_2 I_2$) will demagnetize the main flux $\phi_m$. Hence, decrease in flux reduces primary e.m.f ($E_p$).

→ The difference between the supply voltage and decreased e.m.f of primary winding will increase the primary currents $I_1$.

→ A back e.m.f is set up to oppose the m.m.f produced by the secondary coil.

→ When the primary ampere-turns are increased the demagnetizing ampere-turns of secondary winding are neutralized.

→ Hence, the full-load primary ampere-turns are approximately equal to the full load secondary ampere-turns. Since the primary ampere-turns on the no-load are very small when compared to the full-load ampere turns.

i.e $I_1 N_1 \simeq I_2 N_2$.

$$\therefore \boxed{\frac{I_1}{I_2} = \frac{N_2}{N_1} = \frac{V_2}{V_1}}.$$

The above equation, is the balance equation of the primary and secondary ampere-turns.

$\therefore V_1 I_1 = V_2 I_2$ [At full-load, primary power factor = secondary power factor]

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## Class Notes

Subject: EEE

Faculty: Sudhakar Ajmera

Topic: Construction of a Transformer

The transformers are mainly classified into two types, depending upon the type of construction used. They are (i) core type transformer
(ii) shell type transformer.

### Construction of a Transformer:-

The main components of a transformer are

1. core
2. windings
3. Conservator Tank
4. Bushings
5. Breather ~~Band~~
6. Radiators

### 1. core:

The core of a transformer is made up of sheet steel doped with 4% of silicon, which is also called as silicon steel. Thin silicon steel sheets of thickness 0.35mm to 5mm depending upon the requirement are cut into particular sizes and shapes are stacked together to form the magnetic core.

since the core is cut by the alternating flux produced by the flow of alternating currents, this induces e.m.f in the core, which leads to the flow of eddy currents. This eddy current circulates in the core and gives rise ~~to~~ $I^2R$ ~~Iron~~ loss in the core. To reduce the eddy current loss caused by the flow of eddy current, the core is built up of laminations.

The purpose of the core is to provide low reluctance path between the two windings, so that the flux caused by one winding will fully link the other coil.

2. Windings:-

A single phase transformer has two windings. The windings connected to the A.C source is called primary winding and the one connected to load is called secondary winding. The alternating voltage whose magnitude is to be changed is applied to primary. The primary and secondary windings consists of a series of turns called coils, which wound round the core. The coils of transformer are of two types. They are (i) concentric coils (ii) Sandwich coils.

## 3. Conservator Tank :-

The oil in the transformer main tank is subjected to expand and contract due to the variations in load current. while undergoing expansion and contraction, the oils is subjected to heat. The function of the conservator tank is to help the oil in the tank to settle down by expansion whenever heavy loads appears.

without a conservator tank, the main tank may brust out, because of the high pressure developed inside the tank.

## 4. Bushings :-

connections from the transformer windings are brought out by means of bushings. The function of the bushings is to give proper insulation ~~ofo~~ the output leads. Bushings are fixed on the transformer tank. Bushings made up of porcelain are available and can be used up to 33kV, capacitor and oil filled type of bushings are used for voltages above 33kV.

5. Breather:

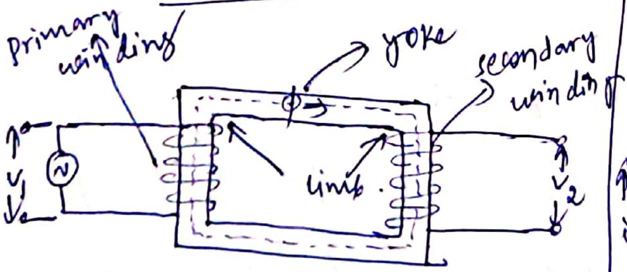
the main transformer tank and some portion of the conservator tank are filled with oil. this oil should not exposed to the atmosphere directly, because it may absorb the moisture and dust and may lose its electrical properties within a very short time. A breather is provided in order to avoid this.

Breather completely prevents the outside atmospheric moisture and dust from coming into contact with oil.

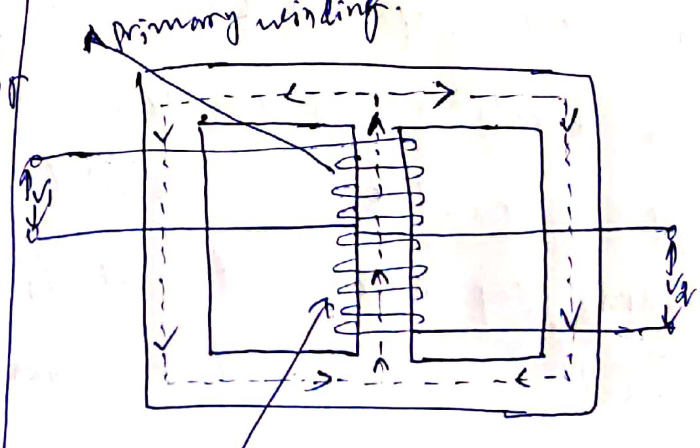
6- Radiators:-

thin metal structures are connected round the transformer tank which acts as a heat sink. the function of the radiators is to cool the transformer tank gradually.

Core Type Transformer




Shell Type Transformer



**Class Notes**

Subject: EEE

Faculty: Sudhakar Ajmera

Topic: EMF equation of a 1ϕ transformer.

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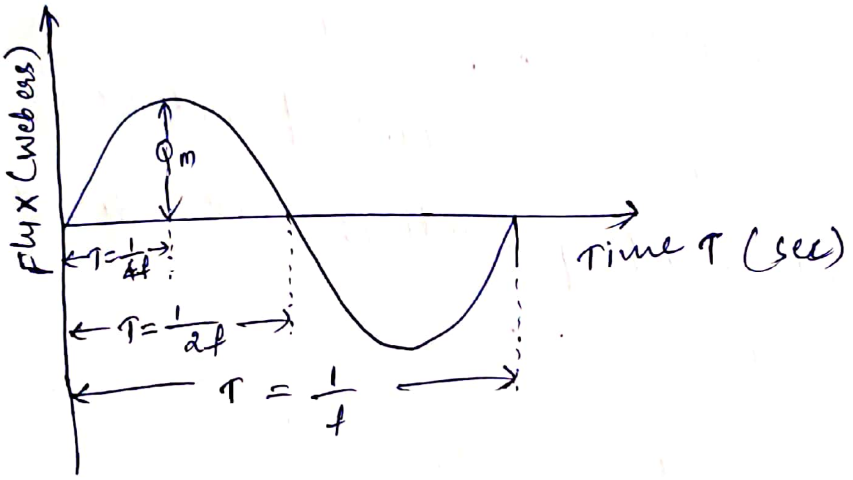
Transformer alternating flux set-up by the voltage source is shown in figure




From above figure, it is clear that, an alternating flux attains its maximum value in a quarter cycle.

Hence, change in flux

$$d\phi = \phi_m - 0 = \phi_m \text{ wb.}$$

$\therefore$ change in time $dt = \frac{1}{4f}$ sec.

By electromagnetic induction principle (mutual induction between coils), rate of change of flux linkages will induce an e.m.f. Then, average induced e.m.f per turns is given as $\frac{E_{av}}{N} = \frac{d\phi}{dt} = \frac{\phi_m}{1/4f} = 4\phi_m f$ volts.

Scanned by CamScanner

$\therefore \dfrac{\text{Average E.m.f } (E_{av})}{\text{turn}} = 4\phi_m f$ volts.

Since flux is varying sinusoidally, form factor of sinusoidal flux (e.m.f) is 1.11 i.e;

$$\frac{E_{rms}}{N} = \frac{E_{av}}{N} \times \text{Form factor.}$$

$$\therefore \text{Form factor} = \frac{\text{r.m.s. Value}}{\text{Average Value}} = 1.11 = 4\phi_m f(1.11) = 4.44\phi_m f$$

If $E_1$ & $E_2$ are the r.m.s. values of induced e.m.f's in primary and secondary windings having $N_1$ and $N_2$ turns respectively

Then, primary induced e.m.f is $E_1 = 4.44\phi_m f N_1$.

Similarly, the secondary induced e.m.f's is $E_2 = 4.44\phi_m f N_2$.

we know that $\phi = BA \Rightarrow \phi_m = B_m A$ where

$A$ = Area of cross-section ($m^2$), $B_m$ = maximum flux density (T)

Now, $E_1 = 4.44 B_m A f N_1$ , $E_2 = 4.44 B_m A f N_2$.

$\therefore$ E.m.F / turn is

$$\boxed{\frac{E_1}{N_1} = 4.44 B_m A f}$$

$$\boxed{\frac{E_2}{N_2} = 4.44 B_m A f}$$

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# Class Notes

Subject: EEE

Faculty: Sudhakar Ajmera

Topic: problems on $1\phi$ transformer.

(1) A single phase 240/20V, 50Hz transformer has the secondary full-load current of 180A. It has 45 turns on its secondary. calculate

(i) the voltage per turn

(ii) the number of primary turns.

Ans:- Given that

single phase transformer : primary voltage $V_1 = 240V$

secondary voltage $V_2 = 20V$; frequency $f = 50Hz$.

Full-load secondary current, $I_2 = 180A$;

Number of secondary turns $N_2 = 45$.

(i) the voltage per turn $= \dfrac{V_2}{N_2}$

$$= \frac{20}{45} = 0.444.$$

(ii) Number of primary Turns

we know $\dfrac{V_1}{V_2} = \dfrac{N_1}{N_2}$

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

$$= \frac{240 \times 45}{20} = 540$$

Number of primary turns $N_1 = 540$.

② Q: From above problem calculate ① Full load primary current and ② the KVA output of the transformer.

Ans:- ① using the relation

$$\frac{V_1}{V_2} = \frac{I_2}{I_1}$$

we have $I_1 = \frac{I_2 \times V_2}{V_1}$

$$= \frac{180 \times 20}{240} = 15\,A$$

Full load primary current $I_1 = 15$ Amps.

② KVA output of the transformer

Output $= V_2 I_2$

$= 20 \times 180$

$= 3600\,VA$

$= 3.6 \times 10^3\,VA$

$= 3.6\,KVA$

$\therefore$ The KVA output of the transformer $= 3.6\,KVA$

# Unit - III :- AC MACHINES

## Transformer :-

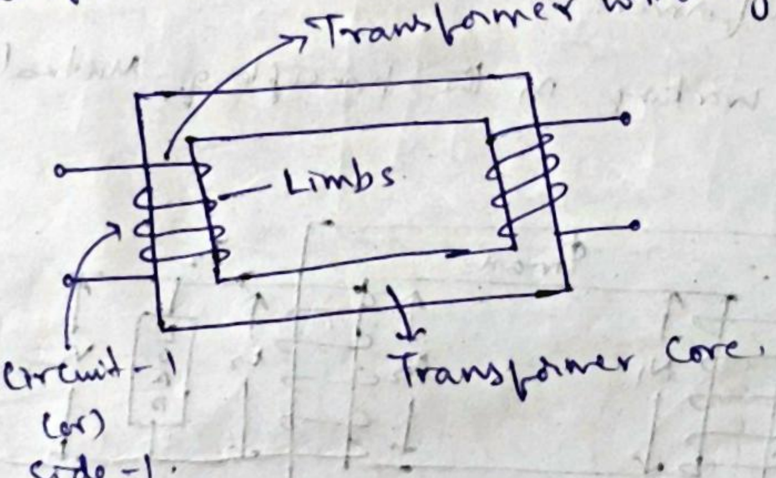
- Transformer is a static / stationary device which do not have no moving part, used to transform the electrical power from one circuit to another circuit (or) one side to another side. without changing frequency, (frequency must be constant) through the magnetic media called as transformer.

## Constructional details of transformer :-

- The transformer mainly consisting of two parts :-

(i) Transformer core.

(ii) Transformer winding.




## Transformer core :

Transformer core is the media (or) platform to wound the winding and also provide the (or) carrying the magnetic flux linkage throughout the core. It is made up of high permeable material i.e. silicon laminated steel by using the above type of core to reduce the overall core loss of transformer.

Transformer winding :-

- It is made up of Cu, material with the enamel coating. It must be a concentrated nature type winding. There are the two types of transformer windings.

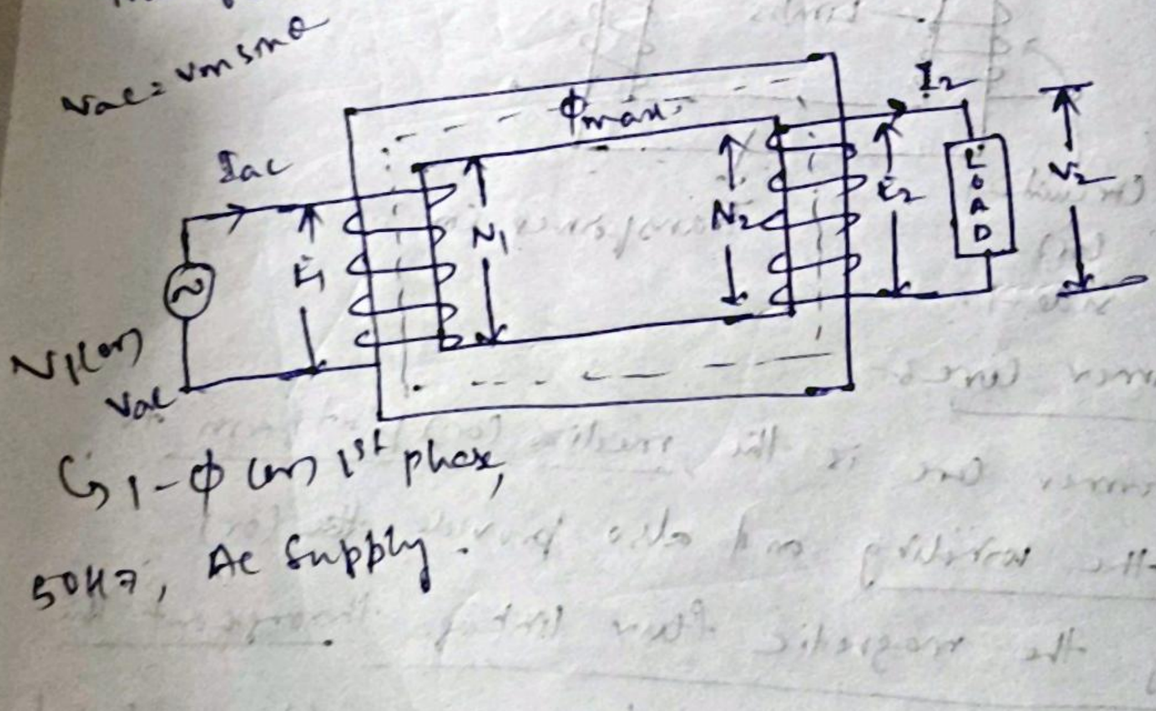
(i) Primary winding.

(ii) Secondary winding. as mentioned in the above diagram.

Working principle of 1-$\phi$ (or) single-phase transformer

It is a static device that transforms electric power from one circuit to another circuit without changing frequency through the magnetic media is called as transformer.

- Transformer working on the principle of Mutual induction




↳ 1-$\phi$ (or) 1st phase,

50Hz, AC supply.

Working :-

- whenever an alternating (AC voltage) applied to the one side of transformer called primary side which drives the alternating current that produce the change in flux $\frac{d\phi}{dt}$.

- whenever the change in flux initially linked to the own coil all the turns according to the faraday law of electromagnetic induction, an emf gets induced in the coil called as self induced emf.

- whenever an instantaneous flux transferred uniformly to the entire core also an emf gets induced in the secondary coil. ~~so~~ this emf is called as mutual induced emf and the whole process is called as mutual induction.

Types of 1-$\phi$ Transformer (single-phase transformer)

- Based on no. of phase

(i) 1-$\phi$ (or) Single phase transformer

(ii) 3-$\phi$ Transformer

(iii) ~~Rotation~~ Auto transformer.

- Based on turns ratio (or) no. of turns

(i) step-up transformer

(ii) step-down transformer.

(iii) Isolation Transformer.

Based on type of Service:-

(i) power transformer

(ii) Distribution transformer

(iii) Instrumentation Transformer

Current Transformer

PT (or) potential transformer

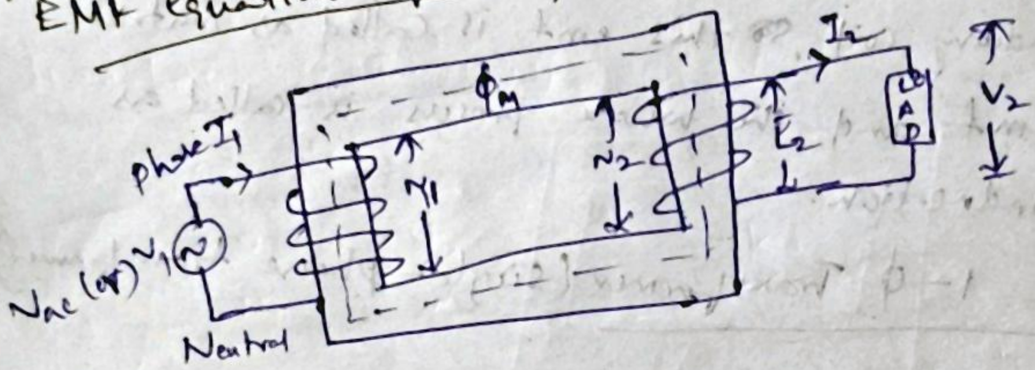
Based on Construction

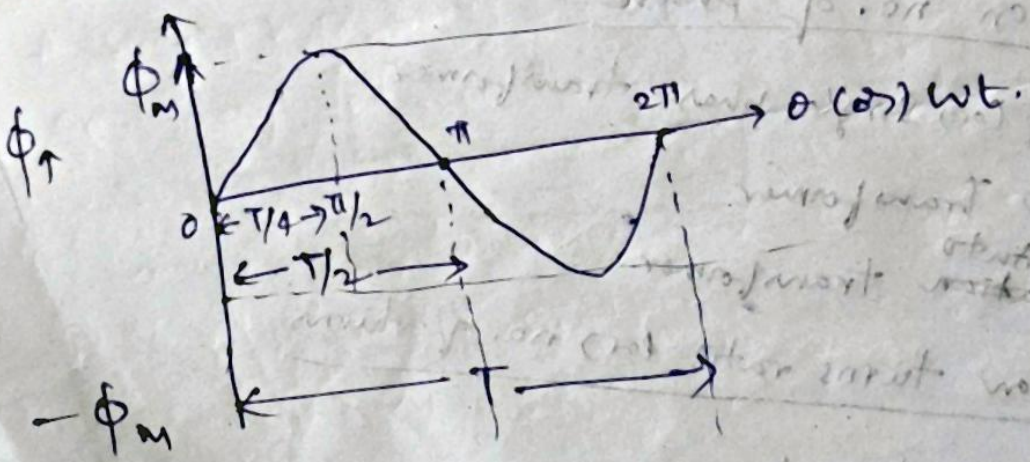
(i) Core type transformer → Core is surrounded the winding.

(ii) shell type transformer

(iii) Berry type T/F.

**Imp** EMF equation of 1-$\phi$ transformer:-



Let,

$N_1 \rightarrow$ primary no. of turns.

$E_1 \rightarrow$ " / self induced emf.

$V_1 \rightarrow$ primary voltage.

$\phi_{max} \rightarrow$ maximum flux in core,

$N_2 \rightarrow$ No. of turns on secondary

$E_2 \rightarrow$ secondary / mutual induced emf.

$I_2 \rightarrow$ " current (secondary).

$I_1 \rightarrow$ primary current.

According to faraday law,

$$E \text{ (or) } E_g \propto \frac{d\phi}{dt}.$$

$$E = N \frac{d\phi}{dt}.$$

where, $N \rightarrow$ No. of turns. $\frac{d\phi}{dt}$.

Average emf / turn (or) $E = \frac{d\phi}{dt}$

$$\frac{d\phi}{dt} = \frac{\text{change in flux}}{\text{change in time}}$$

The change in flux is varied from 0 to $\phi_{max}$ in T/4th cycle. Therefore,

$$\frac{d\phi}{dt} = \frac{\phi_{max} - 0}{\frac{T}{4}} = \frac{\phi_{max}}{\frac{T}{4}} = \frac{\phi_{max}}{\frac{1/f}{4}}$$

$$\frac{d\phi}{dt} = 4\phi_{max} f$$

Emf / turn (or) $E = 4\phi_m \times f$.

* form factor = $\frac{\text{RMS value}}{\text{Avg. value}} = 1.11 \left(\frac{V_m/\sqrt{2}}{2V_m}\right)$.

The RMS value of emf / turn = average value of emf / turn × form factor.

$$E = 4\phi_m f \times 1.11$$

$$E_{rms/turn} = 4.44 \times \phi_m \times f.$$

The RMS value of emf for $N_1$ & $N_2$ turns

$$E_1 = 4.44 \times \phi_m \times f \times N_1.$$

$$E_2 = 4.44 \times \phi_m \times f \times N_2$$

Transformation Ratio of 1 − φ T/F (K):-

For ideal T/F,

$$\boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2} = K.}$$

Q. A single phase 50 Hz transformer has 400 turns (i) on primary and 800 turns on Secondary. The net cross sectional area of the core is 250 cm². The primary side of the transformer is connected to the 230 volts, 50 Hz supply system. Calculate

(i) Secondary induced emf.

(ii) Max. flux density of core.

Given :-

$N_1 = 400$

$N_2 = 800$

$E_1 = V_1 = 230\ V$

$f = 50\ Hz$

$A = 250\ cm^2 = 250 \times 10^{-4}\ m^2$

(i) $\frac{E_2}{E_1} = \frac{N_2}{N_1}$

$E_2 = \frac{N_2}{N_1} \times E_1 \Rightarrow \frac{\cancel{800}}{\cancel{400}} \times 230$

$\boxed{E_2 = 460\ V}$

$E_2 = 4.44 \times \phi_m \times f \times N_2$

$= 4.44 \times 250 \times 10^{-4} \times 50 \times 800$

$\boxed{E_2 = 480\ V}$

X

(ii) $E_1 = 4.44 \times \phi_{max} \times f \times N_1$

$\phi_{max} = \frac{230}{4.44 \times 50 \times 400}$

$\phi_m = 2.5 \times 10^{-3}\ wb.$

(iii) $B_{max} = \frac{\phi_m}{A}$

$= \frac{2.5 \times 10^{-3}}{250 \times 10^{-4}} = 0.1\ Tesla$

32). The emf per turn of single-phase 10 kilo-watt-amperes (kVA), $\frac{2200}{220}$ V, 50Hz transformer is 10 volts. The primary is connected for the 220 volts, 50hz supply system. Calculate the primary & secondary no. of turns. The net cross-sectional area of the core if max. flux density is 1.5 Tesla.

Soln. Given :-

~~$\frac{E}{turn}$ = 10V~~ Emf / turn = 10 V

$$\frac{E_2}{E_1} = \frac{220\cancel{0}}{22\cancel{0}} \Rightarrow 10.$$

$f = 50\,Hz.$

$V_1 = E_1 = 220V.$

$B_{max} = 1.5\ wb/m^2.$

(i) $N_1$ & $N_2$ ?.

from transformation ratio,

$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

$$N_2 = \frac{E_2}{E_1} \times N_1 \rightarrow \frac{E_2}{\frac{E_1}{N_1}} \rightarrow \text{Emf / turn}$$

$$N_2 = \frac{2200}{10} = 220$$

$\boxed{N_2 = 220}$.

$$N_1 = \frac{N_2}{\frac{E_2}{E_1}} = \frac{N_2}{E_2} \times E_1 = \frac{2\cancel{2}\cancel{0}}{\cancel{2}\cancel{2}\cancel{0}\cancel{0}} \times 2$$

$\boxed{N_1 = 22}$

(ii) $B_{max} = \frac{\phi_{max}}{A}$

$A = \frac{\phi_m}{B_{max}}$

$\phi_m = \frac{E_1}{4.44 \times f \times N_1} = \frac{220}{4.44 \times 50 \times 22}$

$\phi_{max} = \frac{1}{4.44 \times 5} = 0.045 \text{ wb/m}^2$

$\therefore A = \frac{0.045}{1.5} = 0.03 m^2$

## Losses and Efficiency:-

Transformer has no rotating part — No mechanical (or) rotational losses.

Losses:-

→ Core losses (or) Magnetic losses — Constant losses

↳ Based on material.

→ Hysterisis losses.

$W_h = \eta_h \times B_{max}^{1.6} \times f \times V$

→ Eddy current losses.

$W_e = \eta_e \times B_{max}^2 \times f^2 \times t^2$

variable loss

↑

→ Copper (or) $i^2R$ losses.

↳ Based on power consumption.

→ primary cu. losses

→ secondary cu. losses.

10kw → 2 watts loss

20kw → 4 watts loss

50kw → 10 watts loss

## Efficiency ($\eta$):-

$$\eta = \frac{\text{power output}}{\text{power input}}$$

$P_{input} = P_{o/p} + \text{Losses}$

$P_{i/p} = P_{o/p} + W_i + W_{cu}$

$$\eta = \frac{P_{o/p}}{P_{o/p} + W_i + W_{cu}}$$ → $\frac{\text{utilised power}}{\text{Total power}}$

$P_{o/p} = x \times \text{KVA Rating} \times \underbrace{\text{power factor}}$ → cosine angle of voltage & current.

$x$ → fraction of load, 1, $\frac{1}{2}$, $\frac{1}{4}$ & $\frac{3}{4}$.   VA

$P_{o/p} = x \times \text{KVA} \times \cos\phi$

$$\therefore \%\eta = \frac{x \text{KVA} \times \cos\phi}{x \text{KVA} \times \cos\phi + W_i + W_{cu}} \times 100$$

Induction Machine:-

3-$\phi$ IM    1-$\phi$ IM.

3-$\phi$ (or) three-phase Induction motor:-

phase → Angle turned by alternating Quantity.

- Basically, it's a 3-$\phi$ AC Machine which works under the principle of mutual induction (or) electromagnetic induction called as 3-$\phi$ IM.

Production of rotating magnetic field:- (RMF):-

1) whenever balanced 3-$\phi$ AC voltage i.e. $V_R \angle 0°$ and $V_Y \angle 120°$ and $V_B \angle 240°$ which produces 3-$\phi$ different fluxes ~~and~~ (i.e. $\phi_R$, $\phi_Y$, $\phi_B$) in each phase. These produces the resultant magnetic flux, which is appear in the air gap should be rotating nature called as Rotating magnetic field.

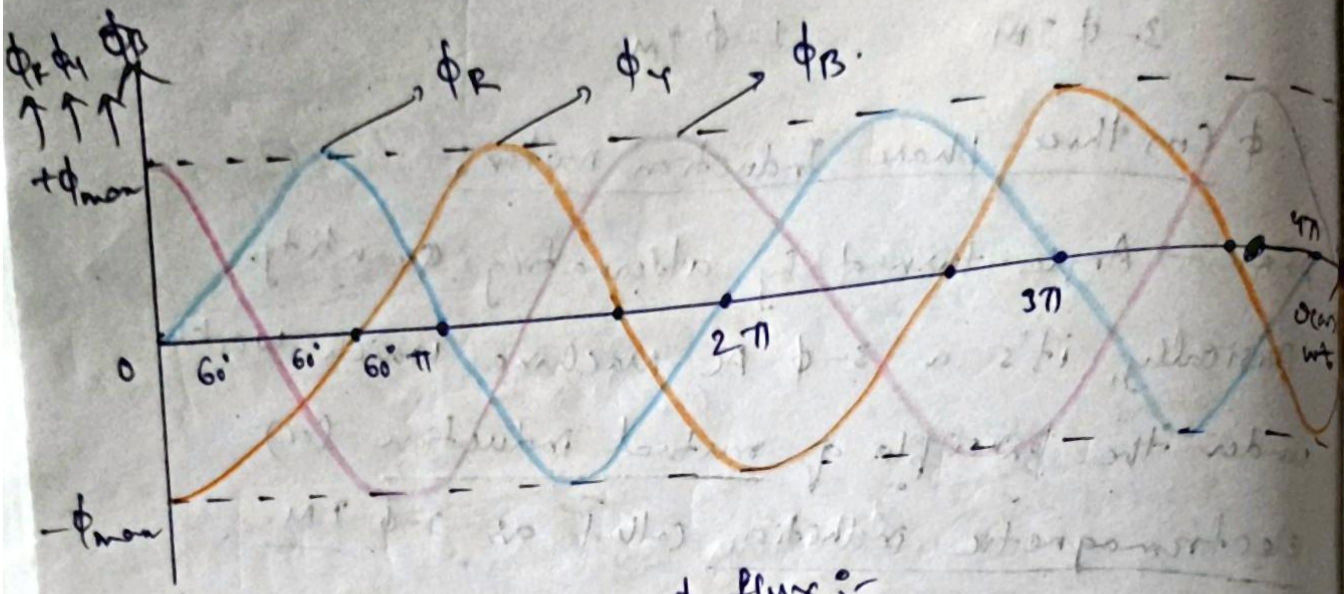
2). The RMF should maintain the constant speed and magnitude at every instant so that it is always rotating with synchronous speed ($N_S$).

3) Mathematically, 3-$\phi$ flux are represented as

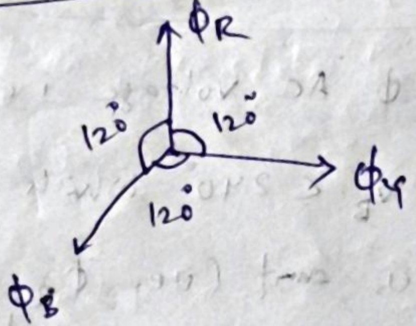
$$\phi_R = \phi_m \sin \omega t$$

$$\phi_Y = \phi_m \sin(\omega t - 120°)$$

$\phi_B = \phi_m \sin(\omega t - 240)$.




phaser diagram of 3-$\phi$ flux :-




Case (i) :- at $\omega t = 0$.

$\phi_R = \phi_m(\sin 0) = 0$

$\phi_Y = \phi_m \sin(-120°)$

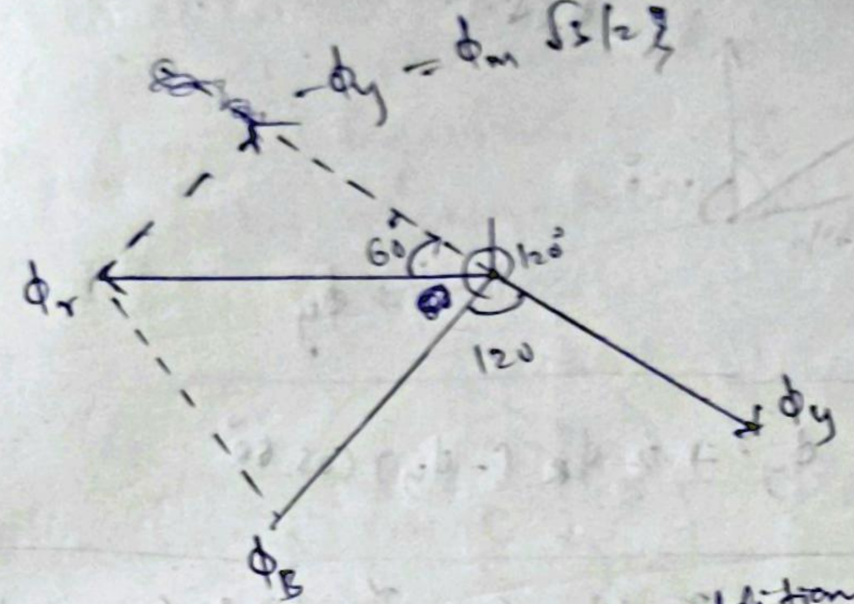
$= -\phi_m \sin(90+30)$

$\phi_Y = -\phi_m \sqrt{3}/2$.

$\phi_B = \phi_m \sin(-240°)$

$= -\phi_m \sin(180° + 60°)$

$\phi_B = \phi_m \sqrt{3}/2$.




According to parallelogram vector addition method.

$$\phi_r = \sqrt{(-\phi_y)^2 + (\phi_B)^2 + 2(-\phi_y)(\phi_B) \cdot \cos 60^\circ}$$

$$\Rightarrow \sqrt{(\phi_m \sqrt{3}/2)^2 + (\phi_m \sqrt{3}/2)^2 + \cancel{2}(\phi_m \sqrt{3}/2)^2 \times \frac{1}{\cancel{2}}}$$

$$\phi_r = \phi_m \sqrt{\frac{3}{4} + \frac{3}{4} + \frac{3}{4}}$$

$$= \phi_m \sqrt{\frac{9}{4}}$$

$$\phi_r = \phi_m \, 3/2 .$$

$$\boxed{\phi_r = 1.5\, \phi_{max}}$$

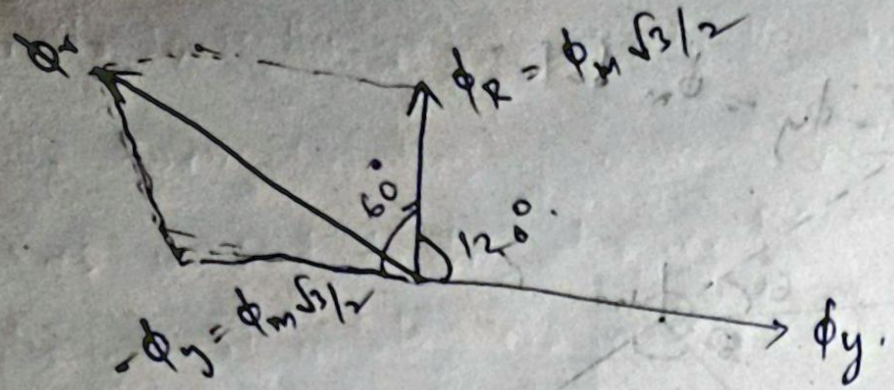
Case – ii) at $\omega t = 60^\circ$.

$$\phi_R = \phi_m \sin 60^\circ = \phi_m \sqrt{3}/2 .$$

$$\phi_Y = \phi_m \sin(60-120) = -\phi_m \sin 60^\circ = -\phi_m \sqrt{3}/2 .$$

$$\phi_B = \phi_m \sin(60 - 240^\circ) = \phi_m \sin(-180^\circ).$$

$$\boxed{\phi_B = 0}$$




$$\phi_r = \sqrt{\phi_R^2 + \phi_y^2 + 2\,\phi_R(-\phi_y)\cos 60^\circ}$$

$$= \sqrt{(\phi_m \sqrt{3}/2)^2 + (\phi_m \sqrt{3}/2)^2 + \cancel{2}\,\phi_m^2\, \sqrt{3}/2 \times \frac{1}{\cancel{2}}}$$

$$\phi_r \Rightarrow \phi_m \sqrt{\frac{3}{4} + \frac{3}{4} + \frac{3}{4}}$$

$$\phi_r = \phi_m \sqrt{\frac{9}{4}}$$

$$\phi_r = 1.5\,\phi_{max}.$$

Case - iii) at $\omega t = 120^\circ$.

$\phi_R = \phi_m \sin 120 = \phi_m(\sin 90 + 30) = \cos 30^\circ \phi_m = \phi_m \frac{\sqrt{3}}{2}$.

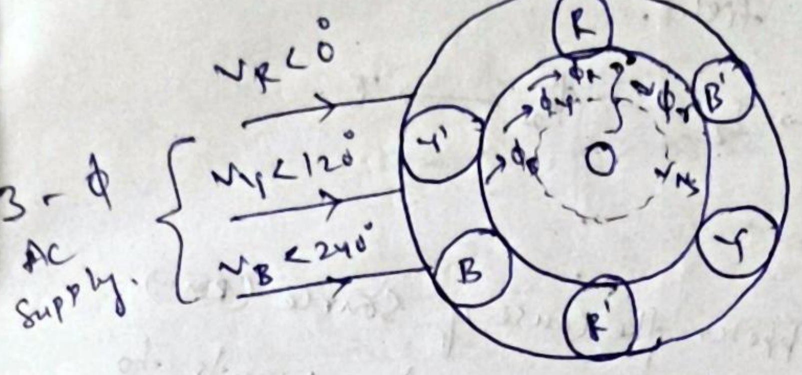
$\phi_Y = \phi_m \sin(\omega t - 120^\circ) = \phi_m \sin(120 - 120) = 0$

$\phi_B = \phi_m \sin(\omega t - 240^\circ) = \phi_m \sin(120 - 240^\circ) = -\phi_m \frac{\sqrt{3}}{2}$.

$\phi_r = 1.5\,\underline{\phi_{max}}$

Working of 3-ϕ Induction motor:-

- It is 3-ϕ AC motor which is working under the principle of mutual induction. and also under the basis of rotating magnetic field.




- whenever we apply the balanced 3-ϕ voltage to the stator (or) induction motor which produce the rotating magnetic field in the area ~~the~~ in the air gap.
- The rotating magnetic field rotates with synchronous speed ($N_S$) which maintains the constant speed & magnitude at every instant.
- whenever the RMF cuts the stationary conductors on rotor due to the relative speed b/w them, according to the faraday's law of electromagnetic induction, an emf gets induced in rotor winding called as secondary emf ($E_2$).
- ~~If the~~ This secondary emf produce the own magnetic flux i.e. $\phi_2$.
- whenever the current carrying coil (or) rotor winding placed in magnetic field, due to the magnetic flux interaction, the rotor will experience a mechanical force.

due to that the rotor will do the turn / twist.

- The turning (or) twisting moment of force about an axis is said to be torque. Because of the torque, the rotor is rotating continuously with the direction of rotating magnetic field.

Rotating magnetic field (RMF) $\quad E_2 \longrightarrow I_2 \longrightarrow \Phi_2 \longrightarrow \tau$

$\hookrightarrow$ Rotation

Rotation (result) opposes the cause of source (RMF).

- According to Lenz's law, the rotor wants to catch the synchronous speed and but it couldn't catch it, slips back w.r.t to the synchronous speed. Therefore, it is settled with the slip speed (or) relative speed.

Slip: ~~speed~~ It is defined as the speed differences b/w synchronous speed to the actual speed.

$$S = \frac{N_S - N_r}{N_S}$$

where,
$N_S \rightarrow$ Synchronous speed
$N_r \rightarrow$ Actual / rotor speed

$$\therefore \%S = \frac{N_S - N_r}{N_S} \times 100$$

from Slip, $S - N_S = N_S - N_r$

$\downarrow$

slip ~~spd~~ / speed (relative speed.

$$S - N_S - N_S = -N_r$$

$$N_S (S - 1) = -N_r$$

$$\boxed{N_r = N_s(1-s)}$$

Actual speed / rotor speed.

Synchronous Speed :- It is the speed of rotating magnetic field i.e. $N_s = \frac{120f}{P}$.

$f \rightarrow$ frequency.

$P \rightarrow$ No. of poles.

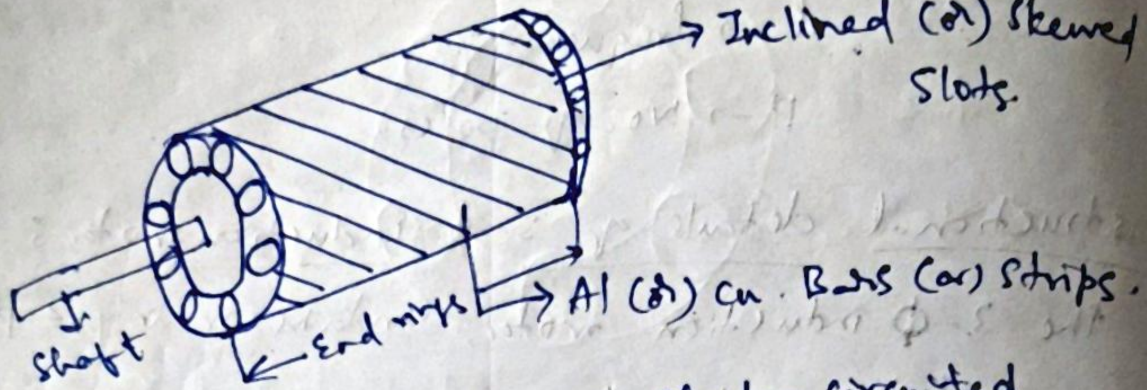
Constructional details of 3-$\phi$ Induction motor :-

In the 3-$\phi$ induction motor, contains mainly 2 parts i.e the Stator and rotor.

$\rightarrow$ (i) Squirrel cage type rotor.

$\rightarrow$ (ii) Sliping type rotor.

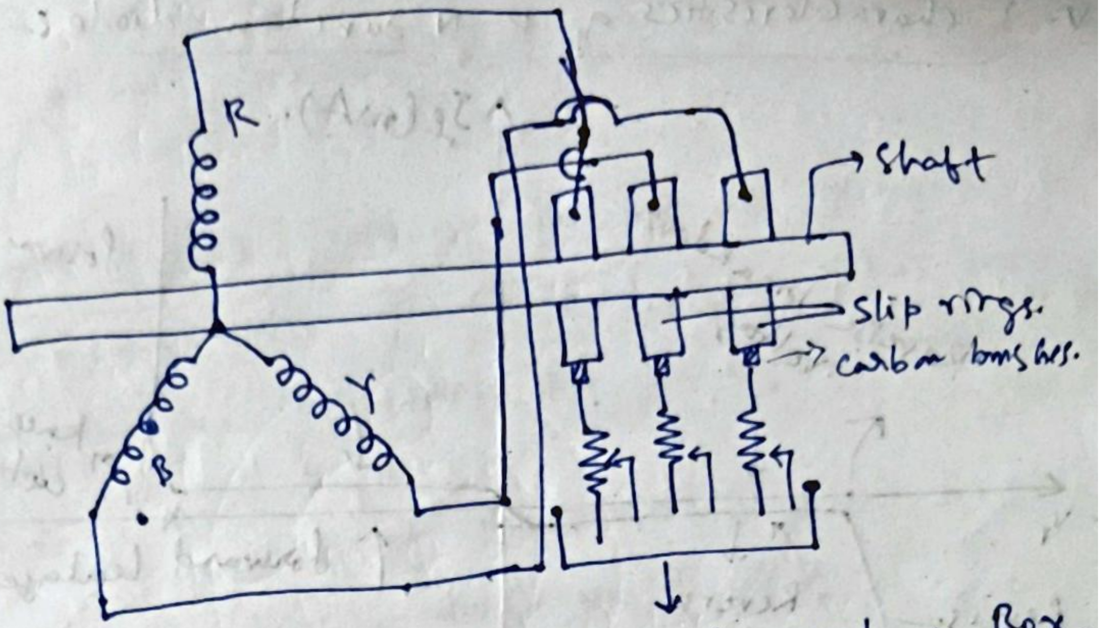
Stator :- It is the stationary part of the motor which is made up of laminated steel material to hold the 3-$\phi$ Stator winding i.e. star (or) delta type winding




- Inclined Al (or) Cu. Bars are short-circuited, with the ~~sam~~ Same end rings with the same material, to improve the Starting torque of the rotor.

slip-ring type Rotor:-

- This rotor construction is similar to stator of Induction motor. It must be Star-connected type only, the designing of 3-$\phi$ star connected winding, placed in the ~~stator~~ rotor slots & outside terminals are connected to the 3-slip rings. as shown in below diagram.




- This type of rotor construction to add the external resistances to each and every phase with the help of slip-rings and brushes. to improve the starting torque of the motor. (or) to obtain maximum starting torque.
- under running condition, the carbon brushes are slightly down and slip rings are formed closed path among all. The entire rotor is looking like squirrel cage type rotor characteristics.

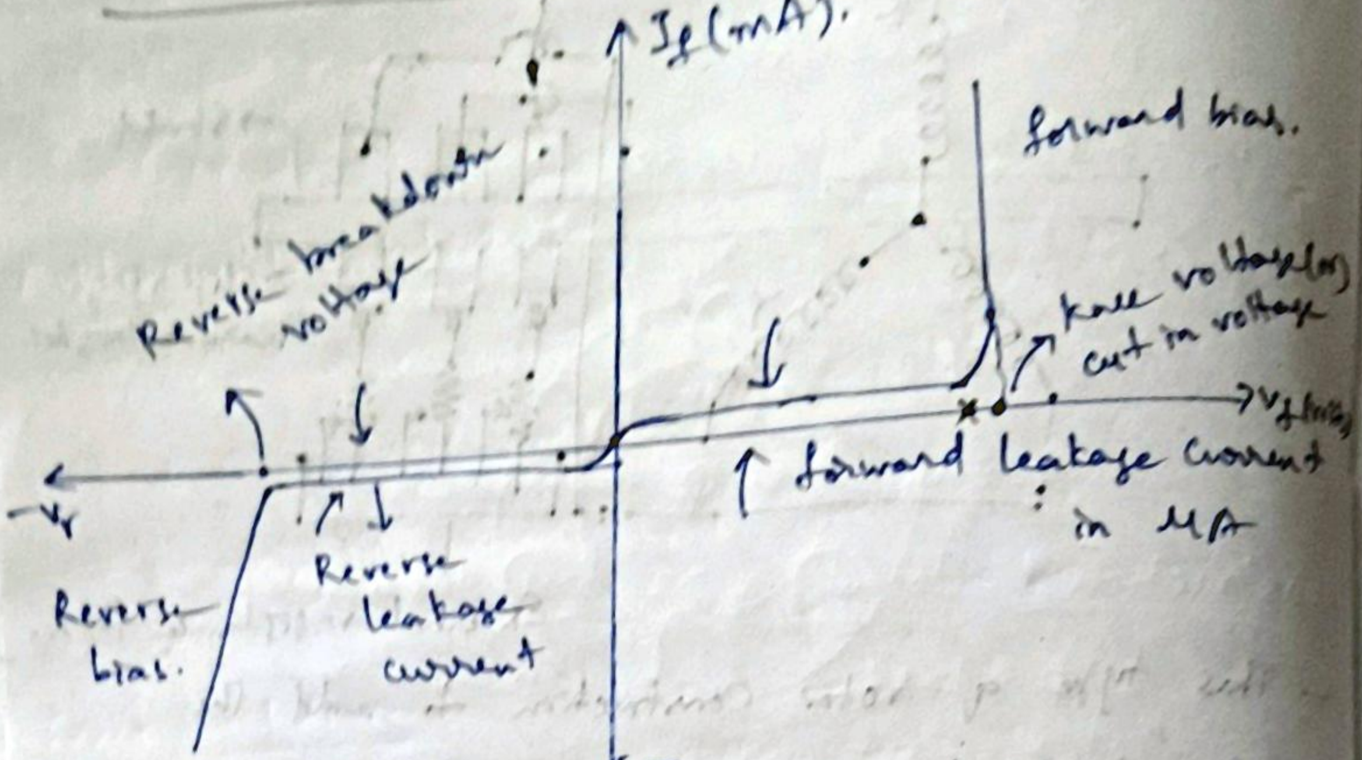
Types of 3-ϕ Induction motors:-

- The classification of induction motor based on rotor construction i.e.

(i) Squirrel-cage type 3-ϕ Induction motor.

(ii) Slip-ring type 3-ϕ induction motor.

## V-I characteristics of P-N Junction diode:-



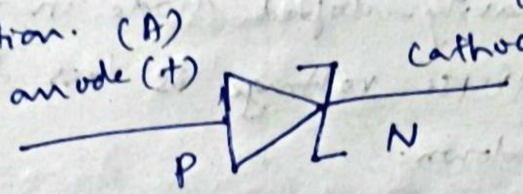

- From the graph, in forward bias condition, the applied voltage is greater than the barrier potential. then the depletion layer is breakdown due to that the current flow begins. The current increases slowly and the curve is obtained like non-linear as shown in above. These are called forward characteristics of PN Junction diode.
- In Reverse bias, due to the reverse voltage, the reverse Saturation current is flowing in diode. Because of minority charge carriers. present in the junction. when the reverse voltage is increases, then the minority charge carriers are increased then the layer width is increases, which offers the high resistance.

-> At this instant, majority charge carriers are also affected.

- At certain reverse voltage, breakdown occured in diode and also rise the temperature. This may cause the damage to whole PN Junction diode.

Zener diode:-

- It is a heavily (highly doped PN Junction diode which operates under reverse breakdown region (or) reverse-bias Condition.




Working:-

- The required biasing is provided to zener diode then it comes under operating mode.

- There are the two ways. for providing the biasing.

(i) Forward bias

(ii) Reverse bias

- In forward bias condition, the zener diode is working like normal PN Junction diode. Hence, the characteristics are similar to Normal PN Junction diode.

- In reverse bias, the voltage is increases and reaches the max. value (or) breakdown voltage, then the current begins to flow across the diode. That voltage is called as breakdown voltage.

- There are two types of breakdown in Zener diode.

(I) Avalanche breakdown

(II) Zener breakdown

Avalanche Breakdown:-

- The Avalanche breakdown occurs in lightly-doped diode when it is operated in reverse bias at the reverse voltage greater than 6V. called as Avalanche breakdown.

Zener breakdown:-

It is occured in heavily-doped diode in reverse-bias condition if the reverse voltage is less than 6V. called as Zener breakdown.

V-I characteristics:- (Zener diode).

The V-I characteristics of Zener diode is divided in two parts. i.e.

(I) Forward bias characteristics

(II) Reverse bias characteristics

(I) Forward bias characteristics:-

In forward bias, the Zener diode is behaving like normal PN Junction diode properties. so that the V-I graph is similar to the PN Junction diode as shown in below.

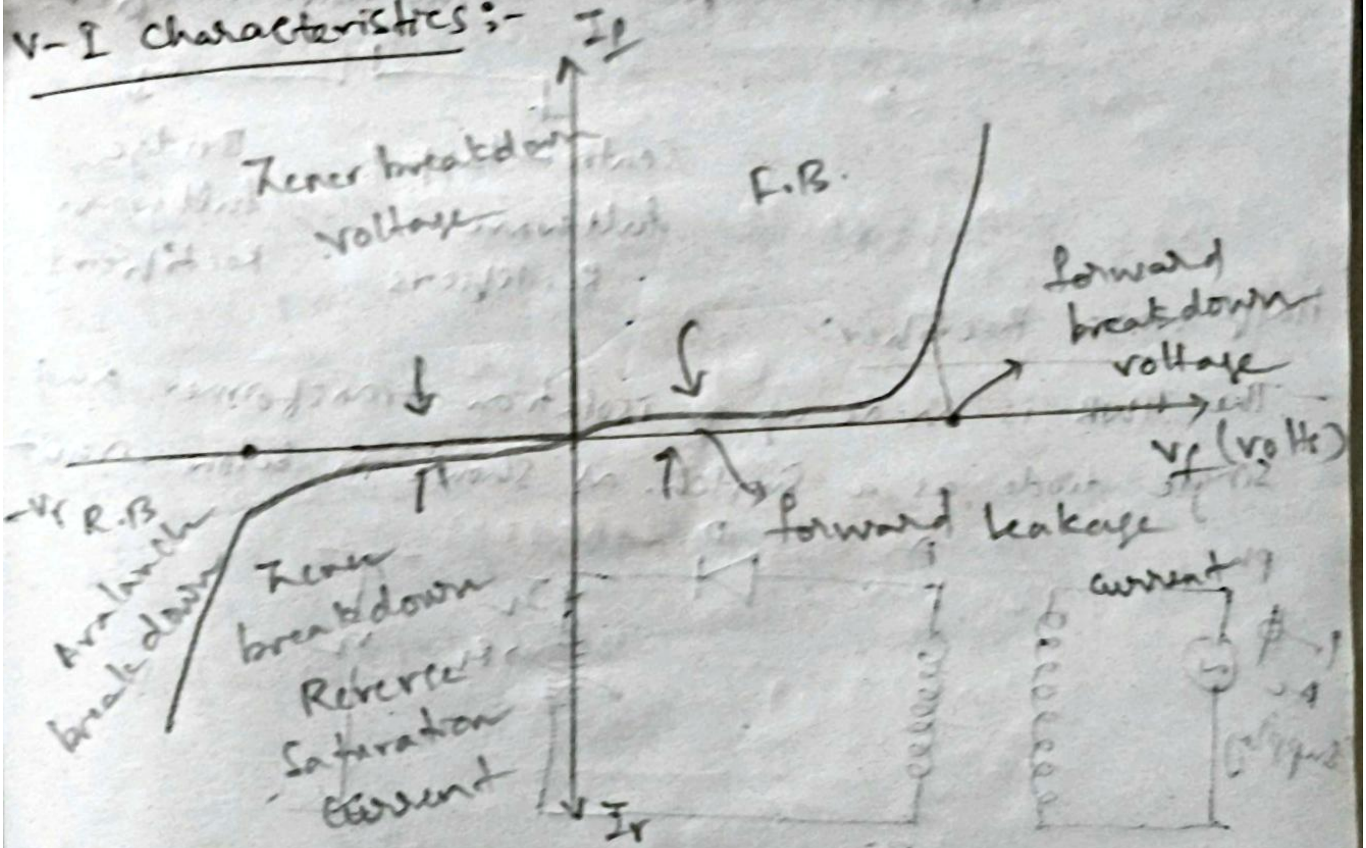
(II) Reverse bias characteristics:-

In the reverse bias condition of Zener diode, if the reverse voltage is applied across it, due to this voltage, a small reverse current flows from P to N.

This ~~cur~~ current is a thermally generated the charge carriers.

- As reverse voltage increases, gradually at certain values of reverse voltage, the reverse ~~voltage~~ current increases drastically. This reverse voltage is called as breakdown voltage. (or) Zener - breakdown voltage.

V-I characteristics:-




Applications of diode:-

1) solar cells panels
2) photovoltaic cells
3) Rectifiers
4) LED's etc.

Applications of Zener diode:-

1) Regulators
2) over-voltage protection system.
3) Clippers

## Rectifiers:-

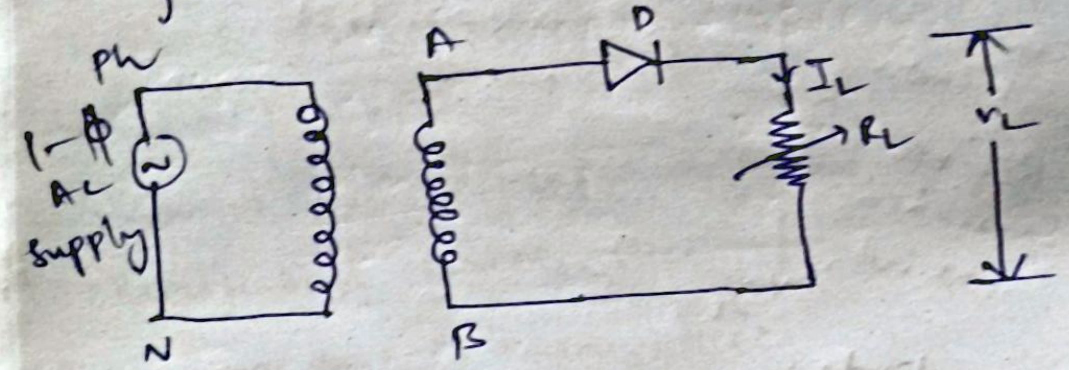
- It is an electronic device which used to convert fixed AC to variable DC voltage.
- Rectifiers are classified in two types based on no. of phases.

1-ϕ (or) single phase rectifiers → Half wave rectifier / full wave rectifier → Centre-tapped full wave Rectifiers / Bridge full wave Rectifiers.

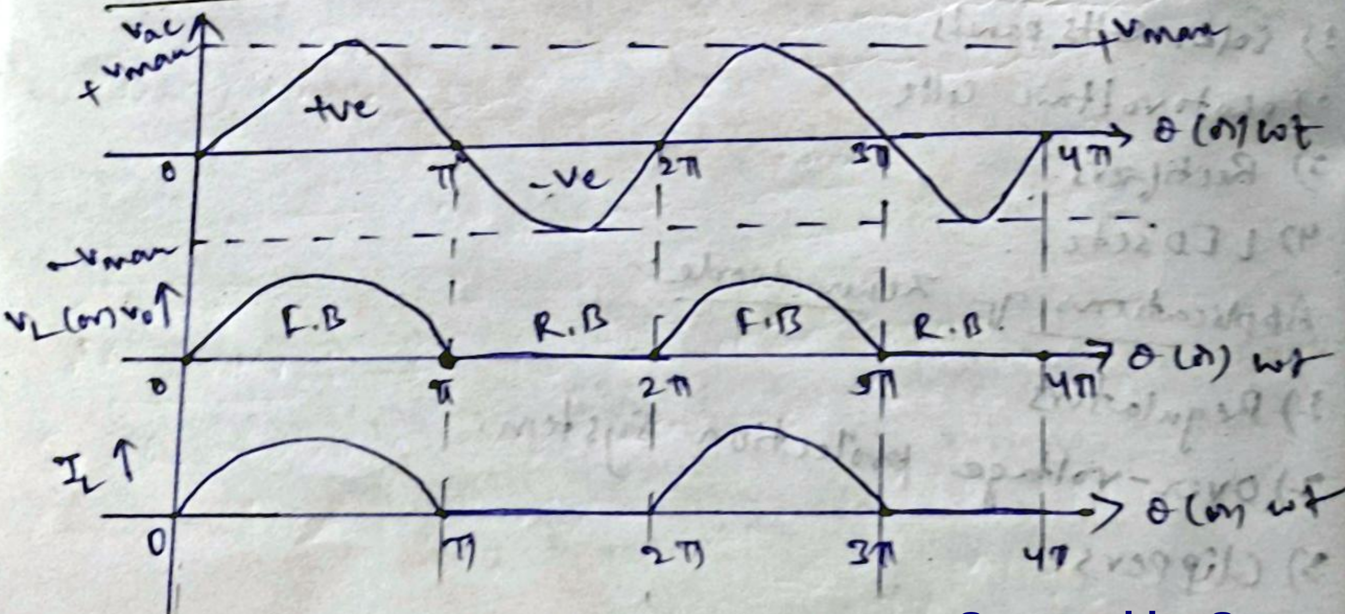
3-ϕ (or) Three phase rectifier

## Half wave Rectifier:-

- The HWR is made up of isolation transformer and single diode as a switch. as shown in below circuit




### wave-forms:-



In the HWR, whenever we apply the AC voltage (sinusoidal voltage) to the rectifier with the help of isolation transformer. In one cycle / single-cycle, during the positive half cycle, the terminal A become positive, B become negative. In this instant, the diode comes under forward bias so that it is allowing voltage & current to the load as shown in above graph.

- During the negative half cycle, the terminal A become negative and B become positive. In this connection, the diode comes under reverse-bias. Due to this, current & voltages are zero as shown in above graph.
- The same process is repeated for further cycles. which is mentioned in above

## Efficiency of HWR:-

- It is the ratio of output power to the input power.

$$\% \eta = \frac{P_{output}}{P_{input}} \times 100.$$

$$P_{o/p} = P_{dc} = I^2 R_L$$

$$P_{input} = P_{ac} = I^2 (R_L + r_f).$$

$$\% \eta = \frac{P_{dc}}{P_{ac}} \times 100$$

where, $R_L \rightarrow$ Load resistor.

$r_f \rightarrow$ forward resistance of diode.

## DC power:-

let,

$v = V_m \sin\theta$

$i = I_m \sin\theta$

$I_m = \frac{V_m}{R_L + r_f}$

DC power, $P_{dc} = I_{dc}^2 R_L = I_{avg}^2 \cdot R_L$.

$$I_{avg} = \frac{\text{Area of one alternation}}{\text{Total Base length}}$$

$$\Rightarrow \frac{\int_0^{\pi} i \cdot d\theta}{2\pi - 0}$$

$$I_{avg} = \frac{\int_0^{\pi} I_m \cdot \sin\theta \cdot d\theta}{2\pi}$$

$$I_{avg} = \frac{I_m}{2\pi}\int_0^{\pi} \sin\theta \cdot d\theta$$

$$I_{avg} = \frac{I_m}{2\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$I_{avg} = \frac{I_m}{2\pi}\left[-\cos(\pi) + \cos(0)\right]$$

$$= \frac{I_m}{2\pi}\left[1+1\right] = \frac{2I_m}{2\pi}$$

$$\therefore \boxed{I_{avg} = \frac{I_m}{\pi}}$$

$$P_{dc} = I_{avg}^2 \cdot R_L$$

$$\boxed{P_{dc} = \left(\frac{I_m}{\pi}\right)^2 \cdot R_L} \Rightarrow \text{DC power}$$

AC power :- It is the input power of rectifier so that diode resistance also taken into consideration. So, therefore $P_{ac} = I_{ac}^2 (R_L + R_f)$

$$\Rightarrow I_{rms}^2 (R_L + r_f).$$

$I_{rms} \rightarrow$ It is the square root of ratio of square of the area of one alternation upon total base length.

$$I_{rms} = \sqrt{\frac{\text{Square of area of one alternation}}{\text{Total base length.}}}$$

$$\Rightarrow \sqrt{\frac{\int_0^{\pi} i^2 \cdot d\theta}{2\pi - 0}} = \sqrt{\frac{\int_0^{\pi} I_m^2 \sin^2\theta \, d\theta}{2\pi}} = \frac{I_m}{\cancel{2\pi}} \int \sqrt{\frac{1-\cos 2\theta}{2 \times 2\pi}}$$

$$\Rightarrow \frac{I_m}{2\sqrt{\pi}} \left(\theta - \sin 2\theta\right)_0^{\pi} \Rightarrow \frac{I_m}{2\sqrt{\pi}} \sqrt{(\pi - 0) - (\sin 2\pi - \sin 0))}$$

$$\Rightarrow \frac{I_m}{2\sqrt{\pi}} \left(\sqrt{\pi - (0-0)}\right) = \frac{I_m}{2\sqrt{\cancel{\pi}}} \sqrt{\cancel{\pi}} = \frac{I_m}{2}$$

$$\boxed{I_{rms} = \frac{I_m}{2}}$$

Ac power, $P_{ac} = I_{rms}^2 (R_L + r_f)$

$$P_{ac} = \left(\frac{I_m}{2}\right)^2 \times (R_L + r_f).$$

$$\therefore \% \eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{\left(\frac{I_m}{\pi}\right)^2 \times R_L}{\frac{I_m^2}{4} \times (R_L + r_f)} \times 100.$$

$$\Rightarrow \frac{4}{\pi^2} \times \frac{R_L}{R_L + r_f} \times 100.$$

If ideal diode, $r_f = 0$.

$$\eta = \frac{4}{\pi^2} \times \frac{R_L}{R_L + 0} \times 100 \Rightarrow \eta = 0.405 \times 100$$

$$\boxed{\% \eta = 40.5}$$

Ripple factor :-

↳ unwanted AC component present in the desired output, known as ripple.

→ Ripple factor is defined as the ratio of AC component to the DC component.

$$\gamma = \frac{\text{AC component}}{\text{DC component}}$$

$$\gamma = \frac{I_{ac}}{I_{dc}}$$

From rms value, $I_{rms} = \sqrt{I_{ac}^2 + I_{dc}^2}$.

$$I_{rms}^2 = I_{ac}^2 + I_{dc}^2$$

$$I_{ac}^2 = I_{rms}^2 - I_{dc}^2$$

$$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

$$\therefore \gamma = \frac{I_{ac}}{I_{dc}} = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}}$$

$$\Rightarrow \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - \frac{I_{dc}^2}{I_{dc}^2}}$$

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} \longrightarrow \text{Ripple factor formula}$$

$$\Rightarrow \sqrt{\frac{\left(\frac{I_m}{2}\right)^2}{\left(\frac{I_m}{\pi}\right)^2} - 1}$$

$$\gamma = \sqrt{\frac{\pi^2}{4} - 1} = 1.21$$

Peak inverse voltage:-

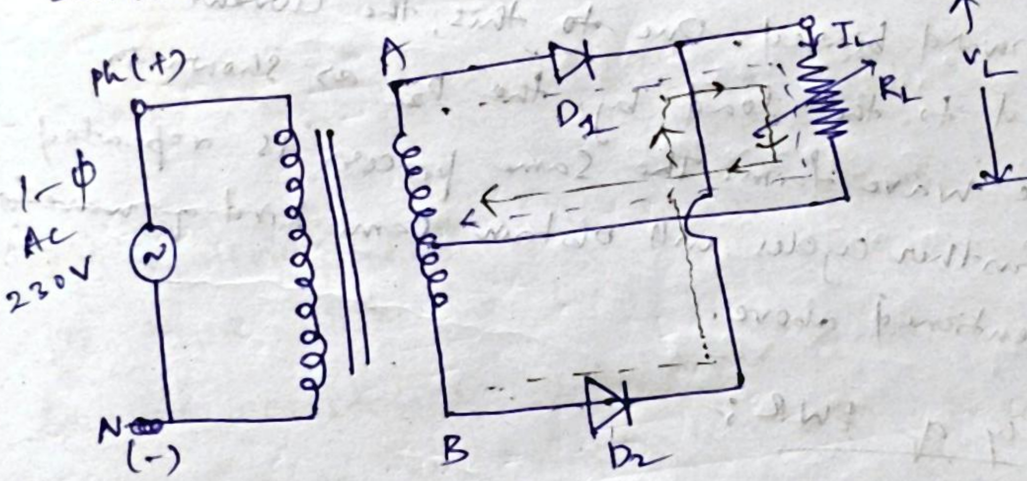
It is the maximum reverse voltage, that can the diode withstand without damage.

$$\boxed{PIV = V_{max}}$$

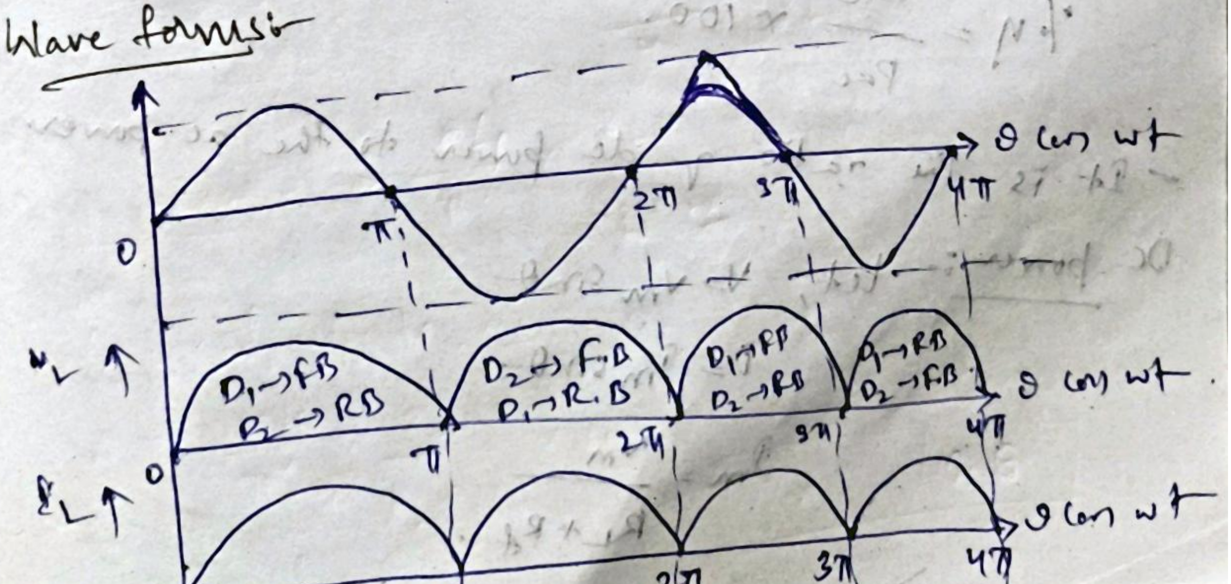
Full wave rectifier:-

(a) Center-tapped full wave rectifier:-

- This rectifier is made up of center-tapped isolated transformer and the two diodes as a switch as shown in below circuit.




Wave forms:-



Working:-

- Whenever we apply the sinusoidal voltage to the rectifier, with the help of isolation transformer as mentioned in the diagram.
- During the positive half cycle, the terminal A become positive, B become negative. In this connection, the diode $D_1$ is forward biased, $D_2$ is reverse-biased, so that, the current is allowed to the load by $D_1$ diode.
- During the negative half cycle, the terminal A become negative and B become positive. In this connection, the diode $D_1$ is reverse biased and $D_2$ is forward biased. Due to this, the current is allowed to the load by the $D_2$. as shown in above wave form. The same process is repeated for further cycles will obtain same kind of waveform as mentioned above.

Efficiency of FWR:-

$$\% \eta = \frac{P_{dc}}{P_{ac}} \times 100.$$

- It is the ratio of dc power to the ac power

DC power:- let, $V = V_m \sin\theta$

$$I = I_m \sin\theta$$

$$I_m = \frac{V_m}{R_L + R_f}.$$

$P_{dc} = I_{dc}^2 \times R_L = (I_{avg})^2 \times R_L$.

$$I_{avg} = \frac{\text{Area of the half alternation}}{\text{Total base length of H.f.}}$$

$$\Rightarrow \frac{\int_0^{\pi} i \cdot d\theta}{\pi - 0}$$

$$I_{avg} = \frac{\int_0^{\pi} I_m \sin\theta \cdot d\theta}{\pi} \Rightarrow \frac{I_m}{\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$\Rightarrow \frac{I_m}{\pi}\left[-\cos\pi + \cos(0)\right] = \frac{I_m}{\pi}\left[1 + 1\right]$$

$$\boxed{I_{avg} \Rightarrow \frac{2I_m}{\pi}}$$

Q1) A sinusoidal peak voltage of 16V is applied to the HWR with the load of 1.1 kΩ and the forward resistence of the diode is 10Ω, calculate

(i) Peak, average and rms values of current

(ii) DC and AC powers

(iii) Efficiency of the rectifier.

(iv) Ripple factor.

Given Data:-

$V_{max} = 16V$

$R_L = 1.1k\Omega = 1100\Omega$.

$r_f = 10\Omega$.

(i) $I_{max}$, $I_{avg}$ & $I_{rms}$.

$$I_{max} = \frac{V_{max}}{R_L + r_f} = \frac{16}{1110} = 0.0144\,A$$

$$I_{avg} = \frac{I_m}{\pi} = \frac{0.0144}{\pi} = 0.0045\,A$$

$$I_{rms} = \frac{I_{max}}{2} = \frac{0.0144}{2} = 0.0072$$

- Rectifiers.
- Induction Machine

(>5kg),

Synchronous

(ii) DC & AC power

$$P_{dc} = I_{dc}^2 \times R_L$$

$$= (0.0045)^2 \times 1100.$$

$$P_{dc} = 0.0222.$$

$$P_{ac} = I_{rms}^2 \times (R_L + r_f).$$

$$= 0.0072 \times 1110.$$

$$P_{ac} = 0.0575.$$

(iii) $$\%\eta = \frac{P_{dc}}{P_{ac}} \times 100.$$

$$= \frac{0.0222}{0.0575} \times 100.$$

$$\boxed{\eta = 38.6\%}$$

(iv) $$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{avg}}\right)^2 - 1}$$

$$\gamma = 1.248.$$

Q2). The sinusoidal peak voltage of 15.4 V is applied to FWR with the load of $\cancel{1204}$ 1.24 kΩ and the forward resistance of the diode is 12 Ω. Calculate

(i) $I_{rms}$, $I_{avg}$

(ii) Efficiency of the rectifier

(iii) Ripple factor.

(iv) Peak inverse voltage of centre-tapped FWR.

Sol^n :- Given Data is

$$V_{max} = 15.4 V$$

$$R_L = \cancel{1204}\ 1.24\ k\Omega = 1240\ \Omega$$

$$r_f = 12\ \Omega.$$

$$I_{max} = \frac{V_{max}}{R_L + r_f} = \frac{15.4}{1240+12}.$$

$$I_{max} = 0.0123$$

$$I_{avg} = \frac{2 I_{max}}{\pi} = \frac{2 \times 0.0123}{\pi} = 0.0078.$$

$$I_{rms} = \frac{I_{max}}{\sqrt{2}} = \frac{0.0123}{\sqrt{2}} = 0.0086$$

(ii) $$\% \eta = \frac{P_{dc}}{P_{ac}} \times 100.$$

$$P_{dc} = (I_{avg})^2 \times R_L = \cancel{0.0716} \rightarrow 0.07544$$

$$P_{ac} = (I_{rms})^2 \times (R_L + r_f).$$

$$P_{ac} = \cancel{0.0092}\ 0.09259$$

(iii) $\% \eta = \frac{P_{dc}}{P_{ac}} \times 100$.

$$\eta = 81.47\%$$

(iv). $\gamma = \sqrt{\left(\frac{I_{rms}}{I_{avg}}\right)^2 - 1}$

$$\boxed{\gamma = 0.471}$$

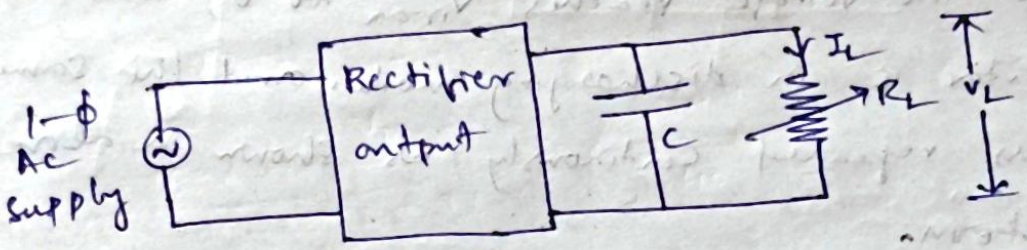
Q. The sinusoidal voltage of $V = 24 \sin 312t$ is applied to the FWR with the load resistance of 1400Ω ~~at~~ and the forward resistance of the diode is 8Ω. calculate the efficiency & ripple factor.

Filters :-

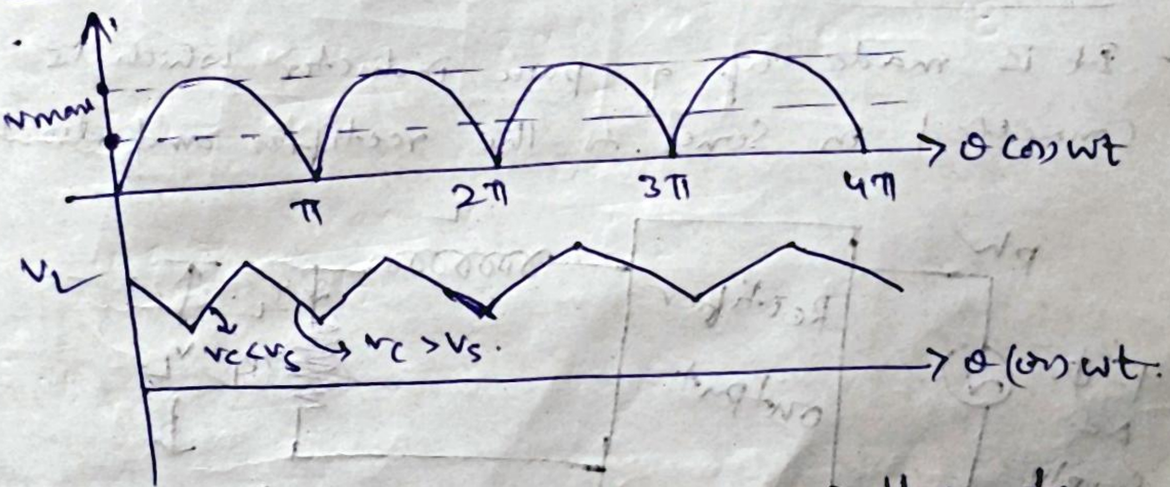
It is a electronic device which is used to remove the unwanted AC component in the desired output known as filter.

- The filters are classified into two types.
  - Capacitor filter
  - Inductor filter

Capacitor filter is made up of pure capacitor which is connected across the rectifier as shown in below circuit.




Wave forms :-

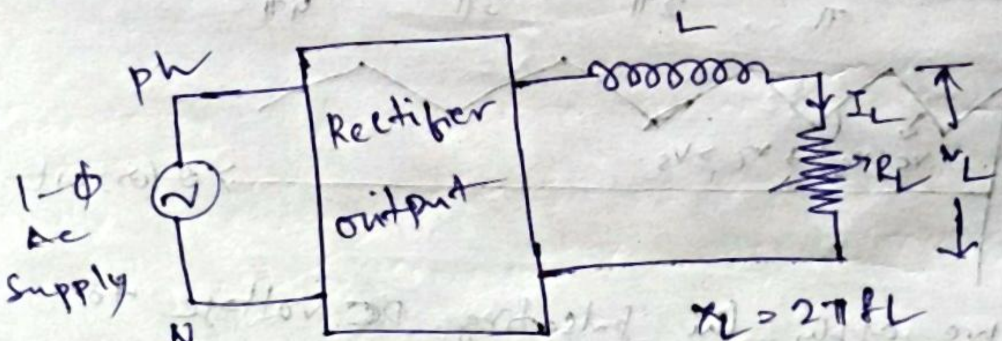



Whenever we apply the pulsating DC voltage to the capacitor filter. If the voltage is increased to Vmax then the capacitor is in charging mode ($V_s$ (source voltage) > $V_C$ (capacitor voltage)). During the above period of the voltage, diode in the rectifier under forward biased then the voltage reaches the maximum value which is appears across the capacitor.

- The capacitor after charging, at Vmax to 0. The voltage is discharging towards the load resistor i.e. the $V_C > V_S$, which is mentioned in the above waveform.
- When the source voltage reaches the maximum value, then the capacitor is in charging mode. when the voltage reaches Vmax to 0, then the capacitor is in discharging mode. and the same process repeated continously as shown in above waveform.

<u>Inductor filter:-</u>

- It is made up of pure inductor which is connected in series to the rectifier and also load.




$X_L = 2\pi f L$

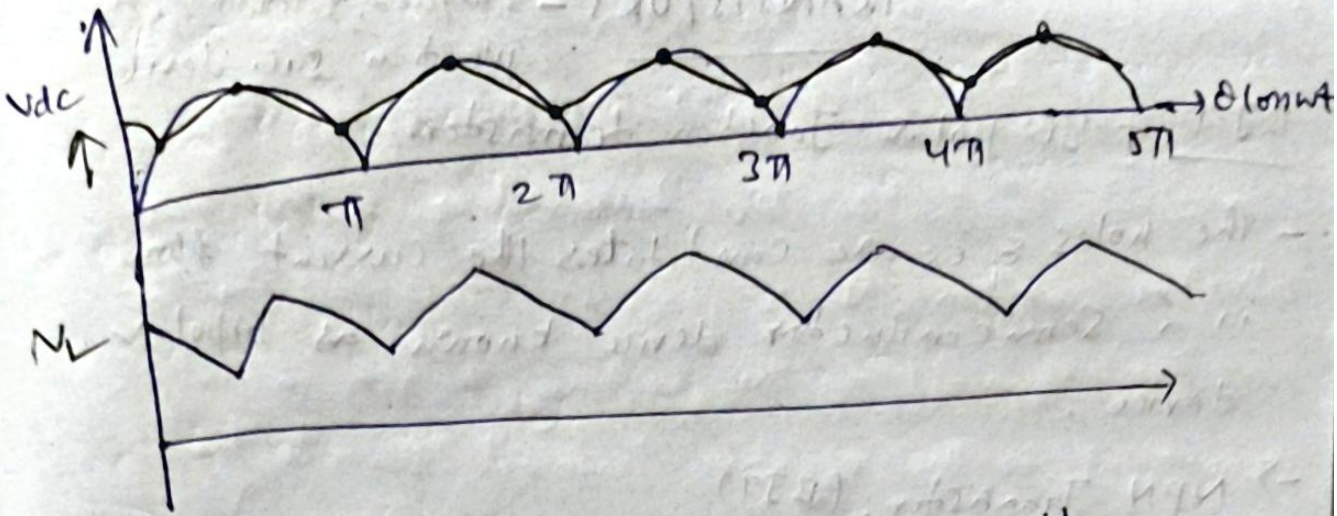
↳ Inductive reactance

$DC \to X_L = 2\pi f L$

$f = 0, \Rightarrow X_L = 0$

$AC \to X_L = 2\pi f L$

$f = 50\,Hz, X_L \uparrow$




- Whenever we apply the pulsating DC voltage applied to the Inductor filter, this voltage has two parts. One is AC component and the other is DC component. The Inductor offers zero reactance ($X_L = 0$) to the DC component, then the current flowing (or) allowing through the inductor to the load resistor.
- The inductor offers the high reactance i.e. $X_L = 2\pi f L$ due to the presence of frequency to the AC component, then the inductor blocks the AC component.
- Above condition, the filter circuit (or) inductor filter removing the AC component from the rectifier output i.e. DC component is allowing towards the load & the AC component is blocking which is mentioned in the above wave form. The same process is also referred for all the pulses.

# TRANSISTORS – 3 layered, 3 terminal, two junction S.C. device

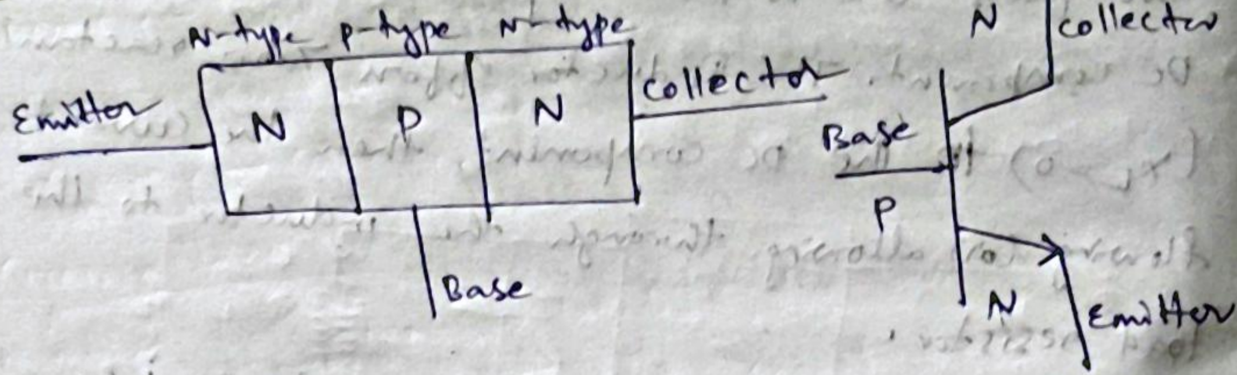
**BJT** – Bi-polar Junction transistor.

- The holes & $\bar{e}$s are constitutes the current flow in a semiconductor device known as bipolar device.

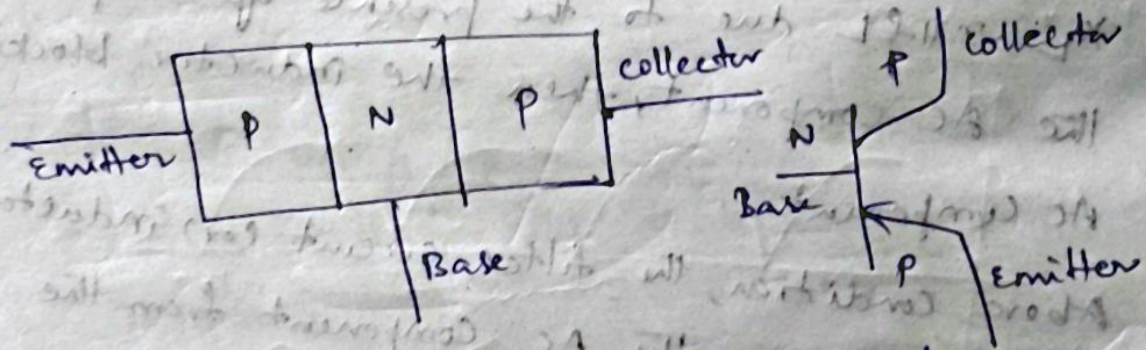
-> NPN Transistor. (BJT)

-> PNP transistor (BJT)

**NPN Transistor :-**




**PNP transistor :-**




**Transistors :-** Amplification of weak signals.

- The transistor (or) BJT is 3-terminal, 3-layered two junction semiconductor device named as emitter, base, collector.

Emitter :-

- It is a highly doped region which emits (or) supplies the majority charge carriers towards the other region.

Base :-

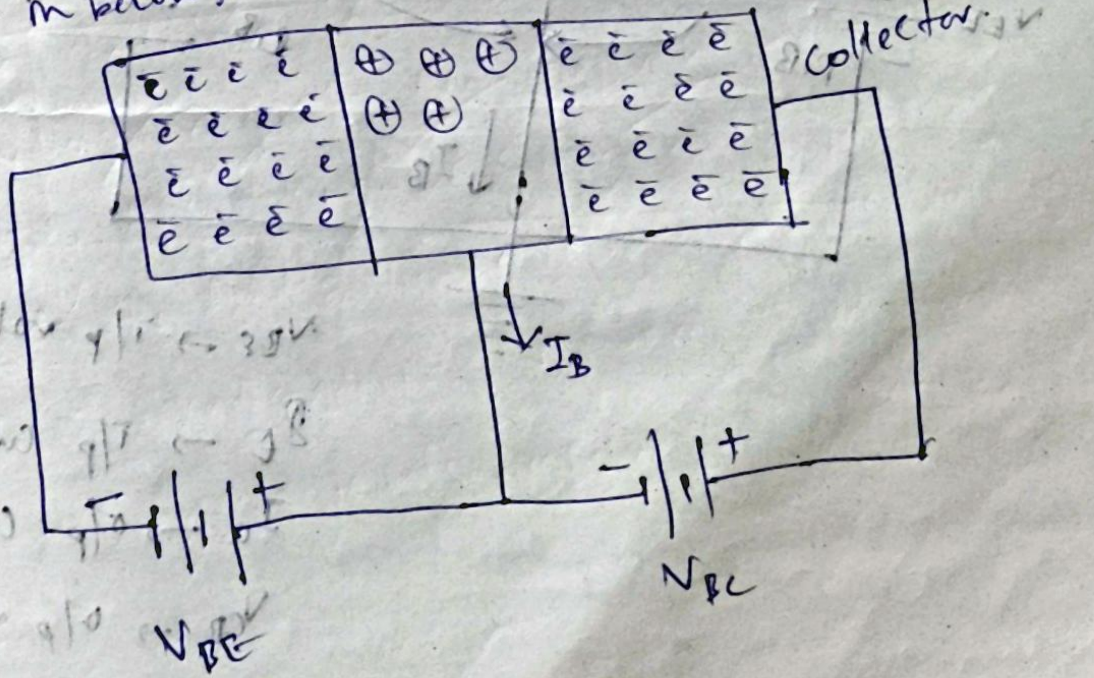
- It is a lightly doped layer, which is formed between emitter & collecter due to the presence of narrow-width. It doesn't have the capability to emit the charges, and also accepting the charges.

collecter :-

- It is a moderately doped region which used to collect (or) accept the charges from emitter region. Known as collecter.

Working of NPN Transistor :-

NPN transistor :- The NPN transistor comes under operating mode to provide two biasings, i.e. b/w emitter to base and ~~collec~~ base to collecter as shown in below;



In NPN ~~transmitter~~ transistor, the N-region is connected to the negative terminal of the battery & P-region is connected to the positive terminal ~~of~~ & the base-~~collector~~ emitter junction, N-region is connected to the positive terminal of the battery, P-region is connected to the negative terminal, said to be reverse-bias.

— pending...

— The transistor can be connected in circuits, 3-ways

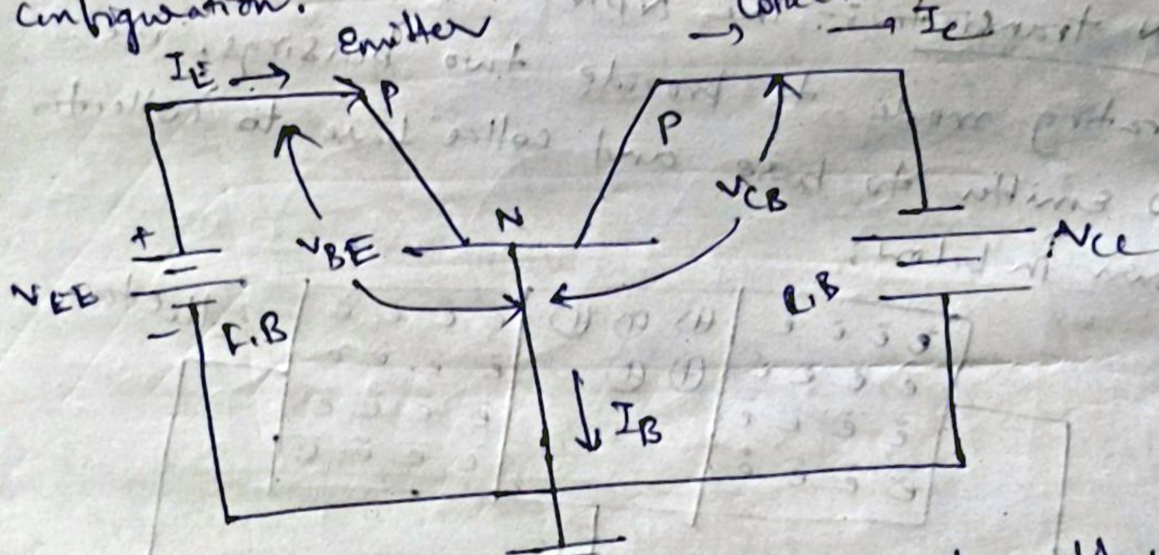
(i) Common-Base Configuration

(ii) Common-emitter Configuration

(iii) Common-collector.

(i) Common base Config:-

The above pnp transistor (or) BJT, the base terminal is connected as common for both the input & output known as CB configuration.




$V_{BE} \rightarrow$ i/p voltage

$I_E \rightarrow$ i/p current

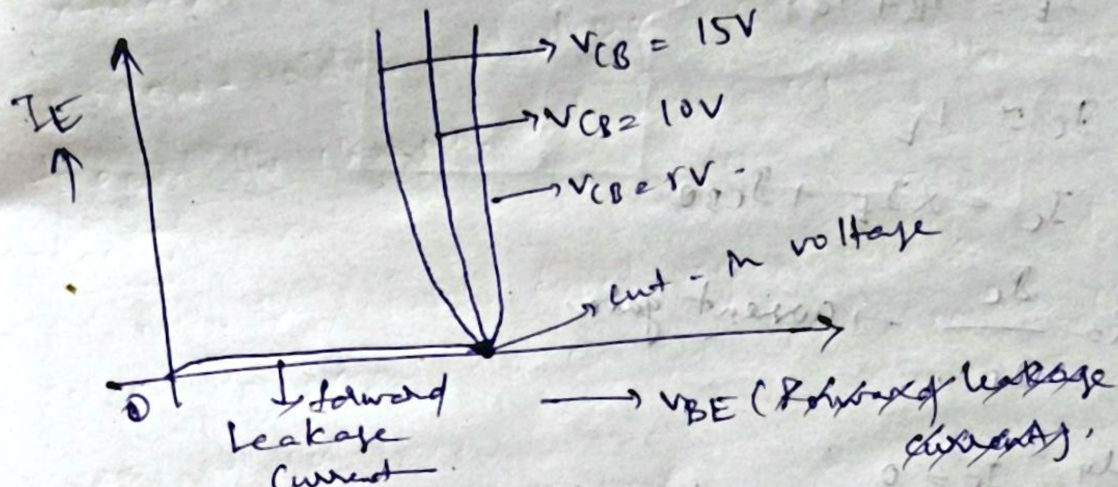
$I_C \rightarrow$ o/p current

$V_{CB} \rightarrow$ o/p voltage

The above BJT Cas transistor working as an amplifier, to connect emitter, base junction as forward bias. The base collector junctions as reverse bias.

Input Characteristics:-

- performance curve is plot b/w $V_{BE}$ against $I_E$ where the output voltage is constant, known as input characteristics of CB configuration.




- In the input side of the transistor, the voltage is applied b/w E to B terminals. biasing
- So that, positive terminal is connected on p-region (emitter) and the -ve terminal is connected to n-region, said to be forward bias.
- In this connection, the BJT contains normal PN junction properties. Hence, the i/p characteristics are similar to E-B characteristics of the PN Junction diode.

Output characteristics:-

- The performance curve is plot b/w $V_{CB}$ against $I_C$, where the i/p current is kept constant known as o/p characteristics.

$I_C$ vs $V_{CB}$ → $I_E$ → Constant.

From BJ current eqn,

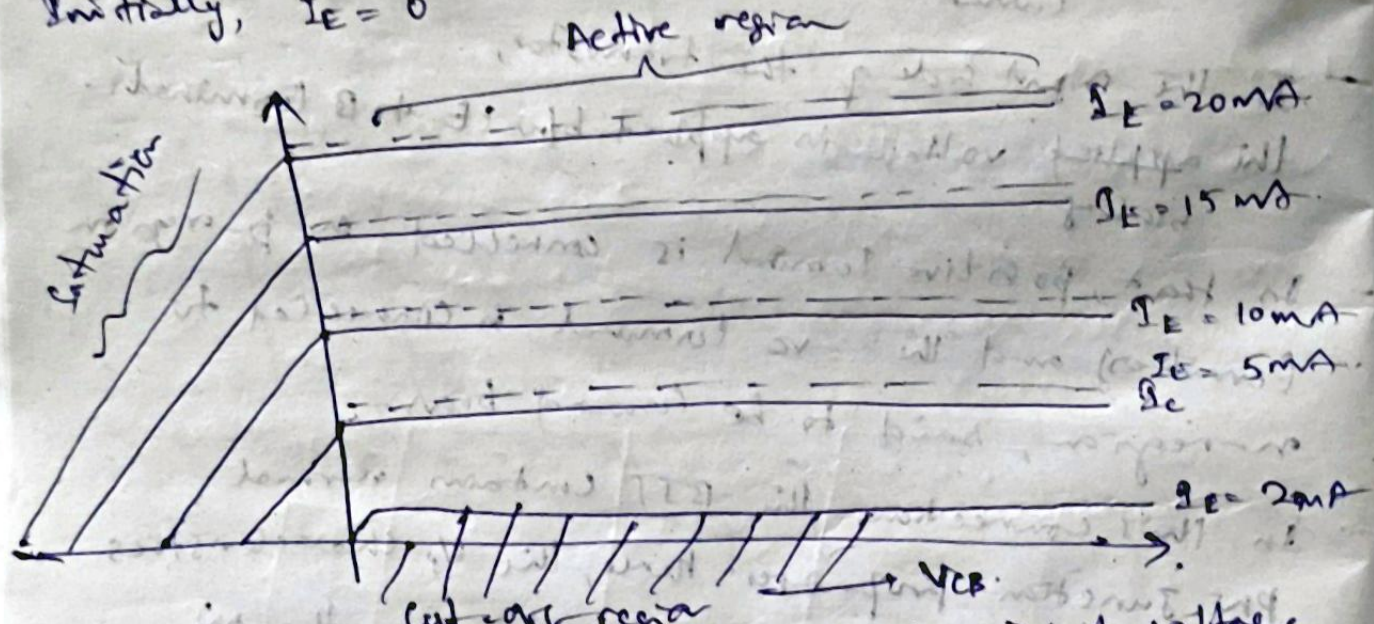
$I_E = I_B + I_C$

$I_C \simeq I_E$

$I_C = \alpha I_E + I_{CBO}$

$\alpha = \frac{I_C}{I_E}$ → current gain.

Initially, $I_E = 0$




- In this o/p characteristics, set the input voltage as constant then only $I_E$ will become constant so that o/p current is nearly i/p current.
- Now $V_{CB}$ made positive, then the $I_C$ value is increases. If it is made negative, the $I_C$ value is sharply decreases. This region is called saturation region

Input resistance:-

- It is obtained from i/p characteristics which defined as the ratio of i/p voltage to the i/p current.

$$R_I = \frac{\Delta V_{BE}}{\Delta I_E} \Big|_{V_{CB}\ \text{constant}}$$

output resistance:-

- From the o/p characteristics, it is the ratio of change in voltage to the change in current.

$$R_0 = \frac{\Delta V_{CB}}{\Delta I_C} \Big|_{I_E \rightarrow \text{const}}$$

Expression for o/p current:-

$$I_C = \alpha I_E + I_{CBO}$$

$\alpha \rightarrow$ current gain / current amplification factor.

$I_{CBO} \rightarrow$ Reverse leakage current.

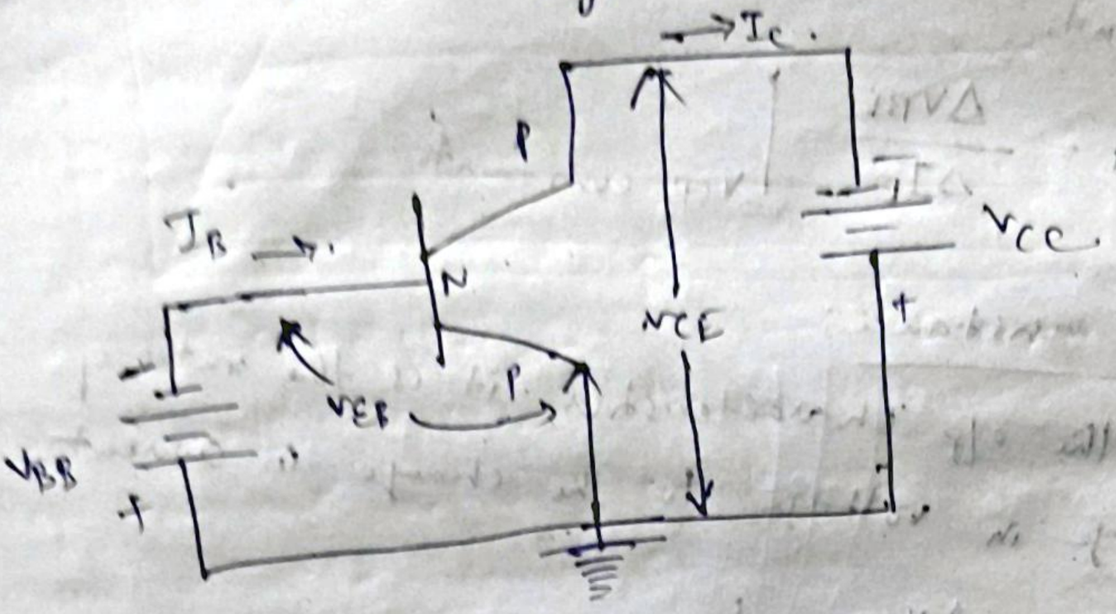
Current amplification factor:-

- It is the ratio of collector current to the emitter current and also define the ratio of o/p current to i/p current.

$$\alpha = \frac{I_C}{I_E}$$

CE configuration:-

- The emitter terminal of the transistor connected as common for CE configuration

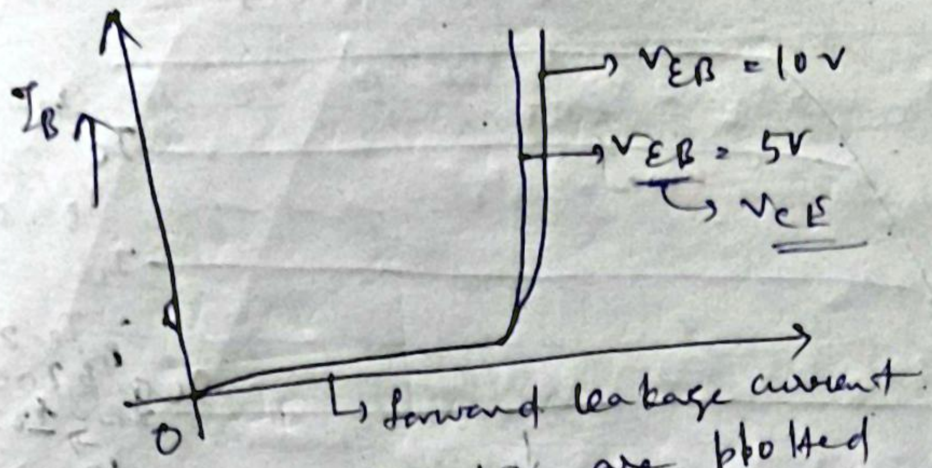



- $I_B \rightarrow$ i/p current
  $V_{BE} \rightarrow$ i/p voltage
  $V_{CE} \rightarrow$ o/p voltage
  $I_C \rightarrow$ o/p current

- The above common emitter config of transistor, should be act as an amplifier to connect the i/p side as forward bias and the output side as the reverse bias.

Input characteristics:-

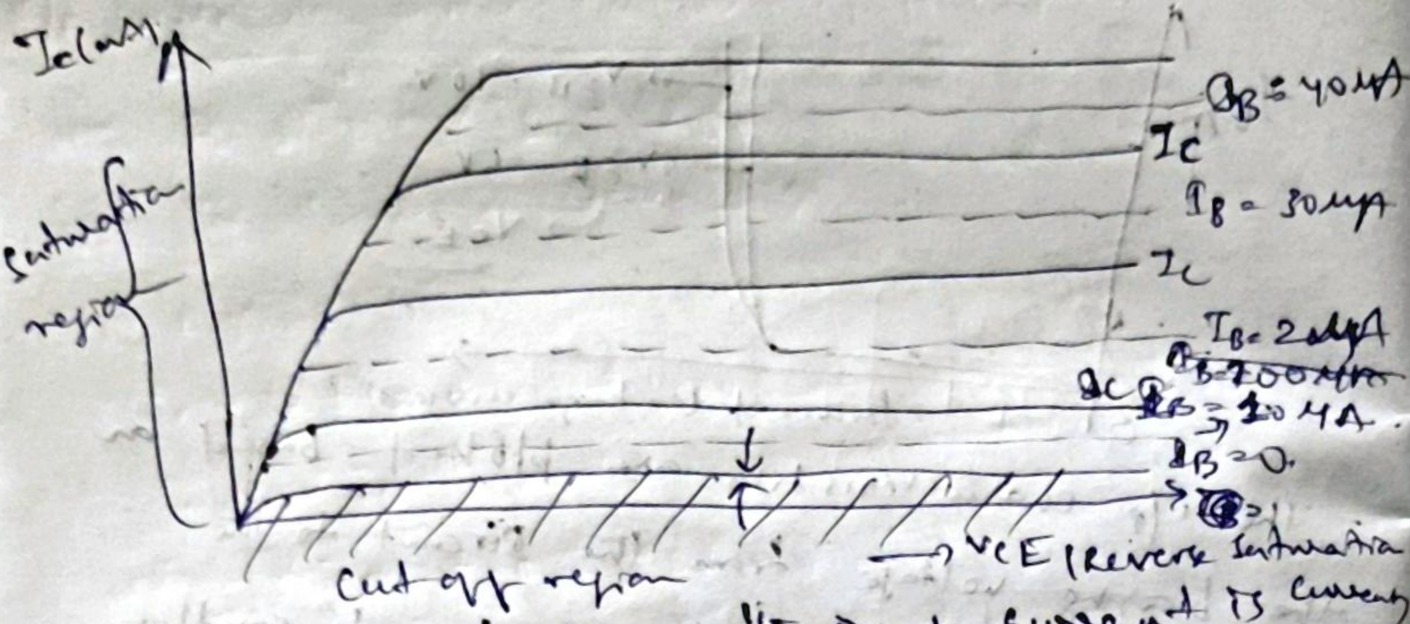
The performance curve is plot b/w input voltage & input current where output voltage is kept constant.




- The i/p characteristics are plotted based on the circuit to the the biasing voltage from the circuit to the input voltage is applied b/w base to emitter region. In that -ve terminal,

output characteristics:-

The performance graph is plot b/w output voltage & o/p current




- From the o/p characteristics, the input current is kept constant initially, a voltage is applied across the input terminals. So that,

- There is a small current flow from collector region to base region i.e. reverse leakage current. There is a small amount of i/p current changes will obtain large changes in o/p current due to the less amount of current flow in base region (or) input region ($\mu A$).

Input resistance:-

- From the i/p characteristics, it is the ratio of change in voltage to the change in current

$$R_I = \frac{\Delta V_{BE}}{\Delta I_B}\Bigg|_{V_{CE}\ \text{constant.}}$$

Output resistance:-

- It is obtained from o/p characteristics which defined as the ratio of output voltage to the output current

$$R_O = \frac{\Delta V_{CE}}{\Delta I_C}\Bigg|_{I_B \to \text{Const}}$$

## current amplification factor:-

- It is the ratio of input current to the o/p current.

$$\beta = \frac{I_C}{I_B}.$$

↳ current amplification factor (current gain in CE)

## Relationship b/w $\alpha$ and $\beta$:-

From the BJT chart eqn,

$$I_E = I_B + I_C.$$

$$I_B = I_E - I_C \longrightarrow (1).$$

$$\alpha = \frac{I_C}{I_E} \Rightarrow \frac{1}{\alpha} = \frac{I_E}{I_C}.$$

$$\beta = \frac{I_C}{I_B}.$$

$$\beta = \frac{I_C}{I_E - I_C} = \frac{1}{\frac{I_E}{I_C} - \frac{I_C}{I_C}}.$$

$$\beta = \frac{1}{\frac{1}{\alpha} - 1} = \frac{1}{\frac{1-\alpha}{\alpha}} \quad \therefore \beta = \frac{\alpha}{1-\alpha}$$

$$\beta(1-\alpha) = \alpha$$

$$\beta - \beta\alpha = \beta = \alpha + \beta\alpha$$

$$\Rightarrow \alpha(1+\beta).$$

$$\boxed{\alpha = \frac{\beta}{1+\beta}}$$

O/p current in common-emitter amplifier:-

From CB, $I_C = \alpha I_E + I_{CBO}$.

From the transistor current eqn

$$I_E = I_C + I_B$$

$$I_C = \alpha (I_B + I_C) + I_{CBO}$$

$$I_C = \alpha I_B + I_C . \alpha + I_{CBO}$$

$$I_C - \alpha I_C = \alpha I_B + I_{CBO}$$

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$$

$$I_C = \beta I_B + \underbrace{\frac{1}{1-\alpha} I_{CBO}}_{I_{CEO}} \rightarrow (1)$$

$$I_C = \beta . I_B + I_{CEO}$$

From $\beta = \frac{\alpha}{1-\alpha}$, $\frac{1}{1-\alpha} = \frac{\beta}{\alpha}$.

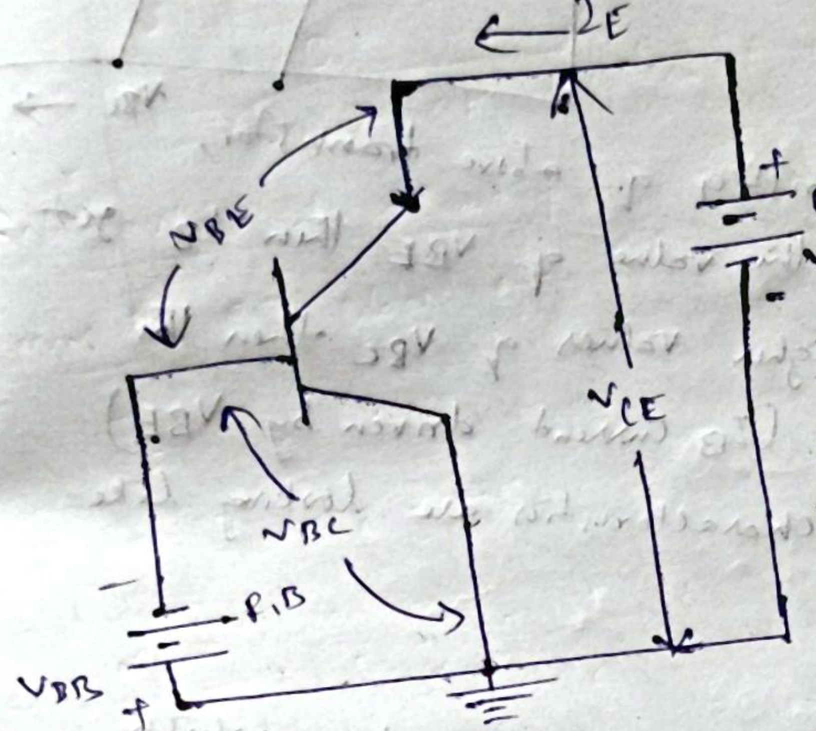
$$\frac{1}{1-\alpha} = \frac{\beta}{\frac{\beta}{\beta+1}} = \frac{\beta}{1} \times \frac{\beta+1}{\beta}$$

$$\frac{1}{1-\alpha} = \beta + 1$$

From (1), $I_C = \beta . I_B + (\beta + 1) I_{CBO}$.

## Common - Collector

- The collector terminal of the PNP transistor, connected as common for both i/p & o/p known as CC configuration as shown in below circuit.




**i/p parameters**

$I_B \rightarrow$ i/p current

$V_{BC} \rightarrow$ i/p voltage

o/p:- $V_{CE}$ - o/p voltage

$I_E$ = o/p current.

- The above transistors operate in active region to provide input side junction is a forward bias and output side junction is a reverse bias, then it amplifies the weak signal into the strength signal, as mentioned in the waveforms.

- **Input characteristics:-**

- The performance curve is plot b/w $V_{BC}$ against $I_B$, where the output voltage is kept constant.

From the ckt:-

$V_{CE} = V_{BC} + V_{BE}$

$V_{BE} \propto I_B \Rightarrow V_{BE} \propto \frac{1}{V_{BC}}$

$V_{BE} = V_{CE} - V_{BC}$.

put, $V_{CE} = 3V$

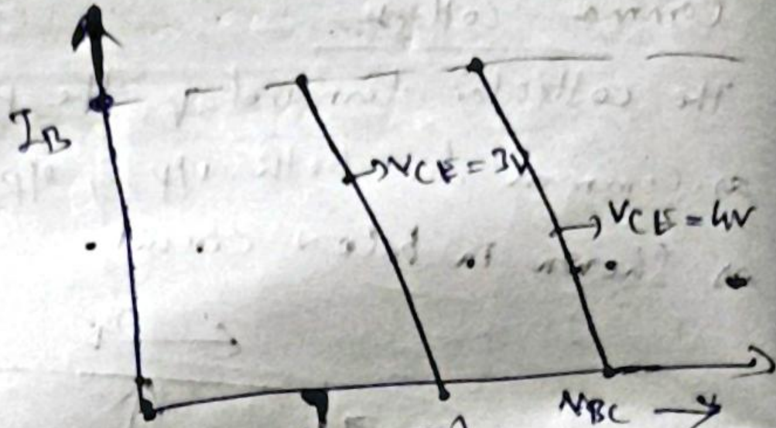
$V_{BC}$

$V_{BE} = 3 - 0 = 3$

$V_{BE} = 3 - 1 = 2$

$V_{BE} = 3 - 2 = 1$

$V_{BE} = 3 - 3 = 0$.




from the i/p characteristics of above transistor, we need to change the value of $V_{BE}$ then $I_B$ get charged. For the higher values of $V_{BC}$ then the lower values of $I_B$ ($I_B$ current driven by $V_{BE}$). So that the i/p characteristics are looking like non-linear.

Input resistance :-

- It is obtained from i/p characteristics, which defined as the ratio of change in input voltage to the change in i/p current.

output characteristics :-

- Performance curve is plot b/w $V_{CE}$ against $I_E$ where the $I_B$ kept constant and to be o/p characteristics as shown in below:-

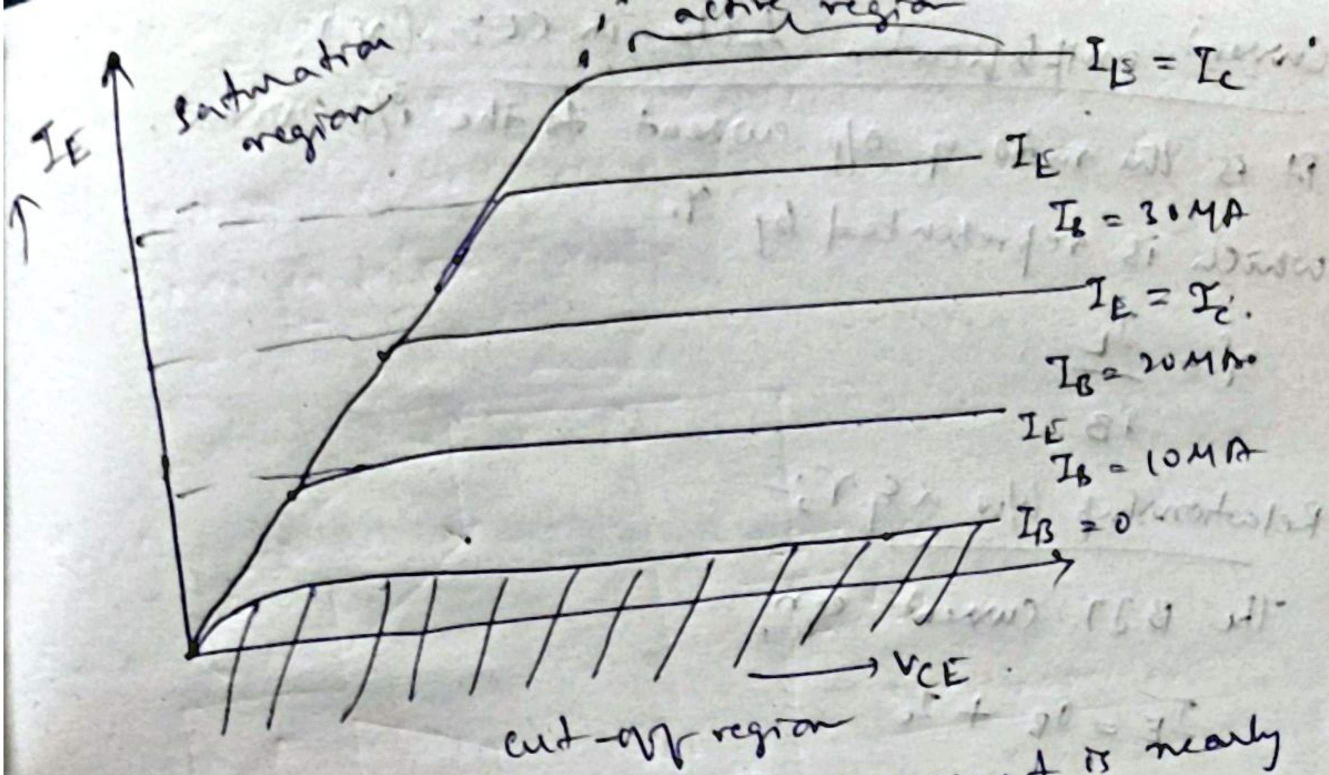
from CE,

$$I_C = \beta . I_B$$

WKT, $I_C = \alpha I_E \Rightarrow I_E \simeq I_C$

Initially, $I_B = 0$, $I_C = 0$.

$$I_E \simeq I_{CBO}.$$




From the o/p characteristics, the o/p current is nearly equal to collector current to perform the graph for o/p parameters i.e. $V_{CE}$ v/s $I_E$, we need to keep $I_E$ constant. These characteristics are similar to o/p characteristics of CE config.

- In the above graph, there'll be a small change in i/p current and the large changes obtained in o/p current as shown in above.

<u>output resistance</u>:-

- It is the ratio of change in output voltage to the change in o/p current

$$R_0 = \frac{\Delta V_{CE}}{\Delta I_E}\Big|_{I_B \to \text{const}}.$$

Current amplification factor in CC :- ($\gamma$).

It is the ratio of o/p current to the i/p current. which is represented by $\gamma$.

$$\gamma = \frac{I_E}{I_B}.$$

Relationship b/w $\alpha$ & $\gamma$ :-

The BJT current eqn,

$$I_E = I_B + I_C$$

$$I_B = I_E - I_C \longrightarrow (1)$$

WKT, $\gamma = \frac{I_E}{I_B}$ and $\alpha = \frac{I_C}{I_E}$

$$\gamma = \frac{I_E}{I_E - I_C} \quad (\because \text{from } (1)).$$

$$\gamma = \frac{1}{\frac{I_E}{I_E} - \frac{I_C}{I_E}}$$

$$\gamma = \frac{1}{1-\alpha}$$

$$\boxed{\therefore \gamma = \frac{1}{1-\alpha}}$$

$$\gamma(1-\alpha) = 1.$$

$$\gamma - \gamma_\alpha = 1$$

$$-\gamma_\alpha = 1 - \gamma$$

$$\alpha = \frac{\gamma - 1}{\gamma}$$

Relationship b/w $\gamma$ and $\beta$:-

WKT,

$$\gamma = \frac{I_E}{I_B} \text{ and } \beta = \frac{I_C}{I_B}$$

$$I_E = I_B + I_C$$

$$\gamma = \frac{I_B + I_C}{I_B} = \frac{I_B}{I_B} + \frac{I_C}{I_B}$$

$$\boxed{\gamma = 1 + \beta}$$

$$\boxed{\beta = \gamma - 1}$$

from CB config,

$$I_C = \alpha I_E + I_{CBO} \longrightarrow (1)$$

we know that, $I_E = I_C + I_B$

$$I_E = \alpha I_E + I_{CBO} + I_B \quad (\because \text{from } (1)).$$

$$I_E - \alpha I_E = I_{CBO} + I_B.$$

$$I_E (1 - \alpha) = I_B + I_{CBO}.$$

$$I_E = \frac{1}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}.$$

$$I_E = \gamma I_B + \gamma I_{CBO}.$$

$$I_E = \gamma (I_B + I_{CBO}).$$

$$\gamma - \gamma_\alpha = 1$$

$$-\gamma_\alpha = 1 - \gamma$$

$$\boxed{\alpha = \frac{\gamma - 1}{\gamma}}$$