Course Code	Course Title						Core / Elective
ISL24UES104EC	**BASIC ELECTRICAL ENGINEERING (Common to all B.E. Course)**						
Prerequisite	Contact Hours Per Week				CIE	SEE	Credits
	L	T	D	P	**40**	**60**	
	3	**1**	**-**	**-**			**4**

Course Objectives:

1. To understand the behavior of different circuit elements R,L&C and the basic concepts of electrical AC circuit analysis.
2. To comprehend the basic principle of operation of AC and DC machines
3. To infer about different types of electrical wires and cables, domestic and industrial wiring safety rules and methods of earthing.

Course Outcomes: After completion of this course, the Student will be able to:

1. Understand the concept of kirchhof's laws and their applications, various Theorems to get solution of simple DC circuits.
2. To predict the steady state response of RLC circuits with AC single phase/ three phase supply.
3. To comprehend the working principles of single phase transformers.
4. Describe the construction, working principle of DC machines and 3-phase induction motor.
5. Acquire the knowledge of electrical wires, cables, earthing, electrical safety precautions in electrical installation and electric shock and energy calculation.

UNIT-I:

D.C. Circuits: Basic cicuit concepts, Electrical circuit elements (R, L and C), voltage and current sources, Source transformation, voltage –current relationship for passive elements kirchoff's current and voltage laws, series-parallel combinations, Superposition, Thevenin's and Norton's Theorems.

UNIT-II:

A.C Circuits: Representation of sinusoidal waveforms, peak and RMS values, phasor representation, Impedance Triangle, real power, reactive power, apparent power, power factor.Analysis of single-phase AC circuits consisting of R, L, C and RL, RC and RLC combinations (series only), . Three-phase balanced circuits, voltage and current relations in star and delta connections.

UNIT-III:

Transformers & Induction Motors:

Transformers: Construction, working principle, EMF equation, Ideal and practical transformer, Equivalent circuit of Transformer, OC & SC tests on a Transformer , Losses, efficiency and voltage regulation, Auto Transformer and three-phase transformer connections.

Induction motors: Construction and principle of operation of single phase Induction Motor, Split phase, capacitor start &capacitor run motor, construction and principle of operation of 3 phase induction motor, Applications.

UNIT-IV:

DC Machines:

DC Generators: Construction and principle of operation, EMF equation, Classification, characteristics of shunt generators, Applications.

DC Motors: Principle of operation of DC Motor, Classification , Torque equation, characteristics, speed control of DC shunt and series motors, Losses & Efficiency, Applications.

UNIT-V:

Electrical Installations: Components of LT Switchgear: Switch Fuse Unit (SFU), MCB, ELCB, MCCB, Types of Wires and Cables, Earthing. Types of Batteries, Important Characteristics for Batteries. Elementary calculations for energy consumption, power factor improvement and battery backup, tariff, types of tariff.

Text Books:

1. L.S. Bobrow, Fundamentals of Electrical Engineering, Oxford University Press, 2011
2. E.Hughes, Electrical and Electronics Technology, Pearson, 2010

Suggested Reading:

1. N.K. De, ―Basic Electrical Engineering‖, Universities Press, 2015.
2. J.B. Gupta, ―Fundamentals of Electrical Engineering and Electronics‖ S.K. Kataria & Sons Publications, 2002.
3. J.B. Gupta, ―Utilization of Electric Power and Electric Traction‖ S.K. Kataria & Sons Publications, 2010.
4. Abhijit Chakrabarti, Sudipta Nath, Chandan Kumar Chanda, ―Basic Elactrical Engineering‖ Tata McGraw Hill, Publications,2009.
5. V.D.Toro, “Electrical Engineering Fundamenals”, Prentice hall India,1989
6. D.P. Kothari & I.J. Nagartah, “basic Electrical Engineering”, Tata McGraw Hill,2010

Ch1: DC Circuits

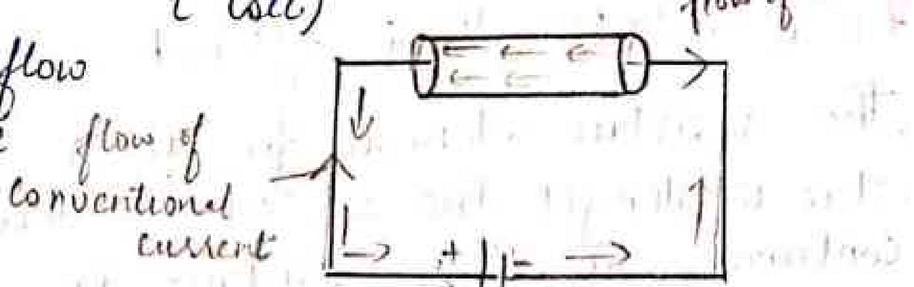
1. **Electricity** The flow of electrons in a closed circuits to do work.

2. **Electric Current** The continuous movement of free electron in an electric circuit from -ive terminal of the cell to +ive terminal through external circuit.

$$\text{current} = \frac{q\ (\text{coulomb})}{t\ (\text{sec})} = \text{Ampere}.$$

or

It is the rate of flow of electrons or charge flowing per sec.



3. **Electric potential** The capacity of a charged body to do work

$$V = \frac{\text{Work done}}{\text{Charge}} = \frac{W\ (\text{Joule})}{Q\ (\text{coulomb})} = \text{Volts}$$

4. **OHM's Law** Keeping the physical condition & temp. of conductor etc as constant, current flowing between any two points of a conductor is directly prop. to potential difference across them. R is in ohm.

$$I \propto V$$

$$\frac{V}{I} = \text{Constant} \qquad V = IR \qquad I = \frac{V}{R}$$

5. **Limitation of OHM's law**

This law is not applicable to.

1. Non linear element such as electric arc, powdered carbon, thyrite etc.
2. Unilateral Networks such as electronic tubes & diode (transistor as these elements are not bilateral)

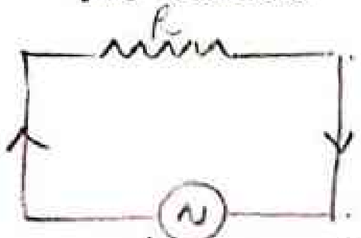
6. **Electric Power** The rate at which work is done in an electrical circuit

$$P = \frac{\text{Work done}}{\text{time}} = \frac{VIt}{t} = VI \qquad W = VQ = VIt$$

1. **Circuit** It is a closed path through which current flow.

2 types

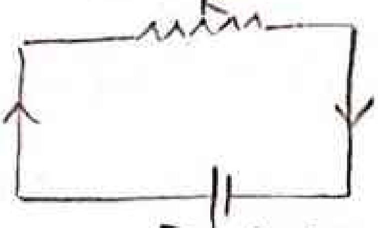
AC Circuit



AC source (generator)

Current and Voltage changes w.r.t to time $f = 50Hz$

DC Circuit



DC source (battery)

$f = 0$

Voltages and current remain constant.

8. **Linear and Non linear element**

The resistive elements for which the Volt Ampere characteristics is straight line are called linear and the circuit containing only linear resistance are called linear circuits.

The resistive elements for which the Volt Ampere characteristic is not straight line are called non linear elements and the circuit containing non linear element are called non linear circuit eg. tungsten lamps, vacuum tubes & transistor etc

9. **Unilateral and bilateral circuit.**

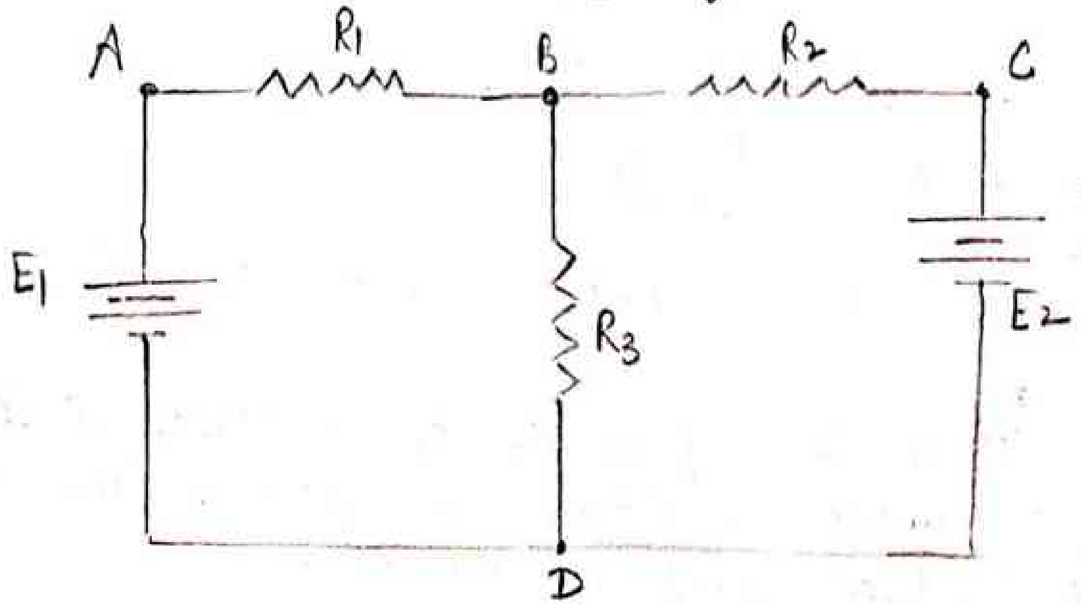
An electric circuit whose characteristic properties change with the direction of its operation (eg diode, rectifier) are called unilateral circuit.

An electric circuit whose characteristic properties remain same in either of direction (eg. distribution or transmission lines) are called bilateral circuits.

10. **Active and passive element**

Those element which receives energy are called ~~active~~ passive element eg Resistor, inductor and capacitor eg (R_1, R_2, R_3) (2)

Those element which supplies energy to circuit is called active element and network having active element is called active network eg any source (ac or dc) eg (E_1, E_2)



11. Node A node is a point in network where two or more circuit element are joined eg A, B, C & D

12. Junction A point in the network where 3 or more element joined eg B.

13. Branch Part of network which lies b/w the 2 circuit joint DAB . BCD

14. Loop The closed path of network is called loop. (ABDA, BCDA) → (ABCDA)

15. Mesh The loop which can't be further divided is called mesh ABDA and BCDB are 2 mesh but ABCDA is loop

* Series and parallel circuit.
(Numericals)

1. Electrical Circuit element (R, L and C)

1. **Resistance**: The opposition offered to the flow of current

$$R = \frac{V}{I} \quad \text{or} \quad R = \rho\frac{l}{a} \quad \text{unit: ohm}$$

$$P(\text{Power absorbed by resistor}) = VI = IR \times I = I^2R$$

or

$$= V \times \frac{V}{R} = \frac{V^2}{R}$$

$$W(\text{energy lost in the form of heat}) = \int_0^t P \cdot dt = \int_0^t I^2R\,dt = I^2Rt \text{ or } \frac{V^2}{R}t$$

2. **Inductance**: It is the property of a material by the virtue of which a change in electric current through it induces emf in conductor.

$$V = L\frac{di}{dt} \quad \text{or} \quad i = \frac{1}{L}\int V\,dt + i_0$$

(i_0 = initial current.)

$$\text{Power absorbed} = V \times I = L\frac{di}{dt} \times i = Li\frac{di}{dt}$$

$$\text{Energy absorbed by inductor} = \int_0^t P\,dt = \int_0^{t=i} Li\frac{di}{dt} \times dt = \frac{1}{2}Li^2$$

3. **Capacitance** The capability of an element to store electric charges with in it.

$$C = \frac{Q}{V} \text{ - 1} \qquad i = \frac{dq}{dt} \text{ - 3} \qquad dq = i\,dt$$

$$Q = CV \text{ - 2}$$

$$i = \frac{d(CV)}{dt} = C\frac{dv}{dt} \quad \text{and} \quad V = \frac{1}{C}\int i\,dt + V_0$$

(V_0 = Initial Voltage)

$$\text{Power absorbed} = P = VI = C\frac{dV}{dt} \times V = CV\frac{dV}{dt}$$

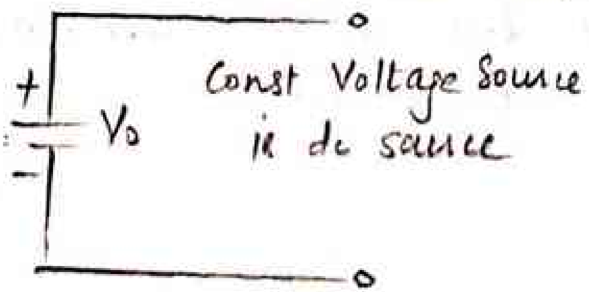
$$\text{Energy stored } W = \int_0^t P\,dt = \int_0^t CV\frac{dv}{dt} \times dt = \int_0^V CV\,dV = \frac{1}{2}CV^2$$

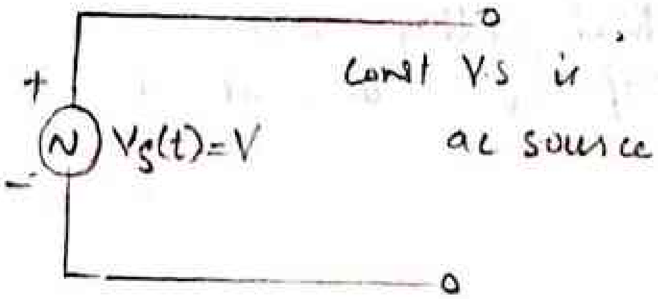
Since at steady state i_0 in inductor and V_0 in capacitor are zero hence energy consumed is zero for both inductor and capacitor in steady state.

A Voltage and current sources / (Energy Sources) V. Imp.

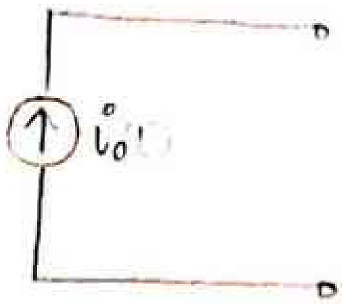
1. Independent Ideal Voltage source
2. Independent Ideal current source
3. Dependent or controlled Voltage sources
4. Dependent or controlled current Sources
5. Real or Non ideal voltage sources
6. Real or Non ideal current sources.

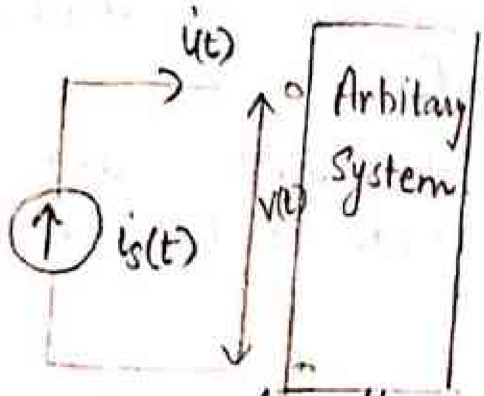
1. IIVS: That maintain as constant terminal Voltage no matter how much current is drawn from it.



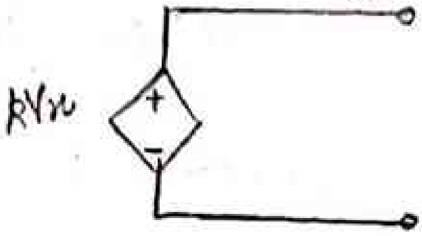


2. IICS: That supply the same current to any resistance connected across it terminal and is independent of Voltage at source terminal.



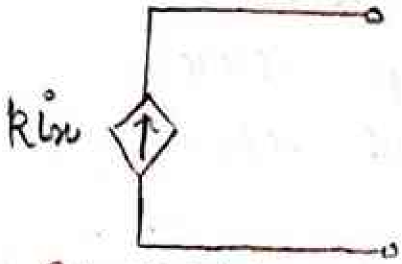


3. Dependent or controlled Voltage source: A voltage source whose Vs(t) depends on the Value of some other Variable either Voltage or current at some other point in the circuit is dependent Voltage source.

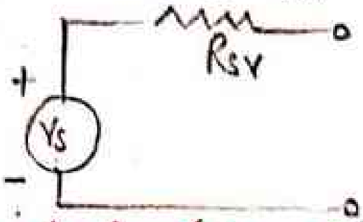


4. Dependent or controlled current source

A current source whose $i_s(t)$ depend on the value of some other variable (either Voltage or current) at some other point in circuit is dependent current source



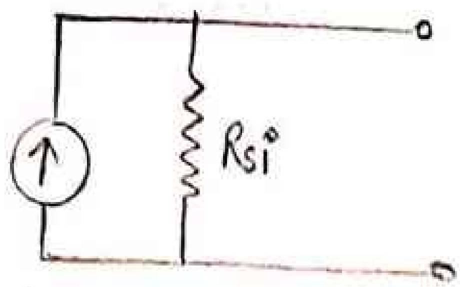
5. Real or Non Ideal Voltage source An non-ideal Voltage source ~~cannot be constructed~~
& Real voltage source has small but finite resistance R_{sv}.
* if $R_{sv} = 0$ then it become an ideal source.



6. Real or non ideal current source

An ideal current source ~~emf~~ cannot be constructed
∴ real current Is source always has some internal resistance R_{si}

if $R_{si} = \infty$ then such current source become ideal current source.

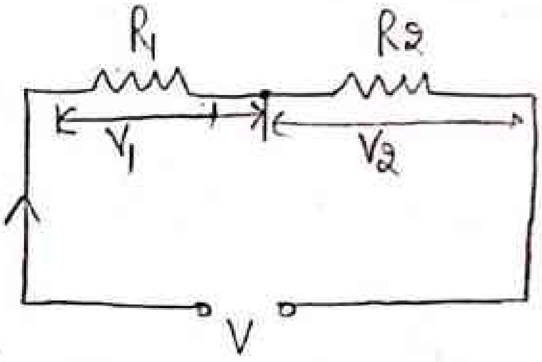


* Can we convert Voltage source into current source and vice versa.

sln Yes

18. Voltage division b/w 2 resistors

Total current $I = \frac{V}{(R_1+R_2)}$



By ohm's law

$V_1 = R_1 I$

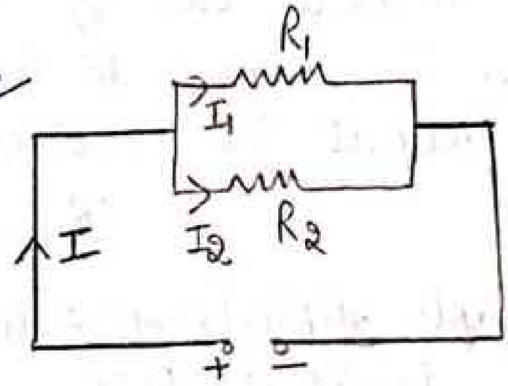
$V_1 = R_1 \times \frac{V}{(R_1+R_2)}$

$V_2 = R_2 I$

$= V \times \frac{R_2}{(R_1+R_2)}$

19. Current division equation

I = Total current R_P = Total Resistance



$R_P = \frac{R_1 \times R_2}{R_1 + R_2}$

$I = \frac{V}{R_P}$ $I_1 = \frac{V}{R_1}$ $I_2 = \frac{V}{R_2}$

So. $\frac{I_1}{I} = \frac{V}{R_1} \times \frac{R_P}{V} = \frac{R_P}{R_1} = \frac{R_1 \times R_2}{R_1(R_1+R_2)} = \frac{R_2}{(R_1+R_2)}$

$I_1 = \frac{R_2}{(R_1+R_2)} \times I$

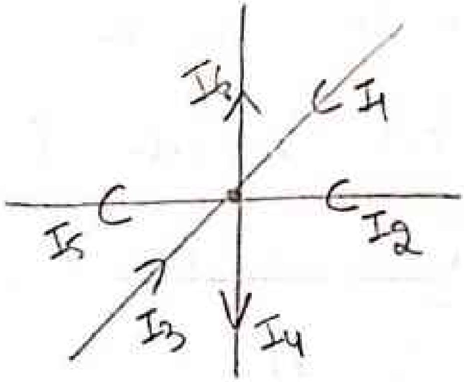
||ly $I_2 = \frac{R_1}{(R_1+R_2)} \times I$.

20. Kirchhoff Current law (KCL or Point law) V.Imp

The algebraic sum of all current meeting at a junction or a point is zero or sum of incoming current towards the junction is equal to sum of outgoing current away from the junction.

(Kirchoff's first law / KCL / Point law)

$$\sum I = 0$$



Here I_1, I_2, I_3 are incoming current

I_4, I_5, I_6 are outgoing current

$$I_1 + I_2 + I_3 - (I_4 + I_5 + I_6) = 0$$

in → +ive

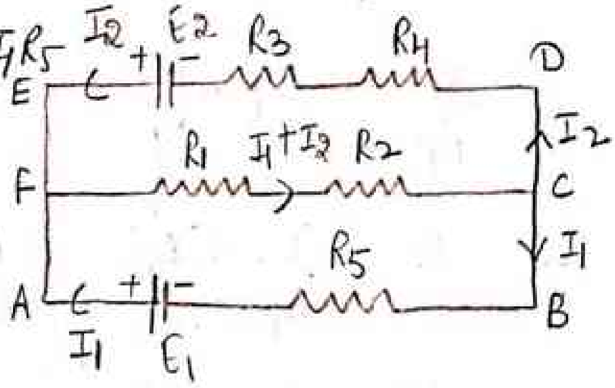
out → −ive

21. Kirchhoff's Voltage law V. Imp

Kirchhoff's second law / KVL / mesh law.

The algebraic sum of emf's acting in that circuit or mesh is equal to the algebraic sum of the products of current and resistance of each part of circuit.

$$\sum IR = \sum emf$$



example. AFCBA: $E_1 = (I_1+I_2)R_1 + (I_1+I_2)R_2 + I_1R_5$

$E_1 = (I_1+I_2)(R_1+R_2) + I_1R_5$

FEDCF: $-E_2 = -I_2R_3 - I_2R_4 - (I_1+I_2)(R_1+R_2)$

$E_2 = I_2(R_3+R_4) + (I_1+I_2)(R_1+R_2)$

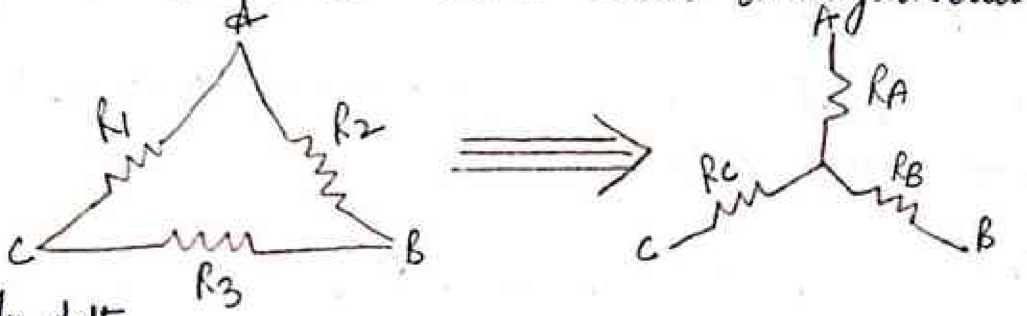
In mesh $E_1 - E_2 = I_1R_5 - I_2(R_3+R_4)$

22. Delta star Transformation V. Imp

The equivalent star resistance connected to given terminal is equal to product of two delta resistance connected to the same terminal divided by sum of delta connected resistance.

$$R_A = \frac{R_1 R_2}{R_1+R_2+R_3} \qquad R_B = \frac{R_2 \times R_3}{R_1+R_2+R_3} \qquad R_C = \frac{R_3 \times R_1}{R_1+R_2+R_3}$$

The replacement of delta or mesh by equivalent star s/s is known as delta star transformation.



In delta

Resistance $R_{BC} = R_3 \parallel (R_1 + R_2)$

So $R_{BC} = \dfrac{R_3(R_1+R_2)}{R_3+R_2+R_1}$ In Delta system. — 1

$R_{BC} = R_B + R_C$ In star system — 2

Delta R_{BC} $\equiv$ Star R_{BC} from 1 and 2

$$\frac{R_3(R_1+R_2)}{R_3+R_2+R_1} = R_B + R_C \quad — (3)$$

IIly $R_C + R_A = \dfrac{R_1(R_2+R_3)}{R_1+R_2+R_3}$ — (4) IIly $R_A + R_B = \dfrac{R_2(R_1+R_3)}{R_1+R_2+R_3}$ — (5)

Now Add 3, 4 and 5

$$2(R_A+R_B+R_C) = 2\left(\frac{R_1R_3+R_2R_3+R_1R_2}{R_1+R_2+R_3}\right) \text{ from 3 eq.}$$

$$R_A+R_B+R_C = \frac{R_1R_3+R_2R_3+R_1R_2}{R_1+R_2+R_3} \quad — 6$$

Put value $R_B + R_C$ from 3 in eq 6

$$R_A + \frac{R_3R_1+R_3R_2}{R_1+R_2+R_3} = \frac{R_1R_3+R_2R_3+R_1R_2}{R_1+R_2+R_3}$$

$$\text{So } R_A = \frac{R_1R_3+R_2R_3+R_1R_2-R_3R_1-R_3R_2}{R_1+R_2+R_3} = \frac{R_1R_2}{R_1+R_2+R_3}$$

IIly $R_B = \dfrac{R_2R_3}{R_1+R_2+R_3}$ $\quad R_C = \dfrac{R_3R_1}{R_1+R_2+R_3}$

if $R_1 = R_2 = R_3 = R$ $\quad R_C = \frac{R^2}{3R} = \frac{R}{3}$

23: Star Delta Transformation

The replacement of star by its equivalent delta system is known as star delta transformation.

The equivalent delta resistance between two terminal is the sum of 2 star resistance connected to those terminal plus the product of same divided by the 3rd star resistance

$$R_1 = R_A + R_C + \frac{R_A R_C}{R_B} \qquad R_2 = R_A + R_B + \frac{R_A R_B}{R_C} \qquad R_3 = R_B + R_C + \frac{R_B R_C}{R_A}$$

In star $R_A R_B + R_B \times R_C + R_C \times R_A$

$$= \left(\frac{R_1 R_2}{R_1+R_2+R_3} \times \frac{R_2 R_3}{R_1+R_2+R_3}\right) + \left(\frac{R_2 R_3}{R_1+R_2+R_3} \times \frac{R_3 \times R_1}{R_1+R_2+R_3}\right) + \left(\frac{R_3 R_1}{R_1+R_2+R_3} \times \frac{R_1 R_2}{R_1+R_2+R_3}\right) \quad -1$$

$$= \frac{R_1 R_2^2 R_3}{(R_1+R_2+R_3)^2} + \frac{R_1 R_2 R_3^2}{(R_1+R_2+R_3)^2} + \frac{R_1^2 R_2 R_3}{(R_1+R_2+R_3)^2} \quad -2$$

$$= \frac{R_1 R_2^2 R_3 + R_1 R_2 R_3^2 + R_1^2 R_2 R_3}{(R_1+R_2+R_3)^2} \quad -3$$

$$= \frac{R_1 R_2 R_3 (R_1+R_2+R_3)}{(R_1+R_2+R_3)^2} = \frac{R_1 R_2 R_3}{(R_1+R_2+R_3)} \quad -4$$

Divide equation-4 $R_A = \frac{R_1 R_2}{(R_1+R_2+R_3)}$

$$\frac{R_A R_B + R_B \times R_C + R_C \times R_A}{R_A} = \frac{R_1 R_2 R_3}{(R_1+R_2+R_3)} \times \frac{(R_1+R_2+R_3)}{R_1 R_2}$$

$$\frac{R_A R_B}{R_A} + \frac{R_B R_C}{R_A} + \frac{R_C R_A}{R_A} = R_3 \qquad \text{so } R_3 = R_B + R_C + \frac{R_B R_C}{R_A}$$

Illy $R_1 = \frac{R_A R_B + R_B R_C + R_C R_A}{R_B} = R_A + R_C + \frac{R_A R_C}{R_B}$

$R_2 = R_A + R_B + \frac{R_A R_B}{R_C}$

if $R_A = R_B = R_C = R$

$R = R + R + \frac{R \times R}{R} = 3R$

Numerical Three resistance r, 2r and 3r are connected in delta. Determine the resistances for an equivalent star connection.

Solution $R_A = \frac{R_1 R_2}{R_1 + R_2 + R_3}$ $R_1 = r$ $R_2 = 2r$ $R_3 = 3r$

$= \frac{r \times 2r}{r + 2r + 3r} = \frac{2r^2}{6r} = \frac{r}{3}$ Ans.

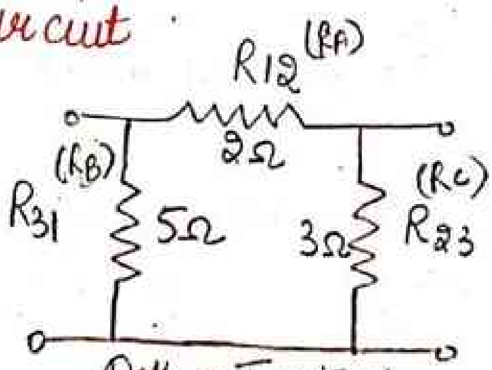
$R_B = \frac{R_2 R_3}{R_1 + R_2 + R_3} = \frac{2r \times 3r}{r + 2r + 3r} = \frac{6r^2}{6r} = r$ Ans

$R_C = \frac{R_3 R_1}{R_1 + R_2 + R_3} = \frac{3r \times r}{6r} = \frac{3r^2}{6r} = \frac{1}{2} r$ Ans.

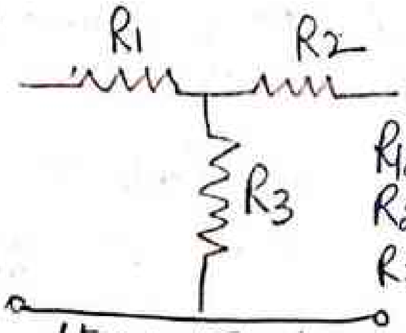
Numerical 2 Convert Π network into T equivalent and as a check convert star circuit back to its delta circuit.

Solution

$R_1 = 1\Omega$
$R_2 = 0.6\,\Omega$
$R_3 = 1.5\,\Omega$



Delta or Π network



Star or T network

$R_{12} = 2\,\Omega$
$R_{23} = 3\,\Omega$
$R_{31} = 5\,\Omega$

24. Network Theorems

Network Theorems

Superposition Theorem   Thevenin's Theorem   Norton Theorem.

Network: A network is a collection of Interconnected component (resistor, Inductor, capacitor).

Network analysis is the process of finding the voltage across, and the currents through every component in the network and the network theorem are used to calculate Voltage and current of complex network. These theorem are derived from ohm's law, KCL & KVL.

Superposition Theorem

Theorem: In a linear dc network containing more than one independent source, the overall current response (current or Voltage) in any branch is equal to algebric sum of the response due to each independent source acting one at a time with all other ideal independent sources set equal to zero.

* Ideal current source equal to zero means it is replaced by an open circuit.
* An Ideal Voltage source equal to zero means it is replaced by short circuit.

Note: It is applicable to linear, time varying and time invarient network and also applies only to independent sources.

Procedure 1. Select any one source in circuit.

2. Set all other Independent source is zero.
ie V.S = Short Circuit —o CS = open circuit o o—

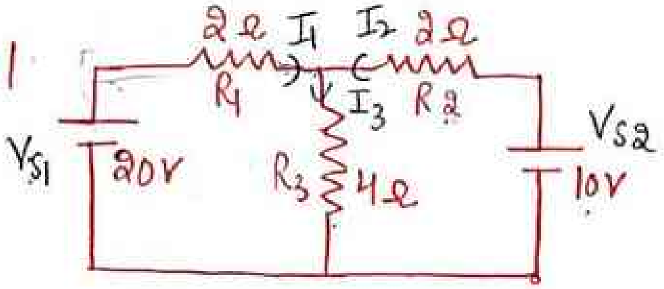
3. Keep the dependent source in circuit undisturbed.

4. Determine the magnitude and direction of current through desired branch due to single source selected.

5. Repeat step 1 to 4 for each source

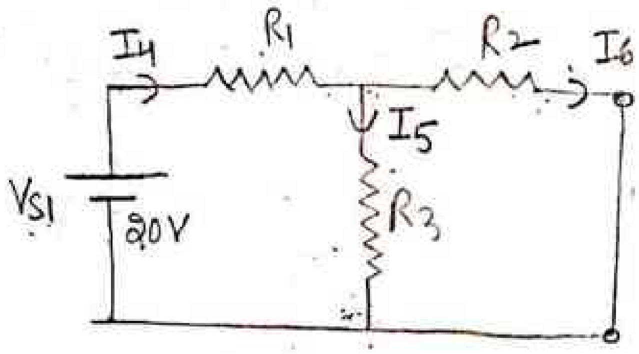
6. Add all the component of current to obtained desired brach current.

Example 1



$I_1 = +I_4 - I_9$

Solution Step 1 consider 20V source alone and 10V source is replaced by S.C



So equivalent Resistance

$$R_{23} = \frac{R_2 R_3}{R_2 + R_3} = \frac{2 \times 4}{2+4} = \frac{8}{6} = \frac{4}{3}\,\Omega$$

Total resistance

$$= R_1 + (R_2 \| R_3)$$

$$R_T = 2 + \frac{4}{3} = \frac{6+4}{3} = \frac{10}{3}\,\Omega$$

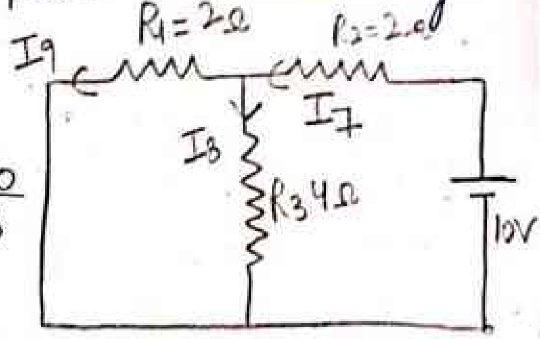
$$\text{So } I_4 = \frac{20}{R_T} = \frac{20}{10} \times 3 = 6A$$

The current I_5 and I_6 found by current divider Theorem.

$$I_5 = I_4 \times \frac{R_2}{R_2 + R_3} = 6 \times \frac{2}{2+4} = \frac{12}{6} = 2A$$

$$I_6 = I_4 \times \frac{R_3}{R_2 + R_3} = 6 \times \frac{4}{4+2} = 6 \times \frac{4}{6} = 4A$$

Step 2 Now considered 10V source and Replace 20V source by SC



here $(R_1 \| R_3) + R_2 = R_T$

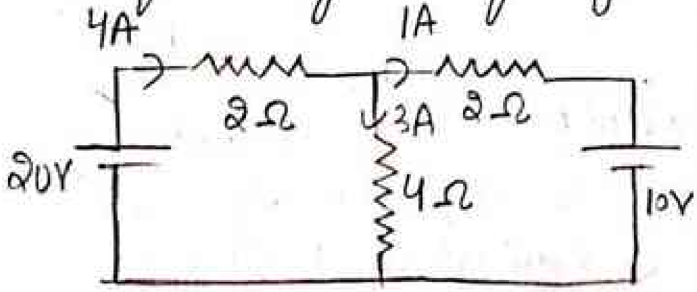
$$R_T = \left(\frac{2 \times 4}{2+4}\right) + 2 = \frac{8}{6} + 2 = \frac{12+8}{6} = \frac{20}{6} = \frac{10}{3}$$

So $I_7 = \frac{V_{sr}}{R_T} = \frac{10}{10} \times 3 = 3A$

$I_8 = \frac{R_1}{R_1 + R_3} \times I_7 = \frac{2}{2+4} \times 3 = \frac{6}{6} = 1A$

$I_9 = \frac{R_3}{R_1 + R_3} \times I_7 = \frac{4}{4+2} \times 3 = \frac{12}{6} = 2A$

Step 3 According to Theorem.
The current through any branch is found by taking algebric sum of current through it.

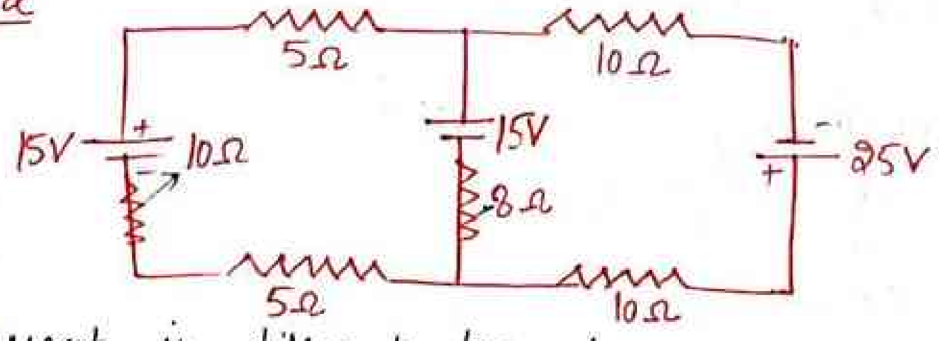


So $I_1 = I_4 - I_9 = 6 - 2 = 4A$

$I_2 = I_7 - I_6 = 3 - 4 = -1A$

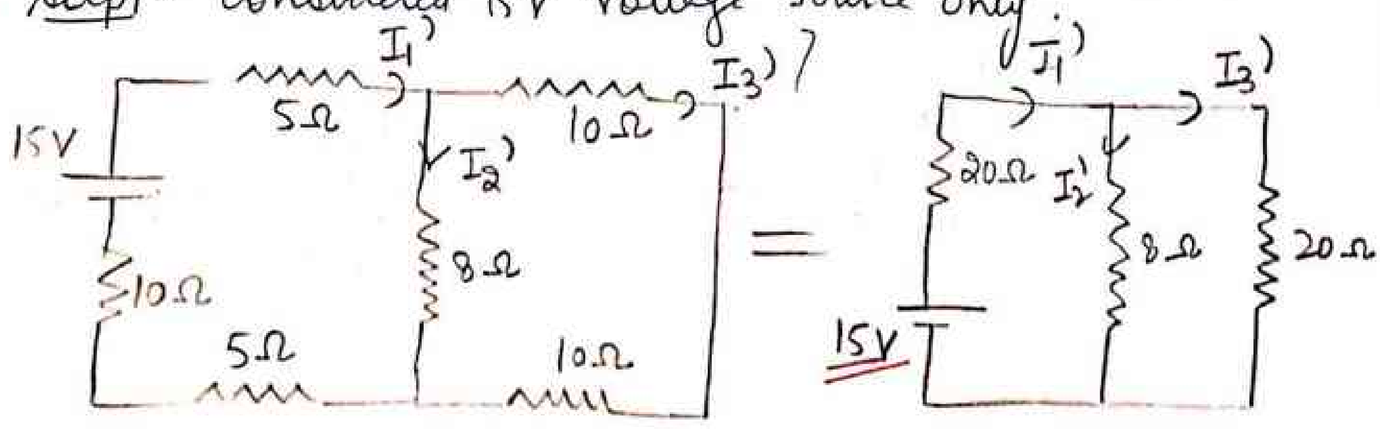
$I_3 = I_5 + I_8 = 2 + 1 = 3A$

Numerical 2



find current in different branches.

Sol. Step 1st Considered 15V voltage source only



Total Resistance $R_T = 20 + (8 \| 20) = 25.714\ \Omega$

Current $I_1' = \frac{15}{25.714} = 0.5833\ A$

So $I_2' = \frac{20}{28} \times 0.5833 = 0.4167\ A$

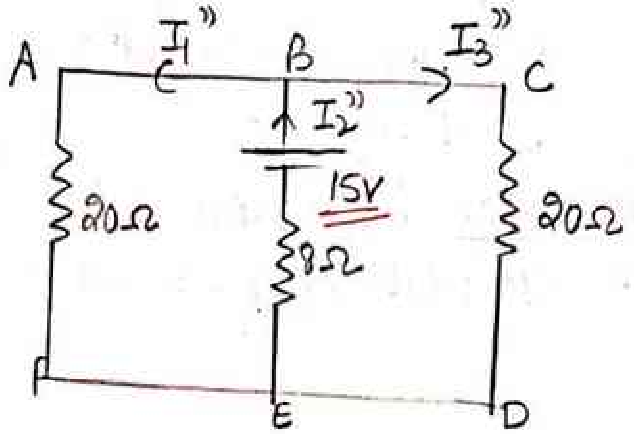
$I_3' = \frac{8}{28} \times 0.5833 = 0.1666\ A$

Step 2 (2nd source) Total $R_T = 8 + \frac{20 \times 20}{20+20} = 18\Omega$

$I_2'' = \frac{15}{18} = 0.8333 A$

So $I_1'' = 0.8333 \times \frac{20}{40} = 0.4167 A$

$I_3'' = 0833 \times \frac{20}{40} = 0.4167 A$

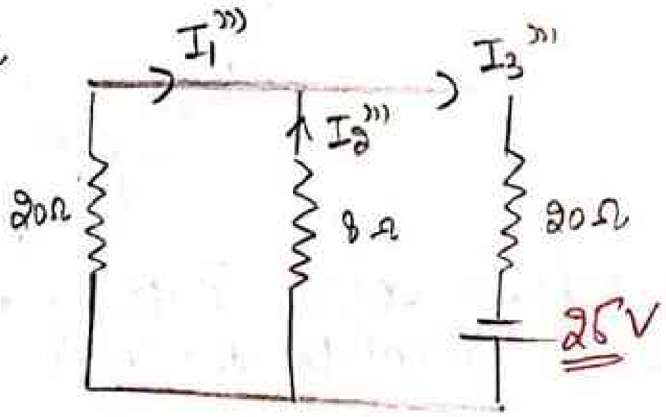


Step 3 (3rd source) $R_T = 20 + \frac{20 \times 8}{28} = 25.714\ \Omega$

$I_3''' = \frac{25}{25.714} = 0.9722$

$I_2''' = 0.9722 \times \frac{8}{28} = 0.2778\ A$

$I_2'' = 0.9722 \times \frac{20}{28} = 0.6944\ A$



Step 4 Overall current in each branch.

$I_1 = I_1' - I_1'' + I_1''' = 0.444\ A$

$I_2 = -I_2' + I_2'' + I_2''' = 1.111\ A$

$I_3 = I_3' + I_3'' + I_3''' = 1.555 A$

Thevenin's Theorem

It state that the current flowing through a resistor connected across any 2 terminals of a network calculated by an equivalent circuit having V.S (E_{th}) in series with a resistor (R_{th})

E_{th} = O.C Voltage b/w 2 terminal called Thevenin Voltage

R_{th} = The equivalent resistance of the network at 2 terminals.

Procedure 1. Remove the load resistance R_L

2. Calculate open circuit Voltage E_{th}/V_{th}

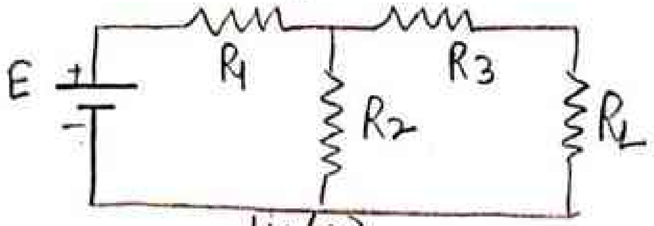
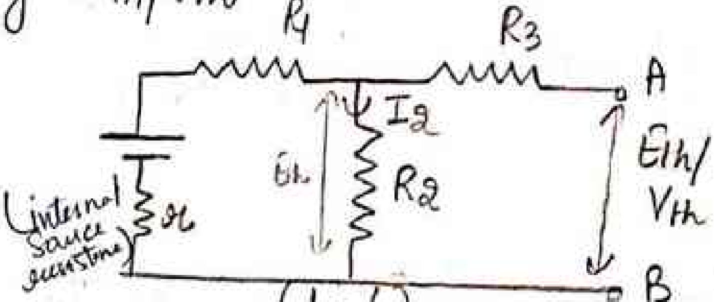


fig (a)



(fig b)

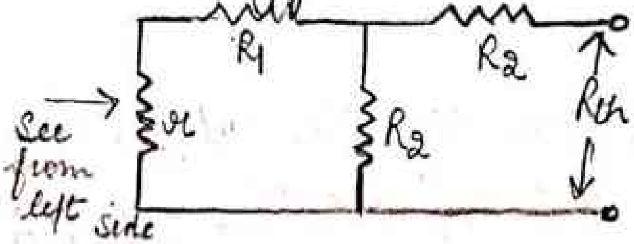
$$E_{th} = I_2 R_2$$
$$= \left(\frac{E}{r+R_1+R_2}\right) \times R_2$$

or voltage division $E_{th} = \left(\frac{R_2}{r+R_1+R_2}\right) \times E$

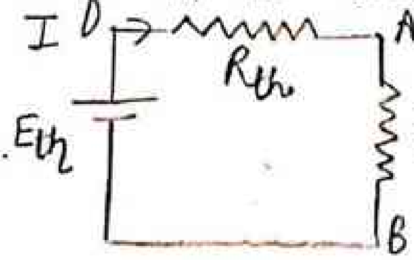
3. Replace source battery by internal source resistance and calculate the total Resistance (fig c).

So $R_{th} = ((r+R_1) \| R_2) + R_3$

$$= \frac{(r+R_1)R_2}{r+R_1+R_2} + R_3$$



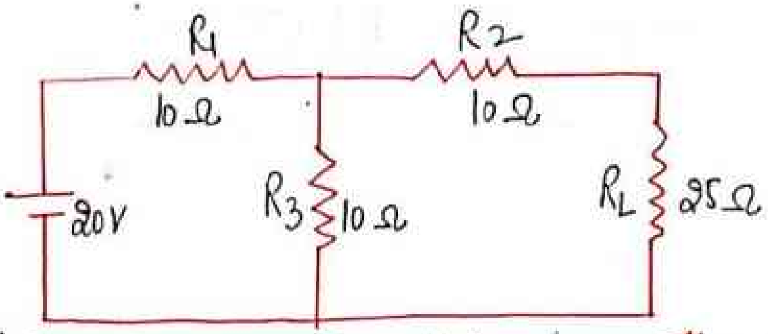
4. Replace the entire network by single thevenin voltage source having an emf E_{th} and Internal resistance R_{th} in series & connect the load R_L back to terminal AB.



$I = I_{th}$ Thevenin current

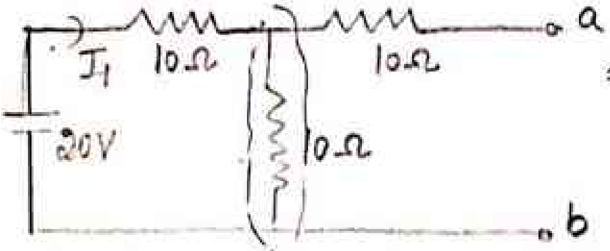
5. Calculate current through the load Resistance R_L $I_{th} = \frac{E_{th}}{R_{th}+R_L}$

Numerical 1.



Use Thevenin's Theorem to determine the current through and voltage across 25 Ω resistor.

Solution Step 1st Remove the R_L (load Resistance) 25 Ω

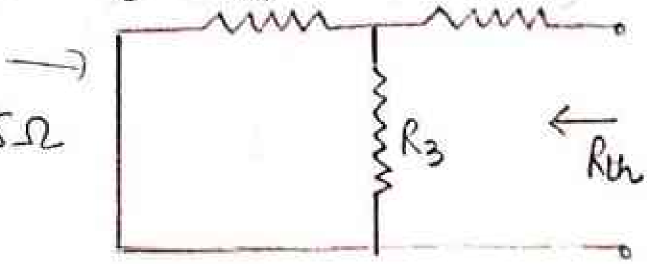


Step 2nd Determine E_{th} / V_{th}.

$$V_{ab} = R_3 \times \frac{V}{R_1 + R_3} = 10 \times \frac{20}{10+10} = 10 \times \frac{20}{20} = 10$$

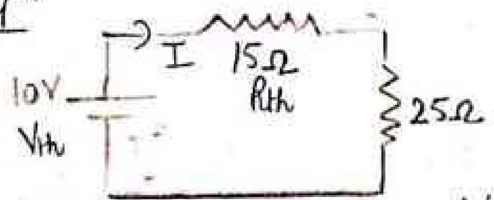
As V_{th} = open circuit voltage at ab = V_{ab} = 10V

Step 3rd Determine R_{th} for this the voltage source is short circuit.



$$R_{th} = (R_1 \parallel R_3) + R_2$$
$$= \frac{10 \times 10}{10+10} + 10 = \frac{100}{20} + 10 = 15\,\Omega$$

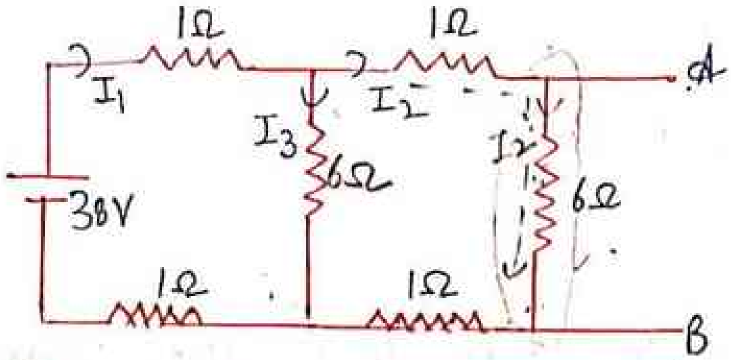
Step 4th



$$I = \frac{V_{th}}{R_{th} + R_L} = \frac{10}{15+25} = \frac{10}{40} = 0.25\,A$$

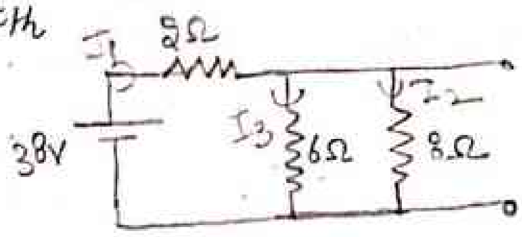
Voltage across 25 Ω Resistance
= 25 × 0.25
= 6.25 Volts.

Numerical 2:



Solve using Thevenin theorem.

Solution Step 1 Determine value of E_{th}



$$R_T = \{(1+6+1)\|6 + 1 + 1\}$$
$$= \{(8\|6) + 2\}$$
$$= \frac{8 \times 6}{8+6} + 2 = \frac{38}{7}$$

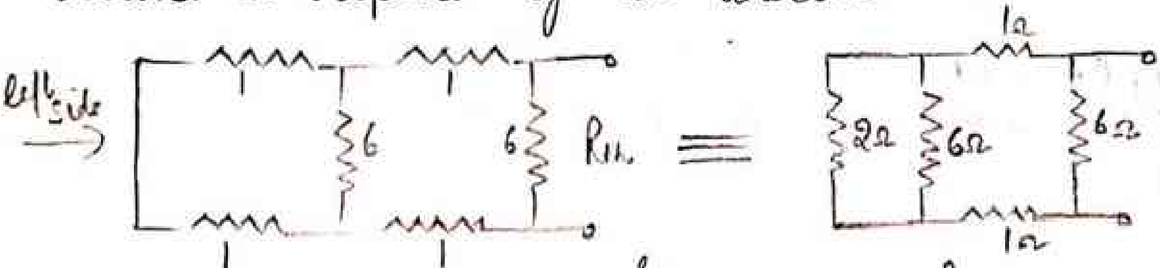
Current supplied by source $= \frac{V}{R_T} = \frac{38}{38} \times 7 = 7A$

Current in 8 Ω Resistor $= \frac{6}{6+8} \times 7 = \frac{3}{14} \times 7 = 3A$ (6 cancelled to 3, 14 to 2 and 7 to 1 in the working)

So current flow in 6 Ω Resistor connected across AB terminal $= 3A$

So thevenin Voltage $E_{th}/V_{th} = I \times R$ (across AB terminal)
$$= 3 \times 6 = 18V$$

Step 2 Thevenin's Resistance across terminal AB when source is replace by its internal resistance is short circuit.

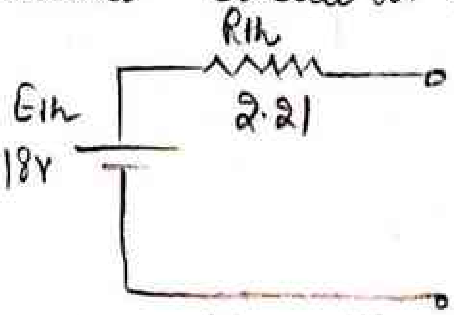


$$R_{th} = \{(2\|6) + (1+1)\|6\} \quad \{\{(2\|6)+1+1\}\|6\}$$
$$= \left(\frac{2 \times 6}{2+6} + 2\right)\|6 = \left(\frac{12}{8} + 2\right)\|6 = 3.5\|6 = \frac{3.5 \times 6}{3.5+6} = 2.21\,\Omega$$

Step 3 The Thevenin's equivalent circuit as shown in fig

$E_{th} = 18V$

$R_{th} = 2.21$

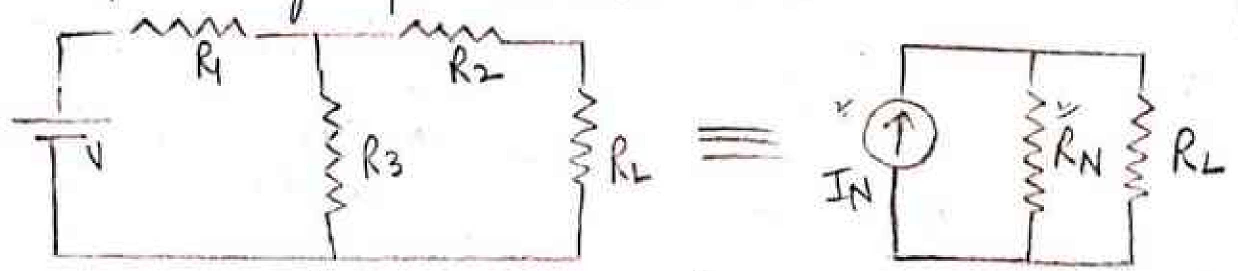


Norton's Theorem. It states that the current flowing through a resistance connected across any two terminal of a network can be determined by replacing the whole a network by an equivalent circuit of a current source having a current output I_N in parallel with resistance R_N.

I_N = Norton Current (Short circuit current supplied by the source that would flow b/w the 2 selected terminals when they S.C)

R_N = equivalent Resistance of network b/w 2 terminals.

* emf source replaced by Internal resistance and current source replaced by open circuit.

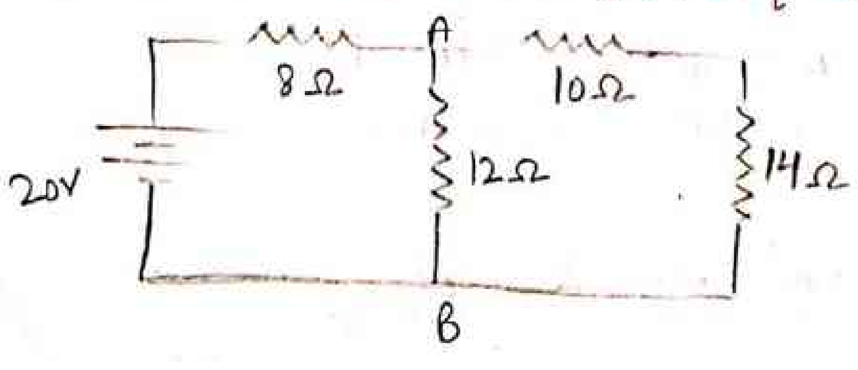


Procedure 1. Short circuit the terminal across which load resistance connected & calculate I_N (Noton current)

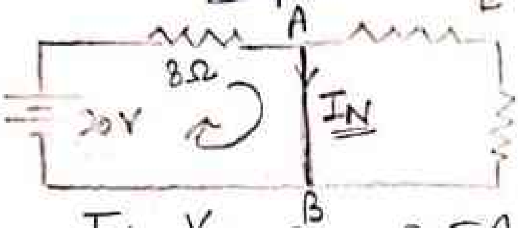
2. Redraw the network replacing each voltage source by short circuit in series with internal resistance if any and current source by open circuit in parallel with its internal resistance.

3. Determine R_N of the network and draw norton equivalent circuit as shown in fig.

Numerical 1 Using Norton theorem determine the current in 12 Ω resistor in the network shown below.

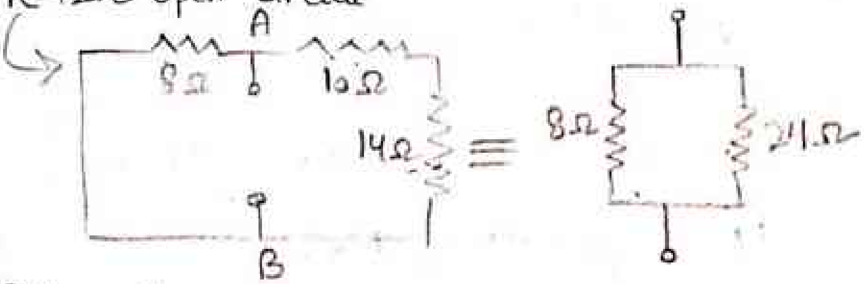


Solution **Step 1st** AB is short circuit.



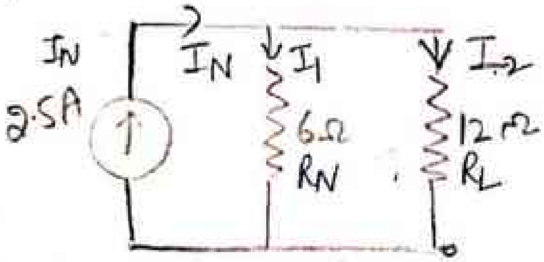
$$I_N = \frac{V}{R} = \frac{20}{8} = 2.5A$$

Step 2 Voltage source replaced by internal resistance and short circuit. Also R=12Ω open circuit



$$R_N = 8 \| (10+14) = \frac{8 \times 24}{8+24} = 6\Omega$$

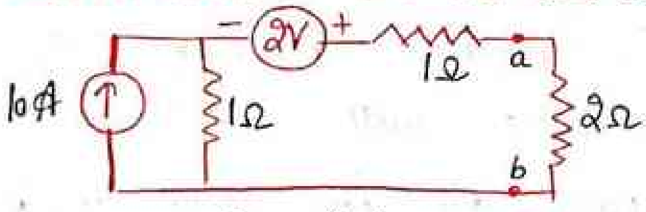
Step 3 Draw equivalent circuit.



Current flow in 12 Ω Resistor

$$I_2 = I_N \frac{R_N}{R_N + R_L} = 2.5 \times \frac{6}{6+12}$$
$$= 0.833 A$$

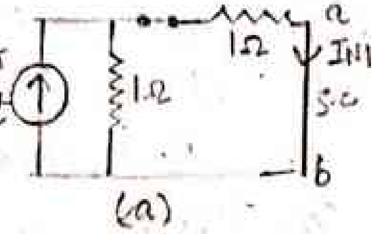
Numerical 2 Determine V across 2Ω resistor using Norton theorem.



Solution 1. Short ckt the load Resistance.

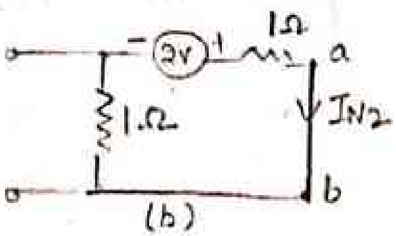
2. Consider only 10A current source in ckt V.S is short ckt

$$I_{1N} = \frac{1}{1+1} \times 10 = \frac{1}{2} \times 10 = 5A \text{ (fig a)}$$



3. Consider only 2V source. CS is open circuit.

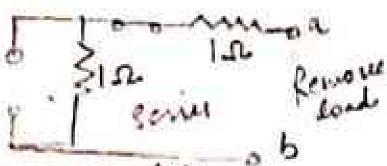
$$I_{2N} \times 1 - 2 + I_{2N} \times 1 = 0 \quad \text{or} \quad I_{2N} = \frac{V}{R} = \frac{2}{2} = 1$$
$$2I_{2N} = 2 \quad I_{2N} = 1 \quad \text{(fig b)}$$



4. Total current $I_N = I_{1N} + I_{2N} = 5 + 1 = 6A$

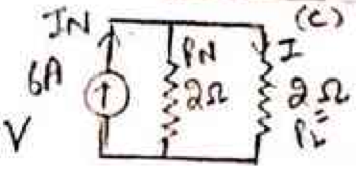
5. Calculate Norton resistance CS is O.C V.S is S.C

$$R_N = 1 + 1 = 2\Omega \quad \text{(fig c)}$$



6. Equivalent Circuit

$$I_L = I_N \times \frac{2}{2+2} = 6 \times \frac{2}{4} = 3\Omega \qquad V_L = I_L R_L$$
$$= 3 \times 2 = 6V$$

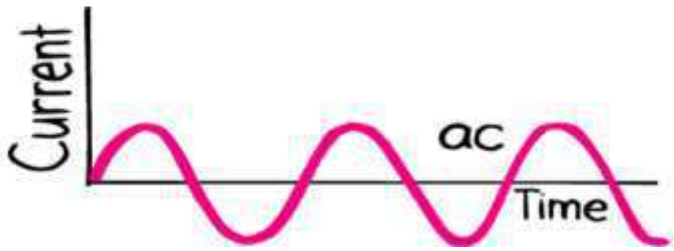


Module 2

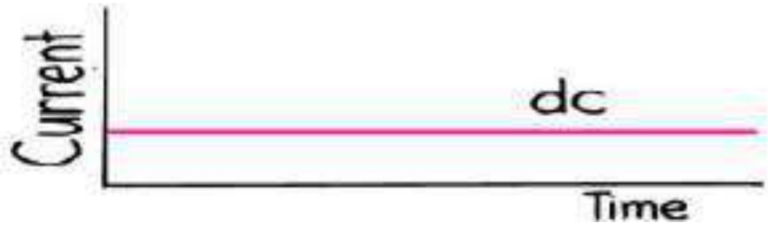
A.C. Circuits

The flow of electricity can be done in two ways like AC (alternating current) and DC (direct current). Electricity can be defined as the flow of electrons throughout a conductor such as a wire. The main disparity among AC & DC mainly lies within the direction where the electrons supplies. In direct current, the flow of electrons will be in a single direction & in the alternating current; the flow of electrons will change their directions like going forward & then going backward.

- In Alternating current, movement of electric charge periodically reverses its direction.



- Whereas in DC, flow of electric charge is only in one direction.

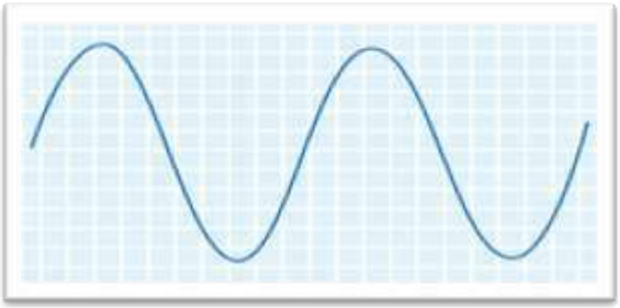


Why we use A.C. in homes

- AC voltage is capable of converting voltage levels just with use of transformers.
  - To transmit AC over a long distance, voltage is stepped up to 400 KV at generating stations and stepped down at a low level , 400/230 V for household and commercial utilization.
  - AC motors are simple in construction, more efficient and robust as compared to DC motors.

Sinusoidal Alternating Quantity:

Alternating quantity that varies according to sin of angle θ.



The instantaneous value of a sine-wave voltage for any angle of rotation is expressed in the formula:

$V = V_m \sin \theta$

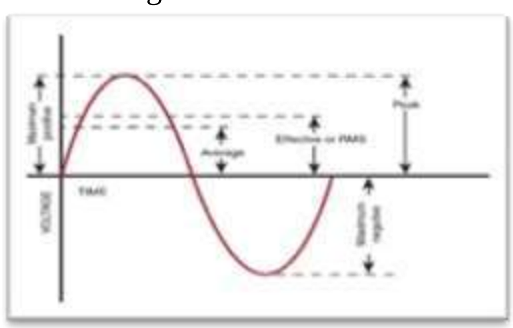
θ is the angle

Vm = the maximum voltage value

V = the instantaneous value of voltage at angle θ

Terms to know

1. Cycle: When an Alternating qty goes through complete set of positive and negative values or goes through 360 electrical degrees.



2. Alternation: One half cycle
3. Time Period: Time taken to complete one cycle by AC.
4. Frequency: No of cycle made per second.
5. Amplitude: Maximum value attained by an alternating quantity in one cycle and also called Peak Value / Max. Value

Peak and RMS Values

The magnitude of alternating quatity can be expressed in three ways:

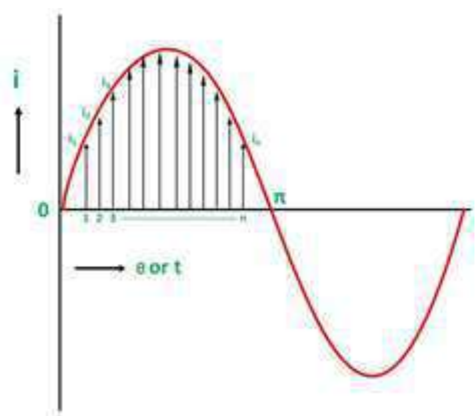
1 Peak Value
2 Average Value
3 Effective or rms value

Peak Value:

The maximum value attained by an alternating quantity during oone cycle is called peak value. This is also called maximum value or amplitude. The peak of an alternating voltage or current is represented by V_m and I_m

Average Value:

The average value of a periodic waveform whether it is a sine wave, square wave or triangular waveform is defined as: "the quotient of the area under the waveform with respect to time".
In other words, the averaging of all the instantaneous values along time axis with time being one full period, (T).
For symmetrical waves like sinusoidal current or voltage waveform, the positive half cycle will be exactly equal to negative half cycle. Therefore, the average value over a complete cycle will be zero. The work is done by both, positive and negative cycle and hence the average value is determined without considering the signs.So, the only positive half cycle is considered to determine the average value of alternating quantities of sinusoidal waves.



Divide the positive half cycle into (*n*) number of equal parts as shown in the above figure

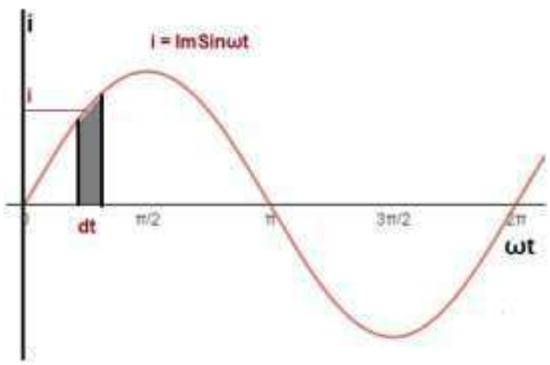
Let i_1, i_2, i_3…….. i_n be the mid ordinates

The Average value of current I_{av} = mean of the mid ordinates

$$I_{av} = \frac{i_1 + i_2 + i_3 + \dots\dots\dots + i_n}{n} = \frac{\text{Area of alternation}}{\text{Base}}$$

Derivation for average value of sinusoidal current:

Let us consider a sinusoidal current $i = I_m \sin\omega t$ as shown in the figure below. We will calculate its average value for one time period $\omega t = \pi$ from the definition of average value of alternating current.



Area of alternation = $\int_0^\pi i \, d(wt)$

$= \int_0^\pi \text{Im} \, sin \, wt \, d(wt)$

$= I_m \int_0^\pi \, sin \, wt \, d(wt)$

$= I_m [-\cos wt]_0^\Pi$

$= I_m [-(-1 - 1)]$

$= 2I_m$

Base = π

Therefore, Average value of sinusoidal current = $2Im/\pi$

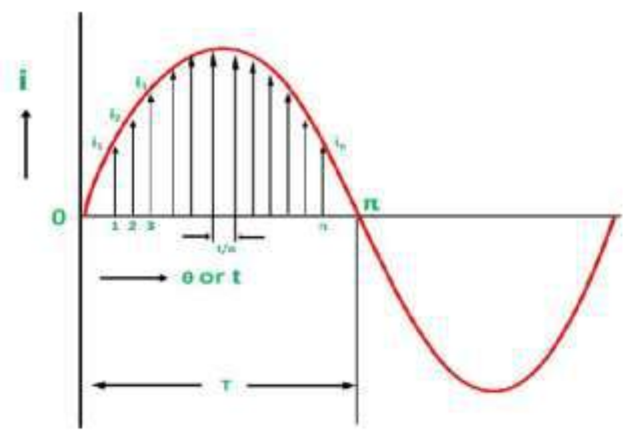
Effective or RMS Value:

"RMS" stands for "Root-Mean-Squared", also called the effective or heating value of alternating current, which would provide the same amount of heat generation in a resistor as the AC voltage would if applied to that same resistor.

That steady current which, when flows through a resistor of known resistance for a given period of time than as a result the same quantity of heat is produced by the alternating current when flows through the same resistor for the same period of time is called R.M.S or effective value of the alternating current.

In other words, the R.M.S value is defined as the square root of means of squares of instantaneous values.

Let I be the alternating current flowing through a resistor R for time t seconds, which produces the same amount of heat as produced by the direct current (I_{eff}). The base of one alteration is divided into n equal parts so that each interval is of t/n seconds as shown in the figure below.



Let i_1, i_2, i_3,………..in be the mid ordinates

Then the heat produced in

$$\text{First interval} = \frac{i_1^2 Rt}{Jn} \quad \text{calories}$$

$$\text{Second interval} = \frac{i_2^2 Rt}{Jn} \quad \text{calories}$$

$$\text{Third interval} = \frac{i_3^2 Rt}{Jn} \quad \text{calories}$$

$$n^{th} \text{ interval} = \frac{i_n^2 Rt}{Jn} \quad \text{calories}$$

$$\text{Total heat produced} = \frac{Rt}{J}\left(\frac{i_1^2 + i_2^2 + i_3^2 + \dots\dots + i_n^2}{n}\right) \quad \text{calories} \dots\dots\dots (1)$$

Since I_{eff} is considered as the effective value of this current, then the total heat produced by this current will be

$$\frac{I_{eff}^2 Rt}{J} \text{ calories } \dots\dots\dots (2)$$

Now, equating equation (1) and (2) we will get

$$\frac{I_{eff}^2 Rt}{J} = \frac{Rt}{J}\left(\frac{i_1^2 + i_2^2 + i_3^2 + \dots\dots + i_n^2}{n}\right) \text{ or}$$

$$I_{eff} = \sqrt{\frac{i_1^2 + i_2^2 + i_3^2 + \dots\dots + i_n^2}{n}}$$

$$I_{eff} = \sqrt{\text{mean of squares of instantaneous values}}$$

RMS value of an alternating quantity:

An alternating current is given by

$I = I_m \sin\theta$

Area of strip $= i^2 d\theta$

Area of squared wave in first half cycle

$$\int_0^{\pi} i^2 d\theta = \int_0^{\pi} (I_m \sin\theta)^2 d\theta$$

$$= I_m^2 \int_0^{\pi} \sin^2\theta \, d\theta = I_m^2 \int_0^{\pi} \left(\frac{1-\cos 2\theta}{2}\right) d\theta$$

$$= \frac{1}{2} I_m^2 \int_0^{\pi} (1 - \cos 2\theta)\, d\theta = \frac{1}{2} I_m^2 \left(\theta - \frac{\sin 2\theta}{2}\right)_0^{\pi}$$

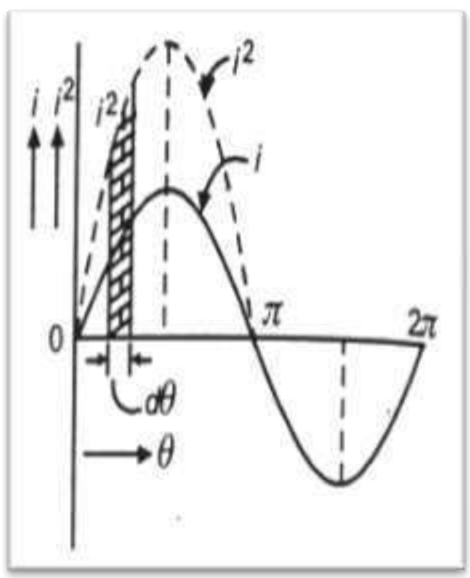
$$= \frac{1}{2} I_m^2 \left((\pi - 0) - \frac{\sin 2\pi - \sin\theta}{2}\right)$$

$$= \frac{1}{2} I_m^2 ((\pi - 0) - (0 - 0))$$

$$= \frac{\pi}{2} I_m^2$$

$$\text{R.M.S. value } I_{rms} = \sqrt{\frac{\text{Area of first half of squared wave}}{\text{Base}}}$$

$$= \sqrt{\frac{\pi I_m^2}{2\pi}} = \sqrt{\frac{I_m^2}{2}} = 0.707 I_m$$



RMS value for pure sinusoidal current is given by $\mathbf{I_{rms} = 0.707\ I_m}$

Form Factor and Peak Factor

Form Factor is defined as the ratio of the root mean square value to the average value of an alternating quantity (current or voltage).

Form Factor = $\frac{Irms}{Iavg}$ = 1.11

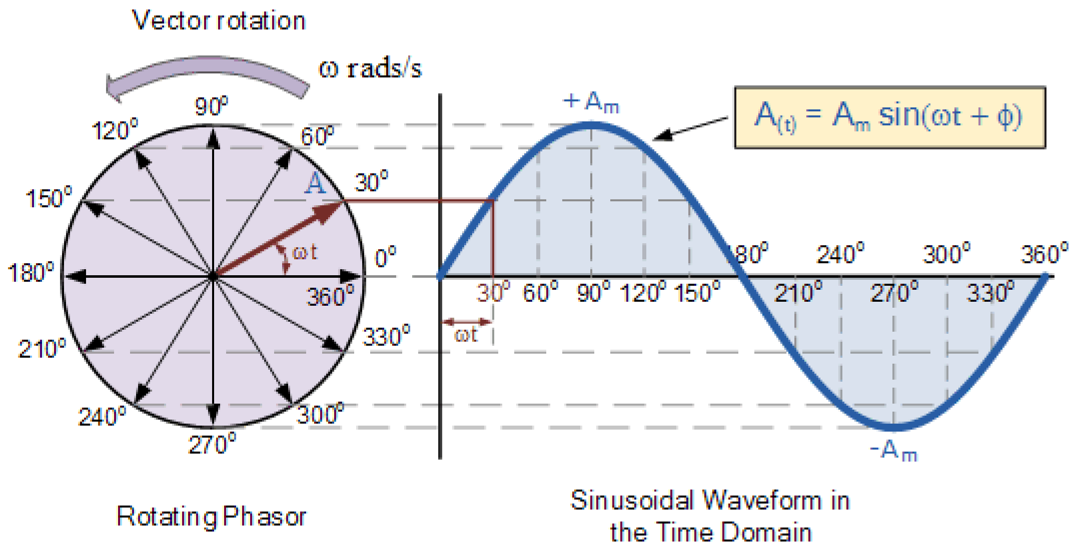
Peak Factor is defined as the ratio of maximum value to the R.M.S value of an alternating quantity. The alternating quantities can be voltage or current.

Peak Factor = $\frac{Imax}{Irms}$ = 1.4142

Phasor Representation of alternating quantity:

An alternating quantity can be represented in the form of wave and equation. The waveform gives the graphical representation whereas equation represents the mathematical expression of the instantaneous value of an alternating quantity. The same alternating quantity can be represented by a line of definite length (representing the maximum value) rotating in counter-clockwise direction at a constant velocity (w rad/sec) Alternating Current (AC) is a type of electric current that reverses its direction periodically in contrast to the Direct Current (DC) which flows in a single direction.

Phasor Diagram of a Sinusoidal Waveform



As the single vector rotates in an anti-clockwise direction, its tip at point A will rotate one complete revolution of 360^o or 2π representing one complete cycle. If the length of its moving tip is transferred at different angular intervals in time to a graph as shown above, a sinusoidal waveform would be drawn starting at the left with zero time. Each position along the horizontal axis indicates the time that has elapsed since zero-time, t = 0. When the vector is horizontal the tip of the vector represents the angles at 0^o, 180^o and at 360^o.

Likewise, when the tip of the vector is vertical it represents the positive peak value, (+Am) at 90^o or $\pi/2$ and the negative peak value, (-Am) at 270^o or $3\pi/2$. Then the time axis of the waveform represents the angle either in degrees or radians through which the phasor has moved.

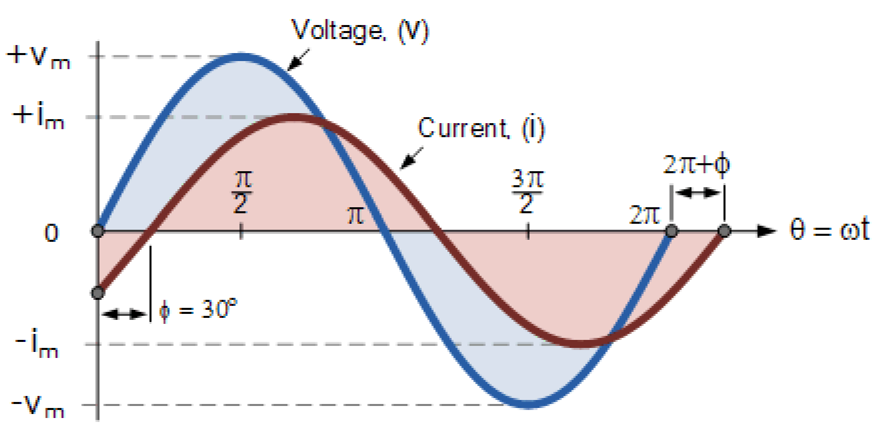
When we are analyzing alternating waveforms, we may need to know the position of the phasor, representing the Alternating Quantity at some particular instant in time especially when we want to compare two different waveforms on the same axis. For example, voltage and current. We have assumed in the waveform above that the waveform starts at time t = 0 with a corresponding phase angle in either degrees or radians.

But if a second waveform starts to the left or to the right of this zero-point or we want to represent in phasor notation the relationship between the two waveforms then we will need to take into account this phase difference, Φ of the waveform.

Phase Difference of a Sinusoidal Waveform

The phase of an alternating quantity at an instant is defined as the fractional part of a cycle through which the quantity has advanced from a selected origin.

The two alternating quantities having same frequency, when attain their zero values at different instants, the quantities are said to have a phase difference.



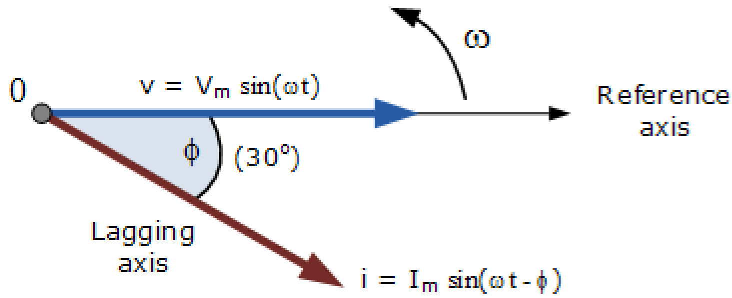
The generalised mathematical expression to define these two sinusoidal quantities will be written as:

$$v_{(t)} = V_m \sin(\omega t)$$

$$i_{(t)} = I_m \sin(\omega t - \phi)$$

The current, i is lagging the voltage, v by angle Φ and in our example above this is 30^o. So, the difference between the two phasors representing the two sinusoidal quantities is angle Φ and the resulting phasor diagram will be.

Phasor Diagram of a Sinusoidal Waveform

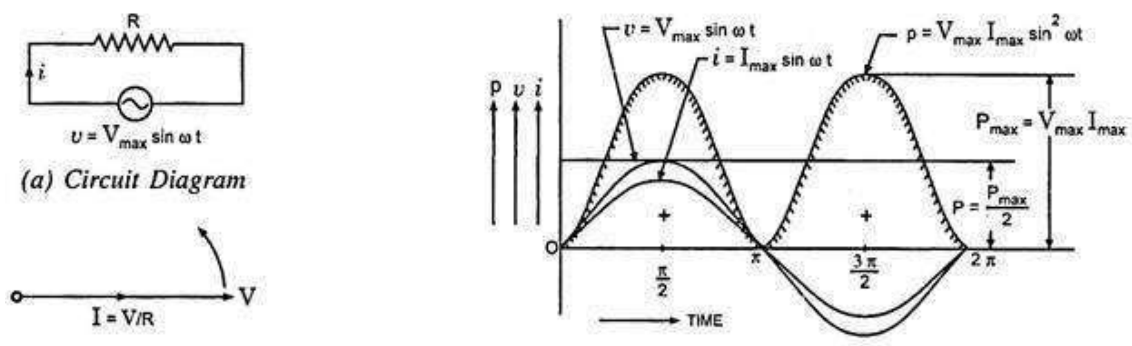


The phasor diagram is drawn corresponding to time zero (t = 0) on the horizontal axis. The lengths of the phasors are proportional to the values of the voltage, (V) and the current, (I) at the instant in time that the phasor diagram is drawn. The current phasor lags the voltage phasor by the angle, Φ, as the two phasors rotate in an *anticlockwise* direction, therefore the angle, Φ is also measured in the same anticlockwise direction.

Analysis of single-phase ac circuits consisting of R, L, C

A purely resistive or a non-inductive circuit is a circuit which has inductance so small that at normal frequency its reactance is negligible as compared to its resistance

Consider an ac circuit containing a non-inductive resistance of R ohms connected across a sinusoidal voltage represented by v = V sin wt



(a) Circuit Diagram

(c) Phasor Diagram

(b) Wave Diagram

When the current flowing through a pure resistance changes, no back emf is set up, therefore, applied voltage has to overcome the ohmic drop of iR only

$$i.e. \quad iR = v$$

$$\text{or} \quad i = \frac{v}{R} = \frac{V_{max}}{R} \sin \omega t$$

$$\text{Current will be maximum when } \omega t = \frac{\pi}{2} \text{ or } \sin \omega t = 1$$

$$\therefore \quad I_{max} = \frac{V_{max}}{R}$$

Instantaneous current may be expressed as:

$i = I_{max} \sin \omega t$

From the expressions of instantaneous applied voltage and instantaneous current, it is evident that in a pure resistive circuit, the applied voltage and current are in phase with each other, as shown by wave and phasor diagrams respectively

Power in Purely Resistive Circuit:

The instantaneous power delivered to the circuit in question is the product of the instantaneous values of applied voltage and current

$$i.e.\quad p = v\,i = V_{max} \sin \omega t\, I_{max} \sin \omega t = V_{max}\ I_{max} \sin^2 \omega t$$

$$\text{or}\quad p = \frac{V_{max}\ I_{max}}{2}(1 - \cos 2\,\omega\, t) \qquad\qquad \text{Since } \sin^2 \omega\, t = \frac{1-\cos 2\,\omega\, t}{2}$$

$$= \frac{V_{max}\ I_{max}}{2} - \frac{V_{max}\ I_{max}}{2} \cos 2\,\omega\, t$$

$$\text{Average power, } P = \text{Average of } \frac{V_{max}\ I_{max}}{2} - \textit{average of } \frac{V_{max}\ I_{max}}{2} \cos 2\,\omega\, t$$

Since average of $\frac{V_{max}\ I_{max}}{2} \cos 2\,\omega\, t$ over a complete cycle is zero,

$$P = \frac{V_{max}\ I_{max}}{2} = \frac{V_{max}}{\sqrt{2}} \cdot \frac{I_{max}}{\sqrt{2}} = V\,I \text{ watts}$$

<u>AC Circuit containing pure inductance only</u>

An inductive circuit is a coil with or without an iron core having negligible resistance. Practically pure inductance can never be had as the inductive coil has always small resistance. However, a coil of thick copper wire wound on a laminated iron core has negligible resistance arid is known as a choke coil.

When an alternating voltage is applied to a purely inductive coil, an emf, known as self-induced emf, is induced in the coil which opposes the applied voltage. Since coil has no resistance, at every instant applied voltage has to overcome this self-induced emf only.

Let the applied voltage $v = V_{max} \sin \omega\, t$
and self inductance of coil = L henry

Self induced emf in the coil, $e_L = -L\,\frac{di}{dt}$

Since applied voltage at every instant is equal and opposite to the self induced emf *i.e.* $v = -e_L$

$$\therefore\quad V_{max} \sin \omega\, t = -\left(-L\frac{di}{dt}\right)$$

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

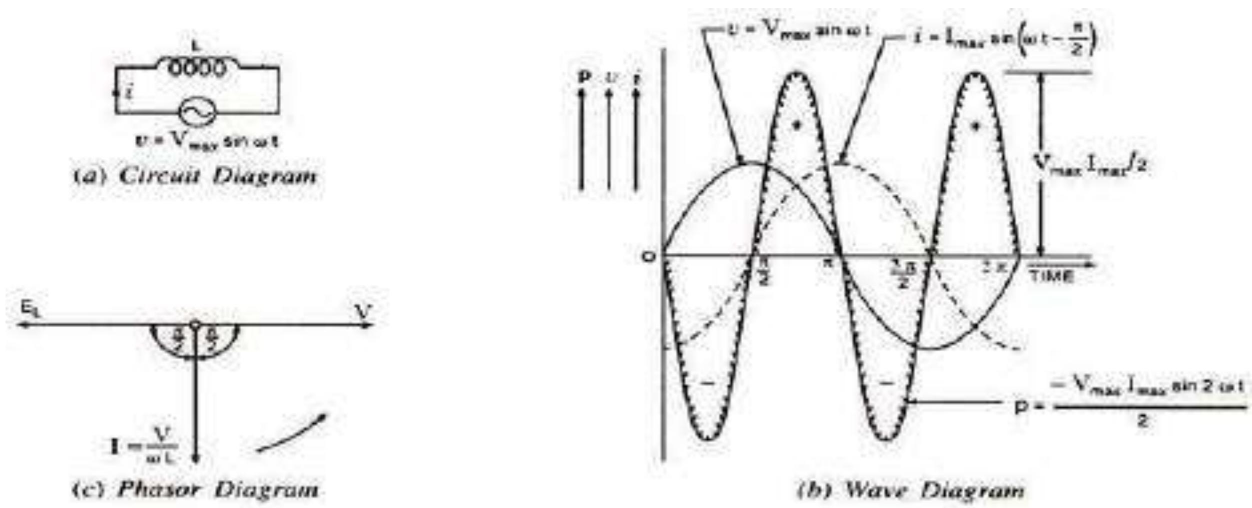
Integrating both sides we get

$$i = \frac{V_{max}}{L} \int \sin \omega\, t\, dt = \frac{V_{max}}{\omega L}(-\cos \omega\, t) + A$$

where A is a constant of integration, which is found to be zero from initial conditions

$$i.e.\quad i = \frac{-V_{max}}{\omega L} \cos \omega\, t = \frac{V_{max}}{\omega L} \sin\left(\omega t - \frac{\pi}{2}\right)$$

From the expressions of instantaneous applied voltage and instantaneous current flowing through a purely inductive coil it is observed that the current lags behind the applied voltage by π/2 as shown by wave diagram and phasor diagram.



(a) Circuit Diagram

(c) Phasor Diagram

(b) Wave Diagram

Inductive Reactance:

ωL in the expression Imax = V_{max}/ωL is known as inductive reactance and is denoted by X_L i.e.,

$X_L = \omega L$

If L is in henry , then X_L will be in ohms.

Power in Purely Inductive Circuit:

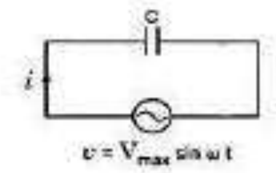
Instantaneous power, $p = v \times i = V_{max} \sin \omega t \, I_{max} \sin(\omega t - \pi/2)$

or $p = -V_{max} I_{max} \sin \omega t \cos \omega t = V_{max} I_{max}/2 \sin 2\omega t$

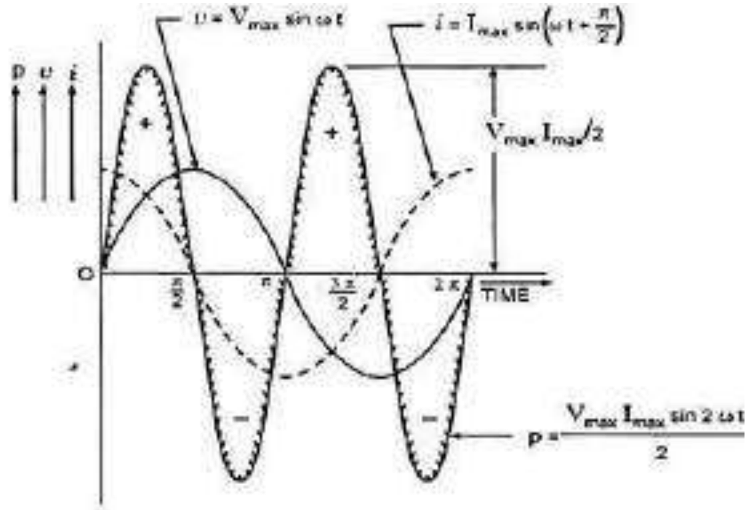
The power measured by wattmeter is the average value of p which is zero since average of a sinusoidal quantity of double frequency over a complete cycle is zero. Hence in a purely inductive circuit power absorbed is zero.

<u>**AC circuit containing pure Capacitor only**</u>

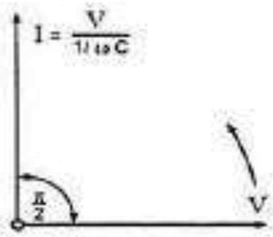
The circuit containing pure capacitor of C farad as shown in fig



(a) Circuit Diagram



(b) Wave Diagram



(c) Phasor Diagram

et an alternating voltage represented by $v = V_{max} \sin \omega t$ be applied across a capacitor of capacitance C farads.

The expression for instantaneous charge is given as:

$q = C V_{max} \sin \omega t$

Since the capacitor current is equal to the rate of change of charge, the capacitor current may be obtained by differentiating the above equation:

$$i = \frac{dq}{dt} = [C V_{max} \sin \omega t] = \omega C V_{max} \cos \omega t = \frac{V_{max}}{1/\omega C} \sin\left(\omega t + \frac{\pi}{2}\right)$$

Current is maximum when $t = 0$

$$\therefore \quad I_{max} = \frac{V_{max}}{1/\omega C}$$

Substituting $\frac{V_{max}}{1/\omega C} = I_{max}$ in the above equation for instantaneous current, we get

$$i = I_{max} \sin\left(\omega t + \frac{\pi}{2}\right)$$

From the equations of instantaneous applied voltage and instantaneous current flowing through capacitance, it is observed that the current leads the applied voltage by π/2, as shown in Figs. 4.4 (b) and (c) by wave and phasor diagrams respectively.

Capacitive Reactance:

$1/\omega C$ in the expression $I_{max} = V_{max}/1/\omega C$ is known as capacitive reactance and is denoted by X_C i.e., $XC = 1/\omega C$. If C is in farads and ω is in radians/s, then X_c will be in ohms.

Power in Purely Capacitive Circuit:

$$p = v\,i = V_{max} \sin \omega t.\ I_{max} \sin\left(\omega t + \frac{\pi}{2}\right) = V_{max}\, I_{max} \sin \omega t \cos \omega t$$

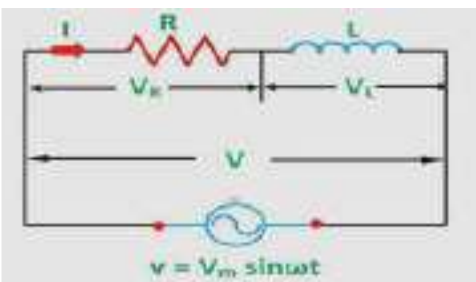
$$= \frac{V_{max}\, I_{max}}{2} \sin 2\omega t$$

Average power, $P = \dfrac{V_{max}\, I_{max}}{2} \times$ average of $\sin 2\,\omega t$ over a complete cycle = 0.

Hence power absorbed in a purely capacitive circuit is zero.

RL Series Circuit

A circuit that contains a pure resistance R ohm connected in series with a coil having pure inductance of L (Henry) is known as R L Series Circuit. When an AC supply voltage V is applied the current, I flows in the circuit. I_R and I_L will be the current flowing in the resistor and inductor respectively, but the amount of current flowing through both the elements will be same as they are connected in series with each other. The circuit diagram of RL Series circuit is shown below

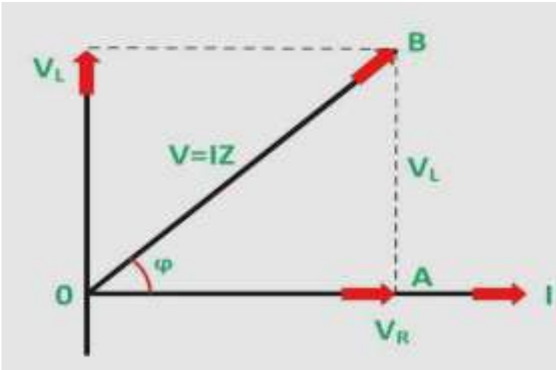


Where,

- V_R – voltage across the resistor R
- V_L – voltage across the inductor L
- V – Total voltage of the circuit

Phasor Diagram of the RL Series Circuit

The phasor diagram of the RL Series circuit is shown below



Steps to draw the Phasor Diagram of RL Series Circuit

The following steps are given below which are followed to draw the phasor diagram step by step.

- Current I is taken as a reference.
- The Voltage drop across the resistance $V_R = I_R$ is drawn in phase with the current I.
- The voltage drop across the inductive reactance $V_L = IX_L$ is drawn ahead of the current I. As the current lags voltage by an angle of 90 degrees in the pure Inductive circuit.
- The vector sum of the two voltages drops V_R and V_L is equal to the applied voltage V.

Now,

In right angle triangle OAB

$V_R = I_R$ and $V_L = IX_L$ where $X_L = 2\pi fL$

$$V = \sqrt{(V_R)^2 + (V_L)^2} = \sqrt{(IR)^2 + (IX_L)^2}$$

$$V = I\sqrt{R^2 + X_L^2} \quad \text{or}$$

$V = IZ$

Where,

$$Z = \sqrt{R^2 + X_L^2}$$

Z is the total opposition offered to the flow of alternating current by an RL Series circuit and is called impedance of the circuit. It is measured in ohms (Ω).

Phase Angle

In RL Series Circuit the current lags the voltage by 90-degree angle known as phase angle. It is given by the equation

$$\tan\varphi = \frac{V_L}{V_R} = \frac{IX_L}{IR} = \frac{X_L}{R} \quad \text{or}$$

$$\varphi = \tan^{-1}\frac{X_L}{R}$$

Power in R L Series Circuit

If the alternating voltage applied across the circuit is given by the equation

$v = V_m \, Sinwt$ ……. ………. (1)

The equation of current I is given as

$I = I_m \, Sin(wt - \phi)$ …………….(2)

Then the instantaneous power is given by the equation

$p = vi$ ………………………(3)

Putting the value of v and i from the equation (1) and (2) in the equation (3) we will get

$$P = (V_m Sin\omega t) x \, I_m \sin(\omega t - \varphi)$$

$$p = \frac{V_m I_m}{2} 2\sin(\omega t - \varphi) \sin\omega t$$

$$P = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} [\cos\varphi - \cos(2\omega t - \varphi)]$$

$$P = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos\varphi - \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos(2\omega t - \varphi)$$

The average power consumed in the circuit over one complete cycle is given by the equation shown below

$$P = \text{average of } \frac{V_m}{\sqrt{2}} \frac{V_m}{\sqrt{2}} \cos\varphi - \text{average of } \frac{V_m}{\sqrt{2}} \frac{V_m}{\sqrt{2}} \cos(2\omega t - \varphi) \quad \text{or}$$

$$P = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos\varphi - \text{Zero} \quad \text{or}$$

$$P = V_{r.m.s} I_{r.m.s} \cos\varphi = V \, I \cos\varphi$$

where $\cos\phi$ is called the power factor of the circuit.

$$\cos\varphi = \frac{V_R}{V} = \frac{IR}{IZ} = \frac{R}{Z} \dots\dots\dots\dots.(4)$$

The power factor is defined as the ratio of resistance to the impedance of an AC Circuit.

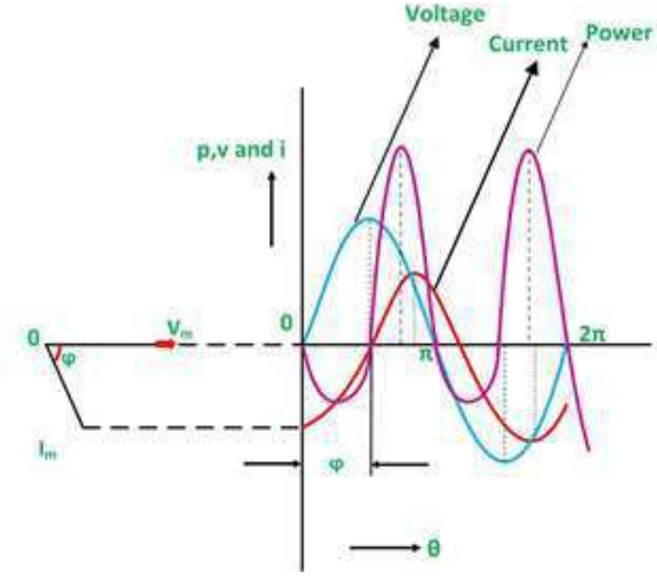
Putting the value of V and $\cos\phi$ from the equation (4) the value of power will be

$$P = (IZ)(I)(R/Z) = I^2 R \dots\dots\dots..(5)$$

From the equation (5) it can be concluded that the inductor does not consume any power in the circuit.

Waveform and Power Curve of the RL Series Circuit

The waveform and power curve of the RL Series Circuit is shown below



The various points on the power curve are obtained by the product of voltage and current. If you analyze the curve carefully, it is seen that the power is negative between angle 0 and ϕ and between 180 degrees and (180 + ϕ) and during the rest of the cycle the power is positive. The current lags the voltage and thus they are not in phase with each other.

Explain the following:

a) Real power

b) Reactive power

c) Apparent power

d) Power factor

a) Real power: The power which is actually consumed or utilized in ac circuit is called true power or active power or real power. It is consumed by the resistive load in the circuit. The unit of real power is watts.

Real power = VI cos ϕ Watts

b) Reactive power: The power which flows back and forth that means it moves in both the directions in the circuit or reacts upon itself, is called Reactive Power. A pure inductor and a pure capacitor do not consume any power since in a half cycle whatever power is received from the source by these components, the same power is returned to the source. This power which returns and flows in both the direction in the circuit, is called Reactive power. This reactive power does not perform any useful work in the circuit. It is measured in a unit called Volt-Amps-Reactive (VAR), rather than watts.

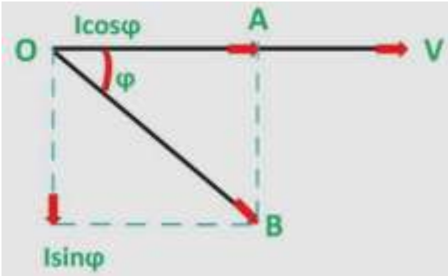
c) Apparent power: The product of root mean square (RMS) value of voltage and current is known as Apparent Power. This power is measured in kVA or MVA.

In a purely resistive circuit, the current is in phase with the applied voltage, whereas in a purely inductive and capacitive circuit the current is 90 degrees out of phase, i.e., if the inductive load is connected in the circuit the current lags voltage by 90 degrees and if the capacitive load is connected the current leads the voltage by 90 degrees.

Hence, from all the above discussion, it is concluded that the current in phase with the voltage produces true or active power, whereas, the current 90 degrees out of phase with the voltage contributes to reactive power in the circuit.
Therefore,

- True power = voltage x current in phase with the voltage
- Reactive power = voltage x current out of phase with the voltage

The phasor diagram for an inductive circuit is shown below:



Taking voltage V as reference, the current I lags behind the voltage V by an angle ϕ. The current I is divided into two components:

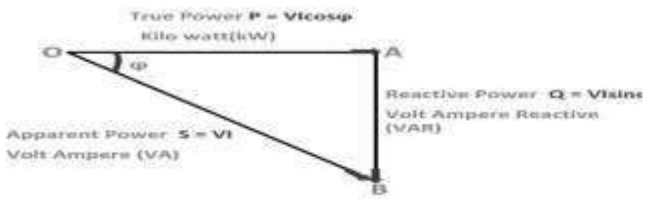
- I Cos ϕ in phase with the voltage V
- I Sin ϕ which is 90 degrees out of phase with the voltage V

Therefore, the following expression shown below gives the active, reactive and apparent power respectively.

- Active power P = V x I cosϕ = V I cosϕ
- Reactive power P_r or Q = V x I sinϕ = V I sinϕ
- Apparent power P_a or S = V x I = VI

Power Triangle:

Power Triangle is the representation of a right angle triangle showing the relation between active power, reactive power and apparent power. When each component of the current that is the active component (Icosϕ) or the reactive component (Isinϕ) is multiplied by the voltage V, a power triangle is obtained shown in the figure below

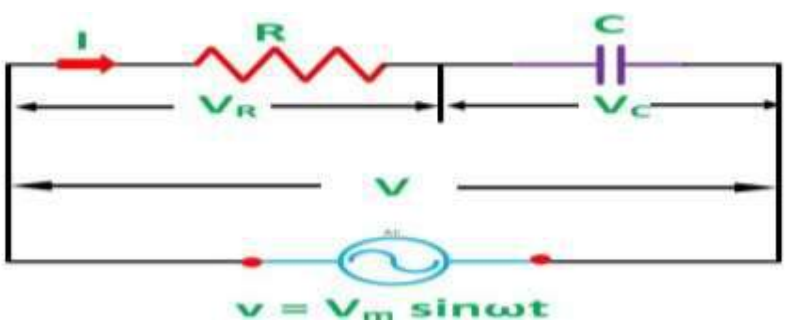


d) Power factor: The power factor in ac circuit is the ratio of the real power that is used to do work and the apparent power that is supplied to the circuit. The power factor can get values in the range from 0 to 1. When all the power is reactive power with no real power (usually inductive load) - the power factor is 0.

Power factor (Cos ϕ) $= \frac{Real\ \ power\ \ in\ watts}{Apparent\ \ \ power\ \ in\ Volt-Amp}$

Resistance — Capacitance (R-C) Series Circuit

A circuit that contains pure resistance R ohms connected in series with a pure capacitor of capacitance C farads is known as **RC Series Circuit.** A sinusoidal voltage is applied and current I flows through the resistance (R) and the capacitance (C) of the circuit.The RC Series circuit is shown in the figure below:

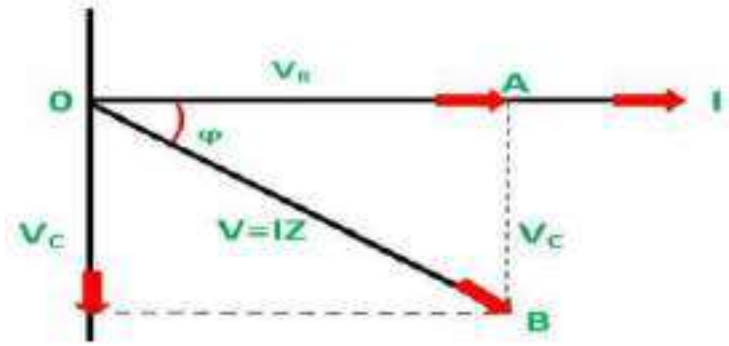


Where,

- V_R – voltage across the resistance R
- V_C – voltage across capacitor C
- V – total voltage across the RC Series circuit

Phasor Diagram of RC Series Circuit:

The phasor diagram of the RC series circuit is shown below:



Steps to draw a Phasor Diagram

The following steps are used to draw the phasor diagram of RC Series circuit

- Take the current I (r.m.s value) as a reference vector
- Voltage drop in resistance VR = IR is taken in phase with the current vector
- Voltage drop in capacitive reactance VC = IXC is drawn 90 degrees behind the current vector, as current leads voltage by 90 degrees (in the pure capacitive circuit)
- The vector sum of the two voltage drops is equal to the applied voltage V (r.m.s value).

Now, $V_R = I_R$ and $V_C = IX_C$, Where $X_C = I/2\pi fC$

In right triangle OAB,

$$V = \sqrt{(V_R)^2 + (V_C)^2} = \sqrt{(IR)^2 + (IX_C)^2}$$

$$V = I\sqrt{R^2 + X_C^2} \qquad \text{or}$$

$$I = \frac{V}{\sqrt{R^2 + X_C^2}} = \frac{V}{Z}$$

Where,

$$Z = \sqrt{R^2 + X_C^2}$$

Z is the total opposition offered to the flow of alternating current by an RC series circuit and is called **impedance** of the circuit. It is measured in ohms (Ω).

Phase angle

From the phasor diagram shown above, it is clear that the current in the circuit leads the applied voltage by an angle ϕ and this angle is called the **phase angle**.

$$\tan\varphi = \frac{V_C}{V_R} = \frac{IX_C}{IR} = \frac{X_C}{R} \quad \text{or}$$

$$\varphi = \tan^{-1}\frac{X_C}{R}$$

Power in RC Series Circuit

If the alternating voltage applied across the circuit is given by the equation

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

Then,

$$i = I_m \sin(\omega t + \varphi) \ldots\ldots\ldots\ldots(2)$$

Therefore, the instantaneous power is given by p = vi
Putting the value of v and i from the equation (1) and (2) in p = vi

$$P = (V_m \text{Sin}\omega t) \times I_m \sin(\omega t + \varphi)$$

$$p = \frac{V_m I_m}{2} 2\sin(\omega t + \varphi)\sin\omega t$$

$$P = \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}[\cos\varphi - \cos(2\omega t + \varphi)]$$

$$P = \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos\varphi - \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos(2\omega t + \varphi)$$

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

$$P = \text{average of } \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos\varphi - \text{average of } \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos(2\omega t + \varphi) \quad \text{or}$$

$$P = \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos\varphi - \text{Zero} \quad \text{or}$$

$$P = V_{r.m.s} I_{r.m.s}\cos\varphi = V\,I\cos\varphi$$

Where cosϕ is called the **power factor** of the circuit.

$$\cos\varphi = \frac{V_R}{V} = \frac{IR}{IZ} = \frac{R}{Z} \ldots\ldots\ldots\ldots\ldots(3)$$

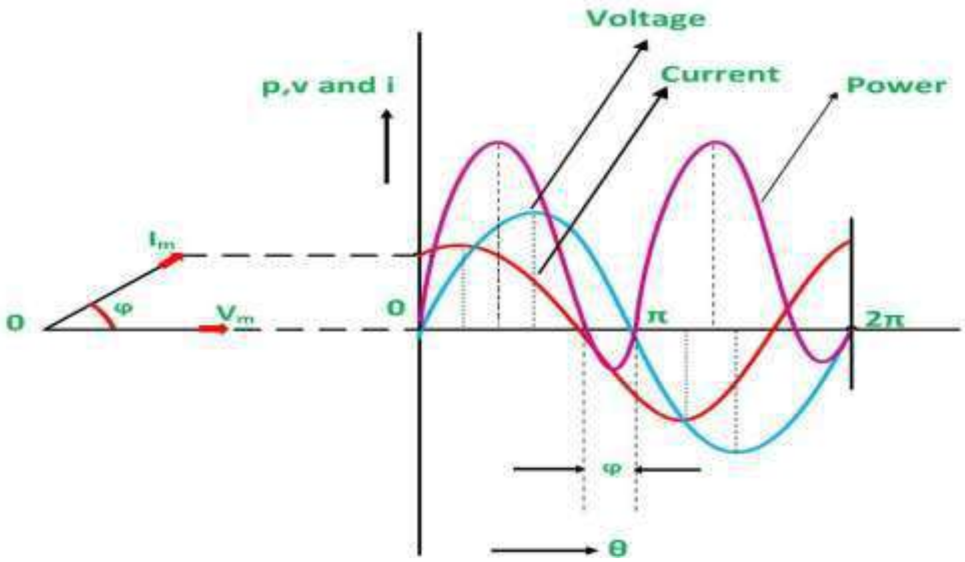
Putting the value of V and cosϕ from the equation (3) the value of power will be

$$P = (IZ)(I)(R/Z) = I^2 R \ldots\ldots\ldots(4)$$

From the equation (4) it is clear that the power is actually consumed by the resistance only and the capacitor does not consume any power in the circuit.

Waveform and Power Curve of the RC Series Circuit

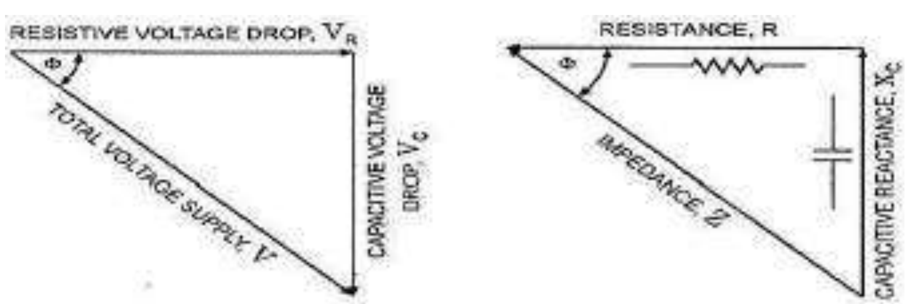
The waveform and power curve of the RC circuit is shown below:



The various points on the power curve are obtained from the product of the instantaneous value of voltage and current.

The power is negative between the angle (180° – ϕ) and 180° and between (360° -ϕ) and 360° and in the rest of the cycle, the power is positive. Since the area under the positive loops is greater than that under the negative loops, therefore the net power over a complete cycle is **positive**.

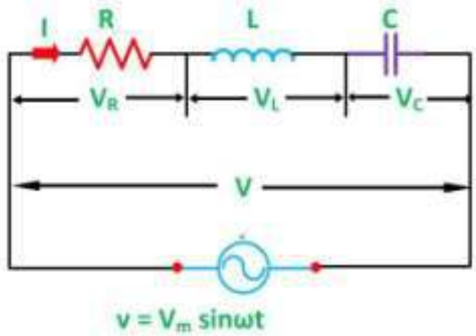
<u>Impedance Triangle</u>



(a) Voltage Triangle (b) Impedance Triangle

RLC Series Circuit

The **RLC Series Circuit** is defined as when a pure resistance of R ohms, a pure inductance of L Henry and a pure capacitance of C farads are connected together in series combination with each other. As all the three elements are connected in series so, the current flowing in each element of the circuit will be same as the total current I flowing in the circuit.
The **RLC Circuit** is shown below-



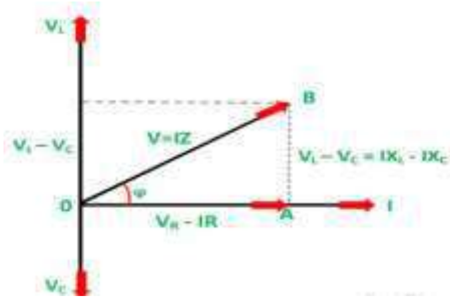
In the RLC Series Circuit, $X_L = 2\pi fL$ and $X_C = 1/2\pi fC$

When the AC voltage is applied through the RLC Series Circuit the resulting current I flows through the circuit, and thus the voltage across each element will be

- $V_R = IR$ that is the voltage across the resistance R and is in phase with the current I.
- $V_L = IX_L$ that is the voltage across the inductance L and it leads the current I by an angle of 90 degrees.
- $V_C = IX_C$ that is the voltage across the capacitor C and it lags the current I by an angle of 90 degrees.

Phasor Diagram of RLC Series Circuit

The phasor diagram of the RLC Series Circuit when the circuit is acting as an inductive circuit that means ($V_L > V_C$) is shown below and if ($V_L < V_C$) the circuit will behave as a capacitive circuit.



Steps to draw the Phasor Diagram of the RLC Series Circuit

- Take current I as the reference as shown in the figure above
- The voltage across the inductor L that is V_L is drawn leads the current I by a 90-degree angle.
- The voltage across the capacitor c that is V_c is drawn lagging the current I by a 90 degree angle because in capacitive load the current leads the voltage by an angle of 90 degrees.
- The two vector V_L and V_C are opposite to each other.

$$V = \sqrt{(V_R)^2 + (V_L - V_C)^2} = \sqrt{(IR)^2 + (IX_L - IX_C)^2} \quad \text{or}$$

$$V = I\sqrt{R^2 + (X_L - X_C)^2} \quad \text{or}$$

$$I = \frac{V}{\sqrt{R^2 + (X_L - X_C)^2}} = \frac{V}{Z}$$

Where

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

It is the total opposition offered to the flow of current by an RLC Circuit and is known as Impedance of the circuit.

Phase Angle

From the phasor diagram, the value of phase angle will be

$$\tan\varphi = \frac{V_L - V_C}{V_R} = \frac{X_L - X_C}{R} \quad \text{or}$$

$$\varphi = \tan^{-1}\frac{X_L - X_C}{R}$$

Power in RLC Series Circuit

The product of voltage and current is defined as power.

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

Where cosϕ is the power factor of the circuit and is expressed as

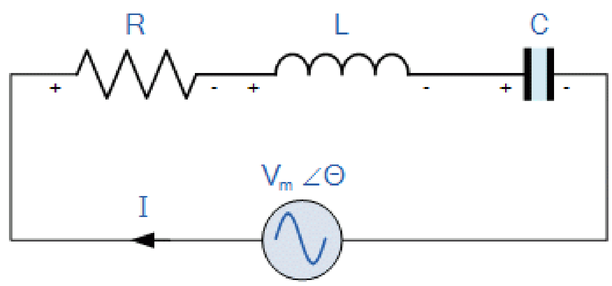
$$\cos\varphi = \frac{V_R}{V} = \frac{R}{Z}$$

The three cases of RLC Series Circuit

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

RLC Series Resonance

Resonance occurs in a series circuit when the supply frequency causes the voltages across L and C to be equal and opposite in phase.



In a series RLC circuit there becomes a frequency point were the inductive reactance of the inductor becomes equal in value to the capacitive reactance of the capacitor. In other words, $X_L = X_C$. The point at which this occurs is called the Resonant Frequency point, (f_r) of the circuit, and as we are analyzing a series RLC circuit this resonance frequency produces a Series Resonance.

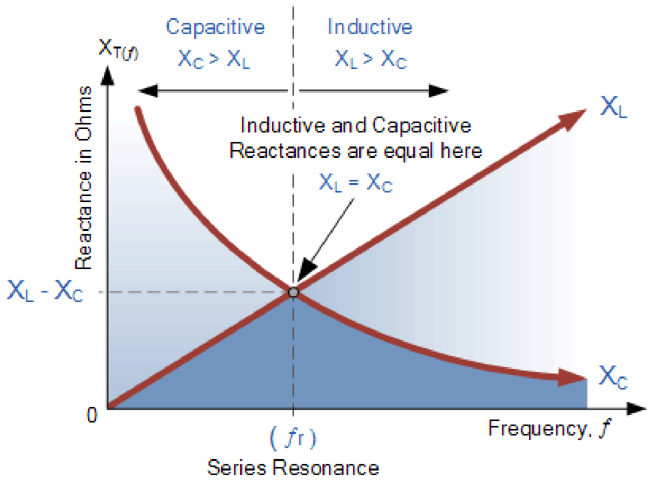
Series Resonance circuits are one of the most important circuits used electrical and electronic circuits. They can be found in various forms such as in AC mains filters, noise filters and also in radio and television tuning circuits producing a very selective tuning circuit for the receiving of the different frequency channels.

Various terms in RLC series circuit:

- Inductive reactance: $X_L = 2\pi f L = \omega L$
- Capacitive reactance: $X_C = \dfrac{1}{2\pi f C} = \dfrac{1}{\omega C}$
- When $X_L > X_C$ the circuit is Inductive
- When $X_C > X_L$ the circuit is Capacitive
- Total circuit reactance = $X_T = X_L - X_C$ or $X_C - X_L$
- Total circuit impedance = $Z = \sqrt{R^2 + X_T^2} = R + jX$

Series Resonance Frequency

Electrical resonance occurs in an AC circuit when the two reactances (inductive reactance and capacitive reactance) which are opposite and equal cancel each other out as $X_L = X_C$ and the point on the graph at which this happens is where the two reactance curves cross each other.



where: f_r is in Hertz, L is in Henries and C is in Farads.

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

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

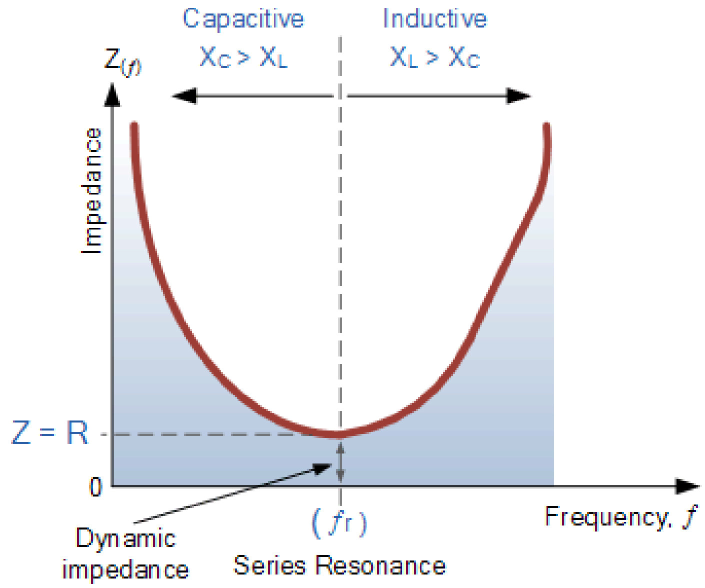
$$f^2 = \frac{1}{2\pi L \times 2\pi C} = \frac{1}{4\pi^2 LC}$$

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

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

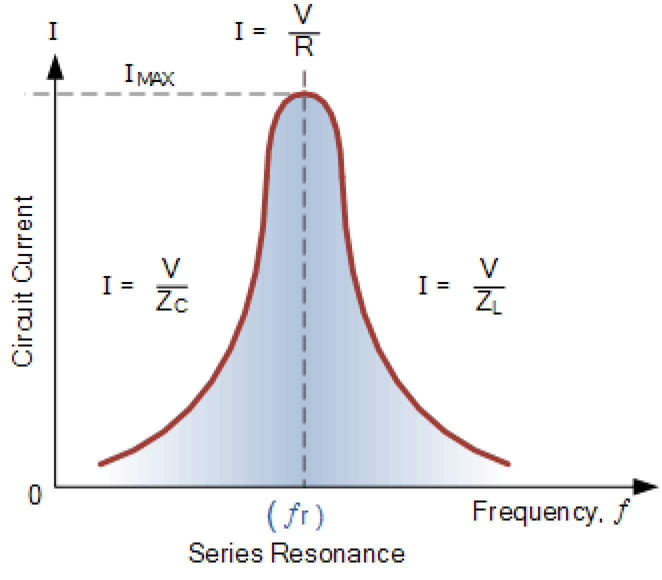
Impedance in a Series Resonance Circuit

At resonance, the two reactance cancel each other out thereby making a series LC combination act as a short circuit with the only opposition to current flow in a series resonance circuit being the resistance, R.So, the total impedance of the series circuit becomes just the value of the resistance and therefore: Z = R.Then at resonance the impedance of the series circuit is at its minimum value and equal only to the resistance, R of the circuit. The circuit impedance at resonance is called the "dynamic impedance" of the circuit and depending upon the frequency, X_C (typically at high frequencies) or X_L (typically at low frequencies) will dominate either side of resonance as shown below.



Series Circuit Current at Resonance

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



The frequency response curve of a series resonance circuit shows that the magnitude of the current is a function of frequency and plotting this onto a graph shows us that the response starts at near to zero, reaches maximum value at the resonance frequency when $I_{MAX} = I_R$ and then drops again to nearly zero as f becomes infinite. The result of this is that the magnitudes of the voltages across the inductor, L and the capacitor, C can become many times larger than the supply voltage, even at resonance but as they are equal and at opposition, they cancel each other out.

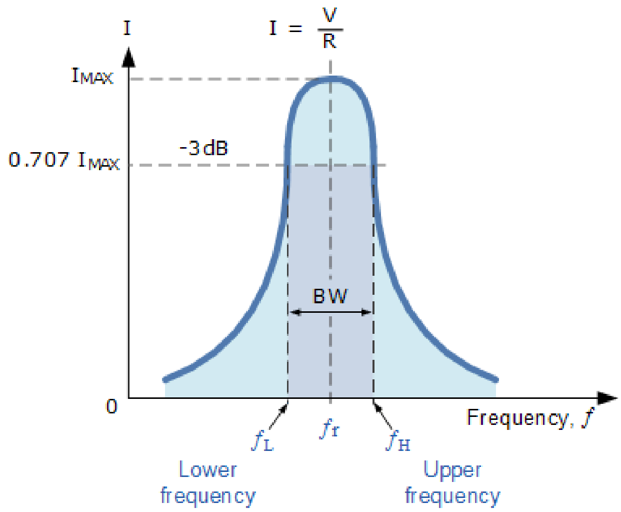
As a series resonance circuit only functions on resonant frequency, this type of circuit is also known as an Acceptor Circuit because at resonance, the impedance of the circuit is at its minimum so easily accepts the current whose frequency is equal to its resonant frequency.

Bandwidth of a Series Resonance Circuit

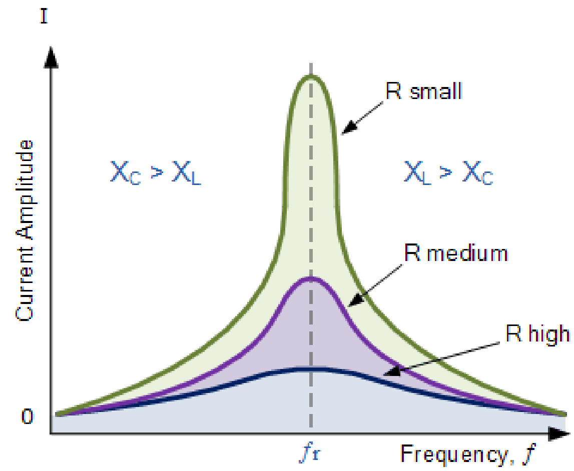
If the series RLC circuit is driven by a variable frequency at a constant voltage, then the magnitude of the current, I is proportional to the impedance, Z, therefore at resonance the power absorbed by the circuit must be at its maximum value as $P = I^2Z$.

If we now reduce or increase the frequency until the average power absorbed by the resistor in the series resonance circuit is half that of its maximum value at resonance, we produce two frequency points called the half-power points which are -3dB down from maximum, taking 0dB as the maximum current reference.

The -3dB points give us a current value that is 70.7% of its maximum resonant value which is defined as: $0.5(I^2 R) = (0.707 \times I)^2 R$. Then the point corresponding to the lower frequency at half the power is called the "lower cut-off frequency", labelled f_L with the point corresponding to the upper frequency at half power being called the "upper cut-off frequency", labelled f_H. The distance between these two points, i.e. ($f_H - f_L$) is called the Bandwidth, (BW) and is the range of frequencies over which at least half of the maximum power and current is provided as shown.



The frequency response of the circuit's current magnitude above, relates to the "sharpness" of the resonance in a series resonance circuit. The sharpness of the peak is measured quantitatively and is called the Quality factor, Q of the circuit. The quality factor relates the maximum or peak energy stored in the circuit (the reactance) to the energy dissipated (the resistance) during each cycle of oscillation meaning that it is a ratio of resonant frequency to bandwidth and the higher the circuit Q, the smaller the bandwidth, $Q = f_r / BW$.

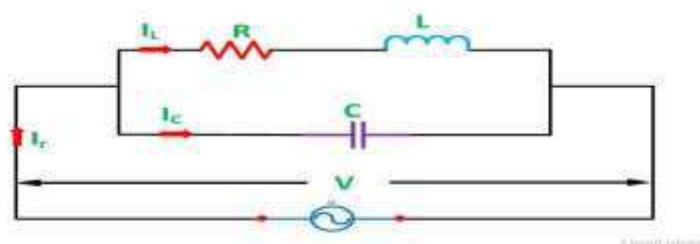


Quality factor of series resonance circuit is given by

$$Q = \frac{\omega_r L}{R} = \frac{X_L}{R} = \frac{1}{\omega_r C R} = \frac{X_C}{R} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

<u>RLC Parallel Circuit and resonance</u>

Parallel Resonance means when the circuit current is in phase with the applied voltage of an AC circuit containing an Inductor and a Capacitor connected together in parallel. Let us understand the Parallel Resonance with the help of a circuit diagram shown below.

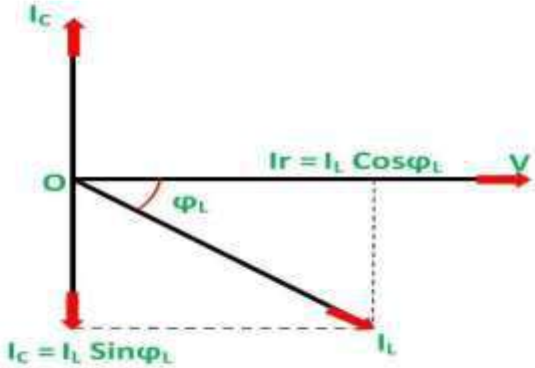


Consider an Inductor of L Henry having some resistance of R ohms connected in parallel with a capacitor of capacitance C farads. A supply voltage of V volts is connected across these elements. The circuit current Ir will only be in phase with the supply voltage when the following condition given below in the equation is satisfied.

$$I_C = I_L \sin\varphi_L$$

Phasor Diagram

The phasor diagram of the given circuit is shown below



At the Resonance condition, the circuit draws the minimum current as under this (resonance) condition the reactive component of current is suppressed.

Frequency at Resonance Condition in Parallel resonance Circuit

The value of inductive reactance $X_L = 2\pi fL$ and capacitive reactance $X_C = 1/2\pi fC$ can be changed by changing the supply frequency. As the frequency increases the value of X_L and consequently the value of Z_L increases. As a result, there is a decrease in the magnitude of current I_2 and this I_2 current lags behind the voltage V.

On the other hand, the value of capacitive reactance decreases and consequently the value of I_C increases.

At some frequency, f_r called resonance frequency.

$$I_C = I_L \, Sin\varphi_L$$

Where,

$$I_L = \frac{V}{Z_L}$$

$$Sin\varphi_L = \frac{X_L}{Z_L} \quad \text{and} \quad I_C = \frac{V}{X_C}$$

$$\frac{V}{X_C} = \frac{V}{Z_L} \times \frac{X_L}{Z_L} \quad \text{or} \quad X_L X_C = Z_L^2 \quad \text{or}$$

$$\frac{\omega L}{\omega C} = Z_L^2 = (R^2 + X_L^2) \quad \text{or}$$

$$\frac{L}{C} = R^2 + (2\pi f_r L)^2 \quad \text{or}$$

$$2\pi f_r L = \sqrt{\frac{L}{C} - R^2} \quad \text{or}$$

$$f_r = \frac{1}{2\pi L} = \sqrt{\frac{L}{C} - R^2} = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$$

If R is very small as compared to L, then resonant frequency will be

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Effect of Parallel Resonance

At parallel resonance line current $I_r = I_L \cos\phi$ or

$$\frac{V}{Z_r} = \frac{V}{Z_l} x \frac{R}{Z_l} \quad \text{or} \quad \frac{1}{Z_r} = \frac{R}{Z_L^2} \quad \text{or}$$

$$\frac{1}{Z_r} = \frac{R}{L/C} = \frac{CR}{L} \quad \left(\text{as } Z_L^2 = \frac{L}{C}\right)$$

Therefore, the circuit impedance will be given as

$$Z_r = \frac{L}{CR}$$

The following **conclusions** are made from the above overall discussion about the **Parallel Resonance.**

- The circuit impedance is purely resistive because there is no frequency term present in it. If the value of Inductance, Capacitance and Resistance is in Henry, Farads and Ohm than the value of circuit impedance Z_r will be in Ohms.
- The value of Zr will be very high because the ratio L/C is very large at parallel resonance.
- The value of circuit current, Ir = V/Zr is very small because the value of Zr is very high.
- The current flowing through the capacitor and the coil is much greater than the line current because the impedance of each branch is quite lower than that of circuit impedance Zr.

Three-phase balanced circuits, voltage and current relations in star and delta connections.

Poly-phase system: An ac system having a group of (two or more than two) equal voltages of same frequency arranged to have equal phase difference between them is called a poly-phase system.

Phase difference = $\frac{360\ electrical\ \ degree}{Number\ \ of\ phases}$

Advantage of three –phase system over single phase system.

1. Power delivered is constant. In single phase circuit the power delivered is pulsating and objectionable for many applications.
2. For a given frame size a poly-phase machine gives a higher output than a single phase machine.
3. Poly-phase induction motors are self starting and are more efficient. Single phase motor has no starting torque and requires an auxiliary means for starting.
4. Comparing with single phase motor, three phase induction motor has higher power factor and efficiency.
5. Three phase motors are very robust, relatively cheap, and generally smaller, have self-starting properties, provide a steadier output and require little maintenance compared with single phase motors.

Generation of 3 Phase E.M.Fs in a 3 Phase Circuit

In a 3 phase system, there are three equal voltages or EMFs of the same frequency having a phase difference of 120 degrees. These voltages can be produced by a three-phase AC generator having three identical windings displaced apart from each other by 120 degrees electrical. When these windings are kept stationary, and the magnetic field is rotated as shown in the figure A below or when the windings are kept stationary, and the magnetic field is rotated as shown below in figure B, an emf is induced in each winding. The magnitude and frequency of these EMFs are same but are displaced apart from one another by an angle of 120 degrees.

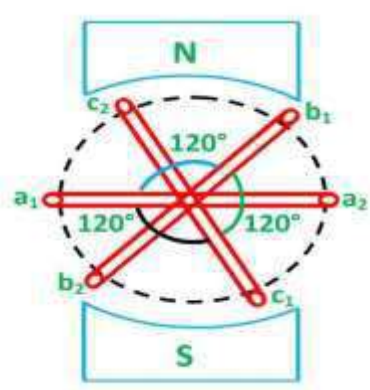


Figure A

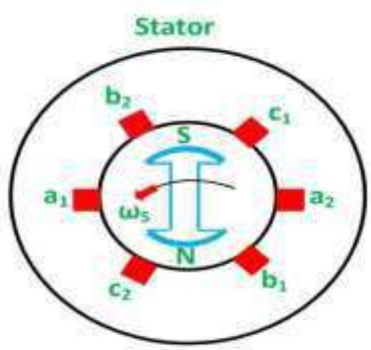


Figure B

Consider three identical coils a_1a_2, b_1b_2 and c_1c_2 as shown in the above figure. In this figure a_1, b_1 and c_1 are the starting terminals, whereas a_2, b_2 and c_2 are the finish terminals of the three coils. The phase difference of 120 degrees has to be maintained between the starts terminals a_1, b_1 and c_1.

Now, let the three coils mounted on the same axis, and they are rotated by either keeping coil stationary and moving the magnetic field or vice versa in an anticlockwise direction at (ω) radians per seconds. Three EMFs are induced in the three coils respectively.

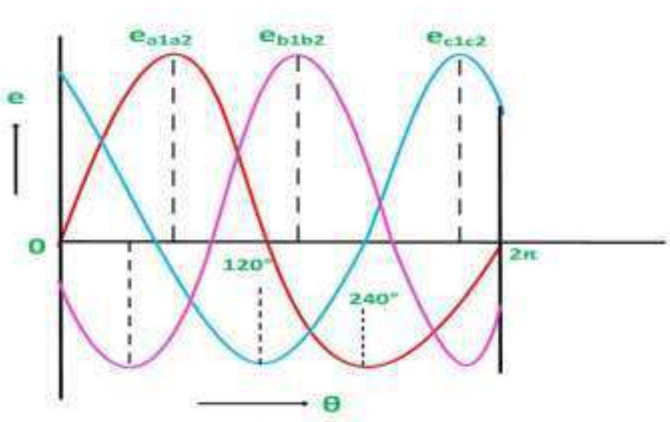


Figure C

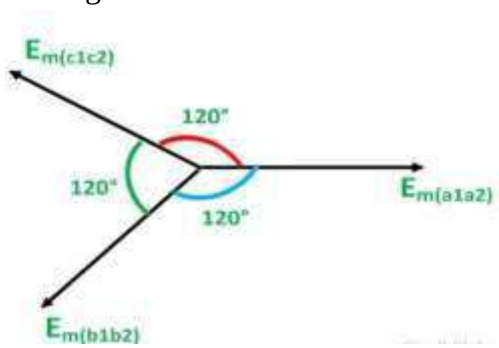
Considering the figure C, the analysis about their magnitudes and directions are given as follows. The emf induced in the coil a_1a_2 is zero and is increasing in the positive direction as shown by the waveform in the above figure C represented as e_{a1a2}.

The coil b_1b_2 is 120 degrees electrically behind the coil a_1a_2. The emf induced in this coil is negative and is becoming maximum negative as shown by the wave e_{b1b2}.

Similarly, the coil c_1c_2 is 120 degrees electrically behind the coil b_1b_2, or we can also say that the coil c_1c_2 is 240 degrees behind the coil a_1a_2. The emf induced in the coil is positive and is decreasing as shown in the figure C represented by the waveform e_{c1c2}.

Phasor Diagram

The EMFs induced in the three coils in a 3 phase circuits are of the same magnitude and frequency and are displaced by an angle of 120 degrees from each other as shown below in the phasor diagram.



These EMFs of a 3 phase circuits can be expressed in the form of the various equations given below.

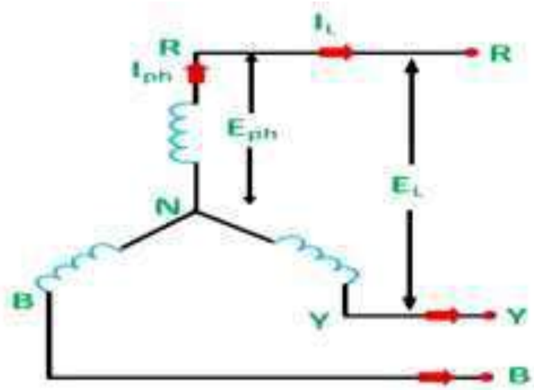
$$e_{a1a2} = E_m \sin \omega t$$

$$e_{b1b2} = E_m \sin(\omega t - 2\pi/3) = E_m \sin(\omega t - 120^\circ)$$

$$e_{c1c2} = E_m \sin(\omega t - 4\pi/3) = E_m \sin(\omega t - 240^\circ)$$

<u>Star or Y connections</u>

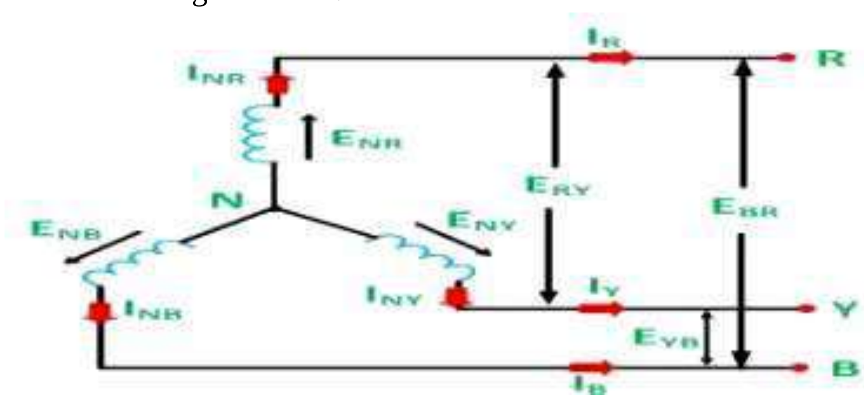
The star connection is shown in the diagram below.



Considering the above figure, the finish terminals of the three windings are connected to form a star or neutral point. The three conductors named as R, Y and B run from the remaining three free terminals as shown in the above figure.

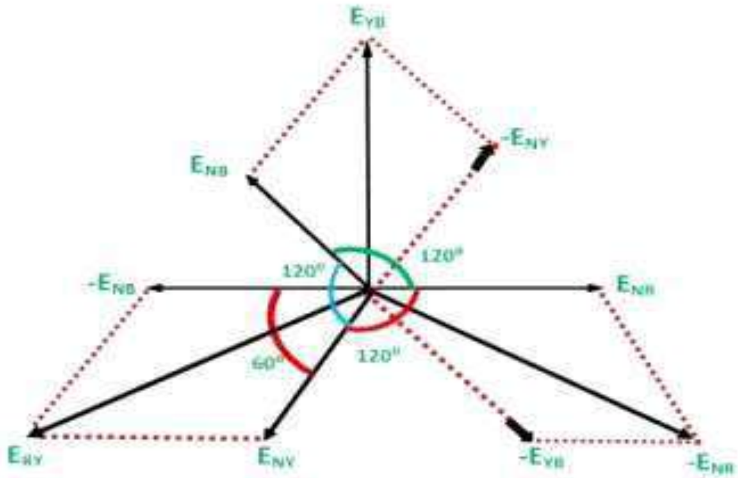
The current flowing through each phase is called Phase current I_{ph}, and the current flowing through each line conductor is called Line Current I_L. Similarly, the voltage across each phase is called Phase Voltage E_{ph}, and the voltage across two line conductors is known as the Line Voltage E_L.

Relation between Phase Voltage and Line Voltage in Star Connection The Star connection is shown in the figure below.



As the system is balanced, a balanced system means that in all the three phases, i.e., R, Y and B, the equal amount of current flows through them. Therefore, the three voltages E_{NR}, E_{NY} and E_{NB} are equal in magnitude but displaced from one another by 120 degrees electrical.

The Phasor Diagram of Star Connection is shown below.



The arrowheads on the emfs and current indicate direction and not their actual direction at any instant.

Now,

$E_{NR}=E_{NY}=E_{NB}=E_{ph}$ (in magnitude)

There are two phase voltages between any two lines.

Tracing the loop NRYN

$$\overline{E_{NR}} + \overline{E_{RY}} - \overline{E_{NY}} = 0 \quad \text{or}$$

$$\overline{E_{RY}} = \overline{E_{NY}} - \overline{E_{NR}} \quad \text{(vector difference)}$$

To find the vector sum of E_{NY} and $-E_{NR}$, we have to reverse the vector E_{NR} and add it with E_{NY} as shown in the phasor diagram above.

Therefore,

$$E_{RY} = \sqrt{E_{NY}^2 + E_{NR}^2 + 2E_{NY}E_{NR}\cos 60^\circ} \quad \text{or}$$

$$E_L = \sqrt{E_{ph}^2 + E_{ph}^2 + 2E_{ph}E_{ph} \times 0.5} \quad \text{or}$$

$$E_L = \sqrt{3E_{ph}^2} = \sqrt{3}\, E_{ph} \quad \text{(in magnitude)}$$

Hence, in Star Connections Line voltage is root 3 times of phase voltage.

$$\text{Line voltage} = \sqrt{3} \times \text{Phase voltage}$$

Relation between Phase Current and Line Current in Star Connection

The same current flows through phase winding as well as in the line conductor as it are connected in series with the phase winding.

$$I_R = I_{NR}$$

$$I_Y = I_{NY} \quad \text{and}$$

$$I_B = I_{NB}$$

Where the phase current will be

$$I_{NR} = I_{NY} = I_{NB} = I_{ph}$$

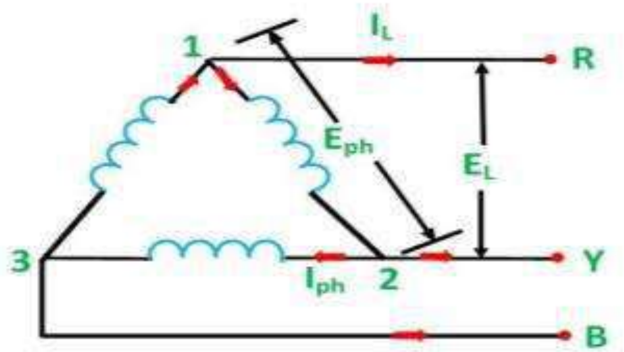
The line current will be

$$I_R = I_Y = I_B = I_L$$

Hence, in a 3 Phase system of Star Connections, the Line Current is equal to Phase Current.

Delta or Mesh connection

In **Delta (Δ) or Mesh connection**, the finished terminal of one winding is connected to start terminal of the other phase and so on which gives a closed circuit. The three line conductors are run from the three junctions of the mesh called Line Conductors. The connection in Delta form is shown in the figure below.

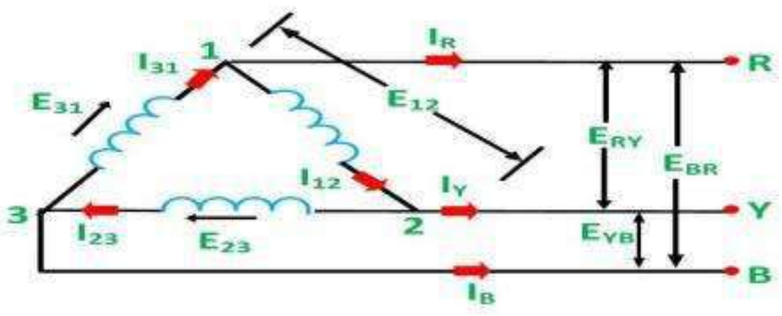


The current flowing through each phase is called **Phase Current (Iph)**, and the current flowing through each line conductor is called **Line Current (I_L).**

The voltage across each phase is called **Phase Voltage (E_{ph})**, and the voltage across two line conductors is called **Line Voltage (E_L).**

Relation between Phase Voltage and Line Voltage in Delta Connection

To understand the relationship between the phase voltage and line voltage in the Delta consider the figure A shown below.



It is clear from the figure that the voltage across terminals 1 and 2 is the same as across the terminals R and Y. Therefore,

$E_{12}= E_{RY}$

Similarly,

$E_{23}= E_{YB}$ and $E_{31} = E_{BR}$

Where, the phase voltages are

$E_{12}= E_{23}= E_{31} = E_{ph}$

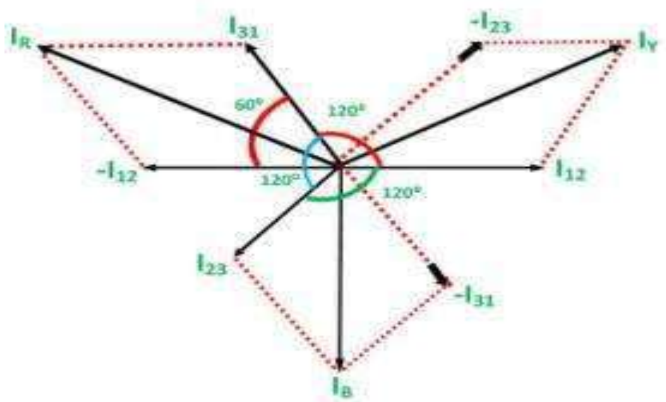
The line voltages are

$E_{RY} = E_{YB} = E_{BR}= E_L$

Hence, in Delta Connection Line Voltage is equal to Phase Voltage.

Relation between Phase Current and Line Current in Delta Connection

As in the balanced system the three phase current I_{12}, I_{23} and I_{31} are equal in magnitude but are displaced from one another by 120 degrees electrical.The **phasor diagram** is shown below.



Hence, $I_{12} = I_{23} = I_{31} = I_{ph}$

If we look at figure, it is seen that the current is divided at every junction 1, 2 and 3.

Applying Kirchhoff's Law at junction 1

The Incoming currents are equal to outgoing currents.

$$\overline{I_{31}} = \overline{I_R} + \overline{I_{12}}$$

And their vector difference will be given as

$$\overline{I_R} = \overline{I_{31}} - \overline{I_{12}}$$

The vector I_{12} is reversed and is added in the vector I_{31} to get the vector sum of I_{31} and $-I_{12}$ as shown above in the phasor diagram. Therefore,

$$I_R = \sqrt{I_{31}^2 + I_{12}^2 + 2I_{31}I_{12}\cos 60^\circ} \quad \text{or}$$

$$I_L = \sqrt{I_{ph}^2 + I_{ph}^2 + 2I_{ph}I_{ph} \times 0.5}$$

As we know, $I_R = I_L$, therefore,

$$I_L = \sqrt{3I_{ph}^2} = \sqrt{3}I_{ph}$$

Line current = $\sqrt{3}$ * Phase Current

Hence, in Delta connection line current is root three times of phase current.

Short questions with answers
Module 2

Q1. Differentiate between rms value and average value.
Ans. "RMS" stands for "Root-Mean-Squared", also called the effective or heating value of alternating current, which would provide the same amount of heat generation in a resistor as the AC voltage would if applied to that same resistor.
The average value of a periodic waveform whether it is a sine wave, square wave or triangular waveform is defined as: "the quotient of the area under the waveform with respect to time". In other words, the averaging of all the instantaneous values along time axis with time being one full period, (T).

Q2. What do you mean by resonance? Explain.
Ans. Resonance in an AC circuit refers to that state of the circuit in which the inductive reactance of the circuit is equal to its capacitive reactance
At resonance, the series impedance of the two elements is at a minimum and the parallel impedance is a maximum.

Q3. Discuss the significance of phasor diagram in electrical engineering.
Ans. Phasor Diagram is a graphical way of representing the magnitude and directional relationship between two or more alternating quantities. Sinusoidal waveforms of the same frequency can have a Phase Difference between themselves which represents the angular difference of the two sinusoidal waveforms. Every phasor in the diagram will have the same angular velocity because they represent sine waves of identical frequency. The length of the each phasor arm is directly related to the amplitude of the wave it represents, and the angle between the phasors is the same as the angle of phase difference between the sine waves.

Q4. Write the mathematical expression for 50Hz sinusoidal voltage supplied for domestic purposes at 230V.
Ans. $V = V_m \text{Sinwt}$

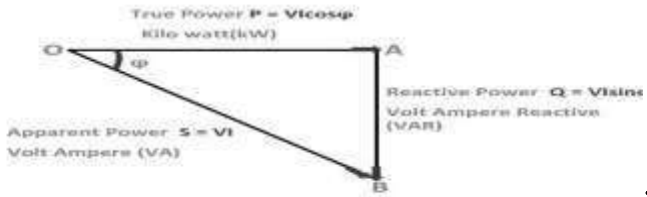
$V_{rms} = 230$ V

$V_m = \sqrt{2} * V_{rms} = \sqrt{2} * 230 = 325.22V$

$w = 2\pi f = 2\pi 50 = 100\pi$

$V = V_m \text{Sinwt} = 325.22 \text{Sin}(100\pi t)$

Q5. Draw the power triangle and define various types of power.
Ans. Power Triangle is the representation of a right angle triangle showing the relation between active power, reactive power and apparent power. When each component of the current that is the active component ($I\cos\phi$) or the reactive component ($I\sin\phi$) is multiplied by the voltage V, a power triangle is obtained shown in the figure below



:

True power: The power which is actually consumed or utilized in an ac circuit.
Reactive power: The power which flow back and forth or reacts upon itself.
Apparent power: The product of the rms voltage and the rms current is called apparent power

Q6. How will you differentiate between AC and DC circuit.

Basis	**Alternating current**	**Direct current**
Definition	The direction of the current reverse periodically.	The direction of the current remain same.
Causes of flow of electrons	Rotating a coil in a uniform magnetic field or rotating a uniform magnetic field within a stationary coil	Constant magnetic field across the wire
Frequency	50 or 60 Hertz	Independent of frequency
Direction of flow of electrons.	Bidirectional	Unidirectional
Power Factor	Lies between 0 and 1	Always 1
Polarity	It has polarity (+, -)	Do not have polarity
Obtained From	Alternators	Generators, battery, solar cell, etc.
Type of load	Their load is resistive, inductive or capacitive.	Their load is usually resistive in nature.
Graphical Representation	It is represented by irregular waves like triangular wave, square wave, square tooth wave, sine wave.	It is represented by the straight line.
Transmission	Can be transmitted over long distance with some losses.	It can be transmitted over very long distance with negligible losses.
Convertible	Easily convert into direct current	Easily convert into alternating current
Harazdous	Dangerous	Very dangerous
Application	Factories, Industries and for the domestic purposes.	Electroplating, Electrolysis, Electronic Equipment etc.

Q7. Define Form Factor and Peak Factor.

Ans. The ratio of the root mean square value to the average value of an alternating quantity (current or voltage) is called Form Factor.

Peak Factor is defined as the ratio of maximum value to the R.M.S value of an alternating quantity. The alternating quantities can be voltage or current.

Q8. Describe the advantage of three –phase system over single phase system.

Ans.

1. Power delivered is constant. In single phase circuit the power delivered is pulsating and objectionable for many applications.
2. For a given frame size a polyphase machine gives a higher output than a single phase machine.
3. Polyphase induction motors are self starting and are more efficient. Single phase motor has no starting torque and requires an auxiliary means for starting.
4. Comparing with single phase motor, three phase induction motor has higher power factor and efficiency.
5. Three phase motors are very robust, relatively cheap, and generally smaller, have self-starting properties, provide a steadier output and require little maintenance compared with single phase motors.
6. For transmitting the same amount of power at the same voltage, a three phase transmission line requires less conductor material than a single phase line. The three phase transmission system is so cheaper.
7. For a given amount of power transmitted through a system, the three phase system requires conductors with a smaller cross-sectional area.
8. This means a saving of copper and thus the original installation costs are less. Polyphase motors have uniform torque whereas most of the single phase motors have pulsating torque.
9. Parallel operation of three-phase generators is simpler than that of single phase generator.
10. Polyphase system can set up rotating magnetic field in stationary windings.

Ch3: Transformer

(1)

Magnetic Materials materials in which a state of magnetisation can be induced.

1. Paramagnetic materials which are not strongly attracted by a magnet eg aluminium, tin (μ_r - relative permeability is small but +ive)
2. Diamagnetic materials which are repelled by a magnet. eg Zinc, mercury, lead (μ is slightly less than unity)
3. ferromagnetic materials The material which are strongly attracted by a magnet eg iron, steel, nickel. (μ is very high several hundred to many thousand).

ferromagnetic materials

a) Soft magnetic materials (which are easily magnetized) eg. iron and its alloy with nickel, cobalt.
Uses Transformer, generators & relay

b) Hard magnetic materials (those retaining their magnetising with great tenacity) eg. Include cobalt steel & alloys of nickle, Aluminium.
Uses Also known as permanent magnet
Uses in loudspeaker.

4. ferrites A special group of ferromagnetic material that occupy an intermediate position b/w ferromagnetic & non magnetic materials.

Ferrites

a) ~~Soft~~ Hard ferrites
These are ceramic permanent magnetic materials. eg. $BaFeO_3$ (barium Iron oxide)
$SrFeO_3$ (Stronium Iron oxide)
Uses: loudspeaker, telephone

b) ~~Hard~~ Soft ferrites.
Ceramic magnets/ferromagnetic ceramic are made of Iron oxide (FeO_3) with one or more divalent oxide such as NiO, MnO, ZnO
Uses Tranducer

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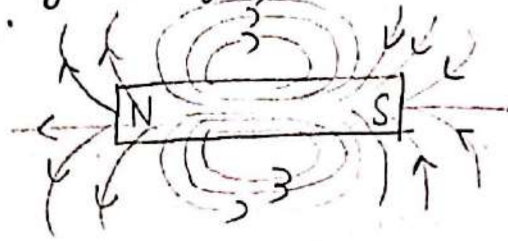
Magnetic field The space around the pole of a magnetic is called magnetic field and is represented by magnetic lines of force.



field around a bar magnet represented by lines of force.

Magnetic flux is the total no. of line of force comprising the magnetic field. ϕ (symbol) webers (unit)

Magnetic flux Density is defined as magnetic flux passing per unit area through any material (& known as magnetic induction)

$$B = \frac{\phi}{a\,(area)}$$ (scalar quantity)

Imp

Relationship b/w Induction density & magnetic field intensity

$B = \mu_0 H$ (in free space)

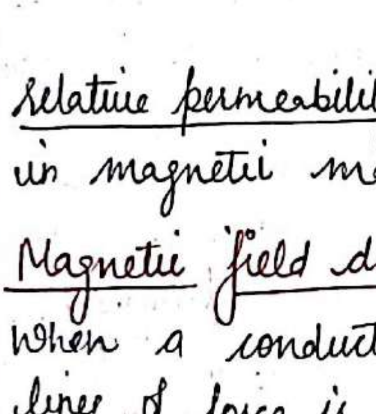
$B = \mu_0 \mu_r H$ — μ_r relative permeability (varies)

$B = \mu H$ — μ_0 = permeability of free space $= 4\pi \times 10^{-7}$ H/m. (const)

Relative permeability is the ratio of flux density produced in magnetic material to flux density produced in vacuum.

Magnetic field due to electric current flow.

When a conductor carries electric current the magnetic lines of force is set up and the region around the magnet where its poles exert a force is called magnetic field.



* field near the conductor is stronger & become weak as radial distance ↑es.
* Strength of magnetic field around the conductor depend upon the current flow through it.
* The direction of M.F ⊥ to direction of flow of current in it. reverse then the direction of flow of current reverse

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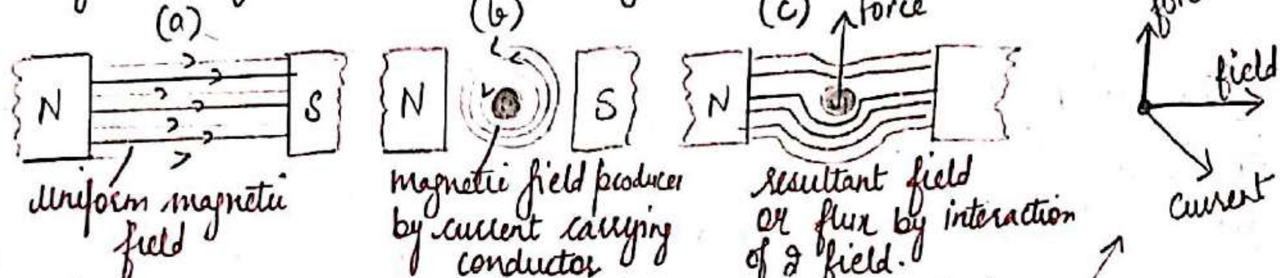
The direction of magnetic lines of force around conductor is determined by: (2)

Right Hand thumb Rule
(thumb point the direction of flow of current
curling fingers: direction of magnetic lines of force)

Right hand cork screw rule
screw rotation (clockwise) direction of magnetic lines of force
current (inward)

<u>force on current carrying conductor place in the M.F</u>

When a current carrying conductor is placed in uniform magnetic field ⊥ to it, a force is experienced by a conductor

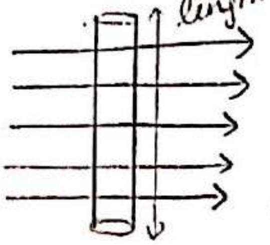


*The direction of force is determine by fleming's left Hand rule.
* If direction of current is reverse in conductor, the force produce on conductor is also reversed.

∴ force experienced by current carrying conductor

$f = BIl$ (at right angle)
or
$f = BIl \sin\theta$ (conductor lies at θ with M.F)

B → flux density
I → current
l → effective length of conductor ⊥ to field.



<u>B-H curve / magnetisation</u> Imp

The curve giving relationship between induction density (B) (magnetic flux density) and magnetising force (H) (magnetic field intensity) is known as B-H curve.
It has 4 distinct region oa, ab, bc and region beyond c.

~~1. oa (In this region the B increases almost linear with H)~~

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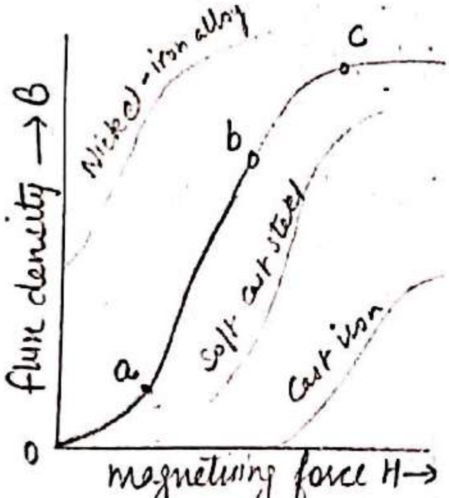
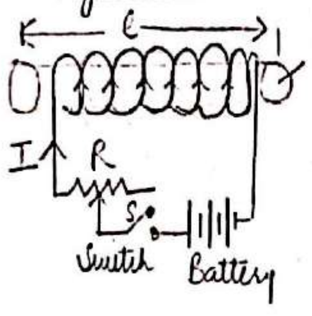
1. Oa: increase in B is very small
2. ab: B increases almost linearly with H
3. bc: Again the increase in B is small
4. Region beyond point c: B is almost const.
(This is due to magnetic saturation of the material)



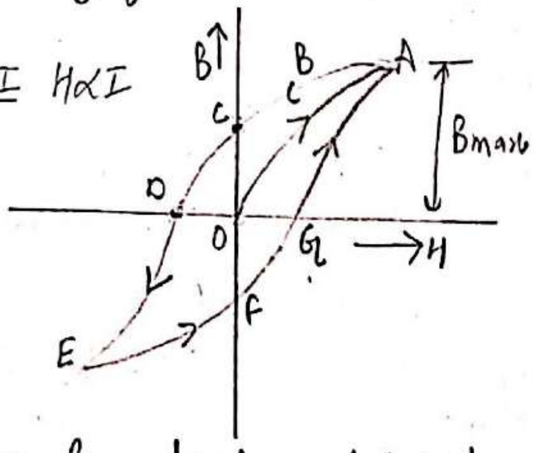
* BH curve depend on material only. So it is different from cast iron, soft cast steel, nickel iron alloy.

Magnetic Hysteresis: If magnetic substance is magnetised in strong M.f, it retains magnetism after the magnetic force has been withdrawn. The phenomenon of lagging of magnetisation or (B) behind the magnetising force is known as magnetic hysteresis.



$H = \frac{NI}{l}$ $H \alpha I$

$B = \mu H$



$H = \frac{NI}{l}$

$H \alpha I$

* When current flows the magnetising force produce. Let H is increased from zero to a certain maximum value and then gradually reduce to zero.

* The values of B in the core is determined from various value of magnetising force (H)

* It will observed that B-H curve obtained for decreasing value of H lies above that obtained for increasing values of H.

* The induction density B is represented by OC and $H=0$ is called as <u>recidulal magnetism</u>. The power of retaining the RM is called retentivity of the material.

* If direction of current flow is reversed, H is reversed. A The current be increased in negative direction until $B=0$ & when $B=0$ $H=OD$ as show in fig. It neutralize the RM, & known as (demagnetising force) <u>Coercive force</u>

* If demagnetising force (H) is increased further to the maximum value and again decreased to zero, reversed and further increased in original or +ive direction of max value, a closed loop ACDEFGA is obtained, which is usually known as <u>hysteresis loop</u> & <u>magnetic cycle</u>

* B lags behind H and these two never attain zero value simultaneously.

Imp
* Faraday's Law of electromagnetic Indution.
* Dynamically & statically induced emf?
* coefficient of coupling $K = \frac{M}{4L_2}$

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* Analogy b/w Electric & Magnetic circuit. V.V. Imp

Electric Circuit	Magnetic Circuit
Similarities:	
1. The closed path for electric current	1. The closed path for magnetic flux.
2. current = $\frac{emf}{resistance}$	2. flux = $\frac{mmf}{reluctance}$
3. Current is in ampere	3. flux in weber
4. Emf in volts	4 mmf in AT
5 Resistance $R = \rho \frac{l}{a}$	5 Reluctance $S = \frac{l}{a \mu_0 \mu_r}$
6. conductance = $\frac{1}{Resistance}$	6 Permeance = $\frac{1}{Reluctance}$
7. Conductivity Permitivity (ε)	7. μ Permeability
8 Resistivity	8 Reluctivity
9. $J = \frac{I}{a}$ current density	9 $B = \frac{\phi}{a}$ flux density
10. $\mathcal{E} = \frac{V}{d}$ electric field intensity	10. $H = \frac{NI}{l}$ magnetic field intensity
Dissimilarities	
1. Electric Current flow	1. Magnetic flux doesnot flow it set up.
2 There are large no. of insulators	2. for ϕ, no perfect insulator need. It can be set up in air, rubber, glass.
3. Energy is expanded and dissipated in the form of heat.	3. Once magnetic field is setup no energy is expanded.

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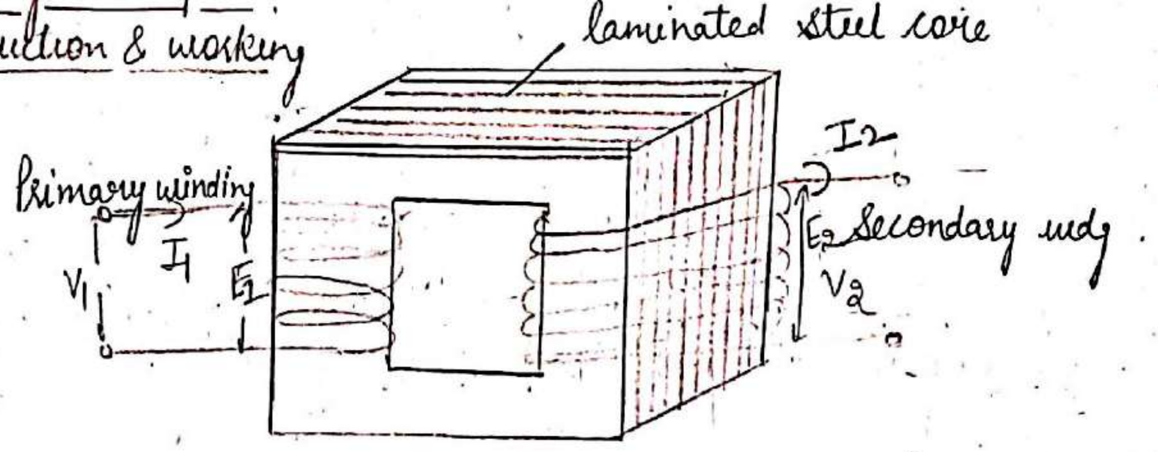
Transformer

A transformer is a static device which transfers ac electric power from one circuit to other at the same freq; but the voltage level is usually changed.

* When the voltage is raised on the output side $V_2 > V_1$ the transformer is called a step up transformer.
* When the voltage is lowered on the output side $V_2 < V_1$ the transformer is said to be step down transformer.

Operating Principle

Construction & working



* The core is built up of thin silicon steel lamination to provide a path of low reluctance to the magnetic flux.
* Primary wdg = connected to supply mains.
  Secondary wdg = connected to the load circuit.
* HV winding: The wdg. connected to higher voltage circuit is called the high voltage winding.
  LV winding: connected to lower voltage circuit.

Basic principle of transformer is electromagnetic induction.

Working If ac supply is given to primary winding, a current flows through it which produces an alternating flux ϕ in the core. Since this flux is alternating and links in with secondary winding also, induces an emf in secondary winding. The emf in secondary winding enables it to deliver current to an external load connected across it.

* Thus energy is transformed from primary winding to secondary winding by means of electromagnetic induction.

* The flux of core links not only with secondary wdg but also with primary wdg, so produces self induced emf in primary wdg. This induced emf in the primary wdg oppose the Voltage applied by the source. ∴ it's known as back emf of the primary.

Transformer on DC

It cannot operate on DC supply and never connected to a dc source.

Reason: If DC voltage is connected to Primary wdg. the flux produced in core will not vary but remain constant in magnitude ∴ no emf will induced in secondary winding except at moment of switching ON. No self induced emf in primary winding. Due to this a heavy current flow through the primary side which may result in damage / burn the primary winding.

* Transformer on load and No load. (refer book) Imp. Phasor diagram

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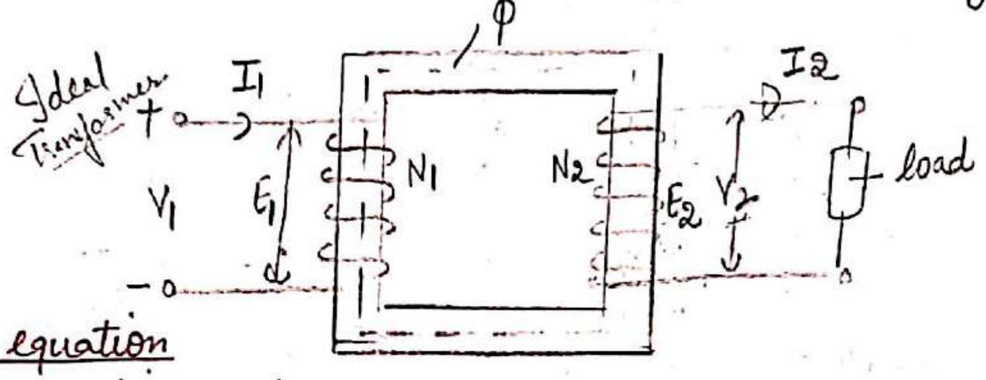
Transformer

Ideal transformer

it is an imaginary transformer that has no winding resistance, no magnetic leakage, no iron loss and zero reluctance

Actual/ Practical transformer

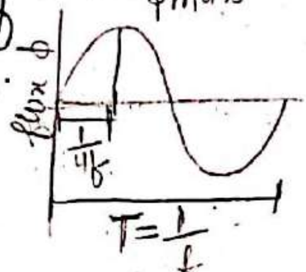
it is an actual transformer which operate at particular frequency and has wdg resistance, magnetic leakage, iron losses, copper loss & magnetic reluctance



Emf equation

EMf equation ϕ_{max}, f ϕ_{max} at $\frac{1}{4f}$ sec ϕ_{max}

Average Rate of change of flux $\frac{d\phi}{dt} = \frac{\phi_{max}}{\frac{1}{4f}} = 4f\phi_{max}$.



form factor

~~Rms~~ Avg. emf induced per turn $= 4f\phi_{max}$ Volts

$\frac{E_{rms}}{E_{avg}} = 1.11$ Rms value of emf induced $= 1.11 \times 4f\phi_{max}$

On primary side

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

On secondary side

$$E_2 = 4.44 f \phi_{max} N_2$$

where $\phi_{max} = B_{max} \times a$ webers)

Transformation Ratio

$$K = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$ } Voltage transformation ratio

$\because$ Output P = Input P

$V_2 I_2 = V_1 I_1$

$$\frac{I_1}{I_2} = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1} = K \quad \text{or} \quad \frac{I_2}{I_1} = \frac{1}{K}$$ Current transformation ratio

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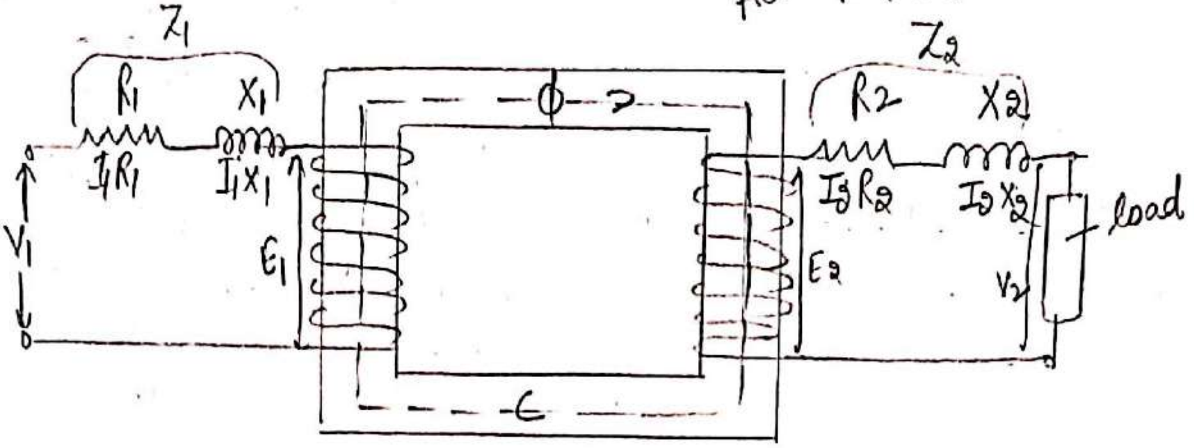
Equivalent circuit of Transformer Imp

1 Equivalent resistance and reactance — Actual/practical Transformer.



Referred to Sec. side

Total Resistive drop $= KI_1R_1 + I_2R_2$

$I_1 = KI_2$ (primary resistive drop)

(As primary resistive drop referred to sec. will be K times of i.e. KI_1R_1 and KI_1X_1))

Total Res. drop $= K^2 I_2 R_1 + I_2R_2$

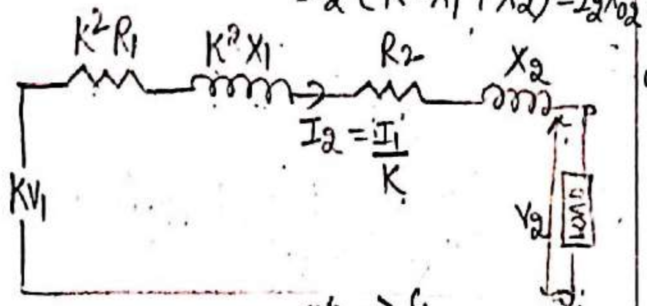
$= I_2 (K^2 R_1 + R_2) = I_2 R_{02}$

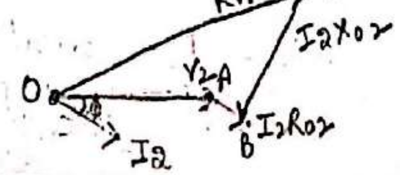
IIly reactive drop

$= KI_1X_1 + I_2X_2$

$= K^2 I_2 X_1 + I_2 X_2$

$= I_2 (K^2 X_1 + X_2) = I_2 X_{02}$





Referred to primary side

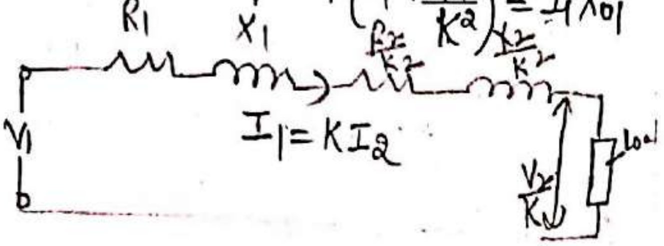
Sec Resistive drop referred to primary

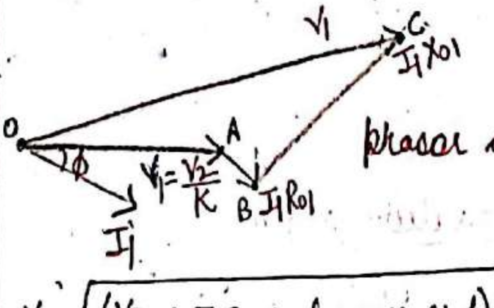
$\frac{I_2R_2}{K} = \frac{I_1 R_2}{K^2}$

IIly reactive drop $\frac{I_2X_2}{K} = \frac{I_1 X_2}{K^2}$

∴ T. Resistive drop $= I_1\left(R_1 + \frac{R_2}{K^2}\right) = I_1 R_{01}$

T. Reactive drop $= I_1\left(X_1 + \frac{X_2}{K^2}\right) = I_1 X_{01}$





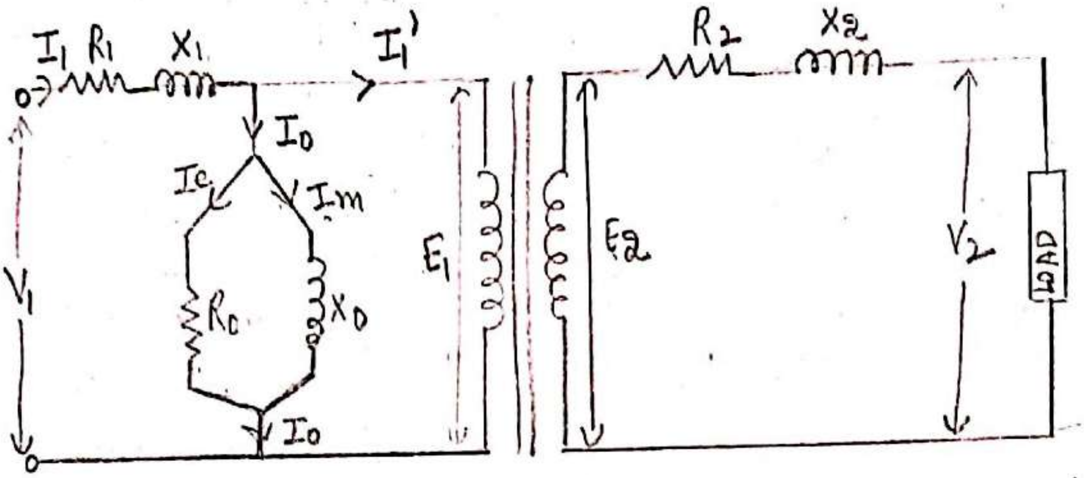
phasor diagram

$V_1 = \sqrt{\left(\frac{V_2}{K} + I_1 R_{01}\cos\phi + I_1 X_{01}\sin\phi\right)^2 + \left(I_1 X_{01}\cos\phi + I_1 R_{01}\sin\phi\right)^2}$

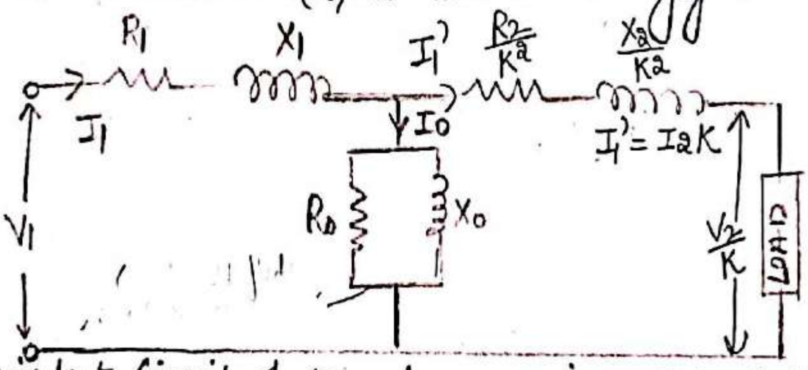
Resistive load $= V_1 = \frac{V_2}{K} + I_1 R_{01}\cos\phi$ (small)

Capacitive load $V_1 = \frac{V_2}{K} + I_1 R_{01}\cos\phi - I_1 X_{01}\sin\phi$

Equivalent circuit of a transformer is very helpful in determination of behaviour of the device under various condition of operation.



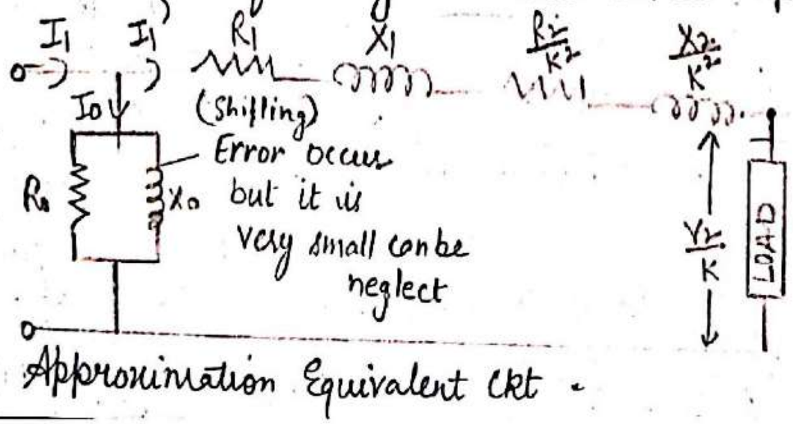
The induced emf in primary wdg. E_1 causes less primary voltage drop: This voltage causes iron loss current (I_c) and magnetising current (I_m) to flow. These 2 component of no load current represented by non inductive resistance R_0 and pure reactance (X_0) as shown in fig.



Where $K = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1}$

No load condition

Equivalent Circuit of transformer with all Sec. Impedances transferred to Primary side



I_0 is very small as compare to full load rated current.

So under load condition this branch can be omitted.

Approximation Equivalent Ckt.

Losses in Transformer

The transformer is static device so there are no friction or windage losses.

losses occuring in a transformer

- Iron or Core losses (Constant losses)
- Copper or ohmic losses (Variable losses) — full load losses

1. **Iron losses**. Caused by alternating flux in the core.

a) **Hysteresis loss** The core is subjected to an alternating magnetizing force and for each cycle of emf a hysteresis loop is traced out.

(When the magnetic material is subjected to reversal of flux, power is required for continous reversal of molecular magnets. This power is dissipated in the form of heat and called hystersis loss. This loss can be minimized by using silicon steel material for construction of core)

$$P_H = K_h (B_{max})^{1.6} f v$$

(K_h – hysteresis coefficient, B_{max} – flux density, f – frequency, v – volume)

2 b. **Eddy current loss**: Since flux in the core of transformer is alternating, it links with the magnetic material of the core itself. This induces an emf in the core & circulates eddy currents. Power is required to maintain these eddy currents. This power is dissipated in the form of heat and is called eddy current loss.

$P_e = K_e v f^2 t^2 B_{max}^2$ (minimised by making core of thin lamination)

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2. Copper or Ohmic losses

These losses occur due to the ohmic resistance of transformer windings.

$$\text{Copper losses } (P_c) = I^2 R \text{ or } (I_1^2 \cdot R_{01} + I_2^2 R_{02})$$

(Primary) (Secondary)

These losses are variable loss (as load varies the current varies)

Voltage Regulation

When a T/f is loaded, with a const. supply voltage the terminal voltage changes due to voltage drop in the internal parameter of the transformer i.e. primary and secondary resistance and inductive reactance.

The internal V.D is also depends upon the load and its power factor.

* At const. supply voltage, the change in secondary terminal voltage from no load to full load w.r.t no load voltage is called Voltage regulation of T/f

$$V.R = \frac{E_2 - V_2}{E_2}$$

$$\% V.R = \frac{E_2 - V_2}{E_2} \times 100$$

for inductive load $E_2 = V_2 + I_2 R_{02} \cos\phi + I_2 X_{02} \sin\phi$

for capacitive load $E_2 = V_2 + I_2 R_{02} \cos\phi - I_2 X_{02} \sin\phi$ (leading p.f)

where E_2 = secondary terminal voltage at ~~full~~ no load

V_2 = secondary terminal voltage at full load.

Condition for zero regulation. If numi zero

$I_2 R_{02} \cos\phi + I_2 X_{02} \sin\phi = 0 \quad \tan^{-}\phi = \frac{-R_{02}}{X_{02}}$ occurs at leading power factor

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V. Imp
Efficiency

$$\eta = \frac{\text{Output power}}{\text{Input power}} = \frac{\text{Output power}}{\text{Output power + losses}}$$

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

P_i (Iron loss) = hysteresis + eddy current losses.

P_c (Copper losses) = $I_2^2 R_{02}$ — equivalent resistance referred to secondary side.

{ If x is the fraction of the full load KVA at which η is maximum

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

Condition of η_{max}.

$$\eta = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + I_2^2 R_{02}} = \frac{I_2 (V_2 \cos\phi)}{I_2 \left(V_2 \cos\phi + \frac{P_i}{I_2} + I_2 R_{02}\right)}$$

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

$\frac{d\eta}{dI_2} = 0$ - 2nd

1st: efficiency is max. $\frac{d\eta}{dx} = 0$

$$\frac{d\eta}{dI_2}\left\{V_2 \cos\phi + \frac{P_i}{I_2} + I_2 R_{02}\right\} = 0$$

$$-\frac{P_i}{I_2^2} + R_{02} = 0$$

$$-P_i + I_2^2 R_{02} = I_2^2 \times 0$$

$$I_2^2 R_{02} = P_i$$

$$\boxed{P_c = P_i}$$

Copper loss = iron losses

$$\eta_{max} = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + P_i}$$

✓ $$\boxed{\eta_{max} = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + 2P_i}}$$

✓ $$I_2 = \sqrt{\frac{P_i}{R_{02}}}$$

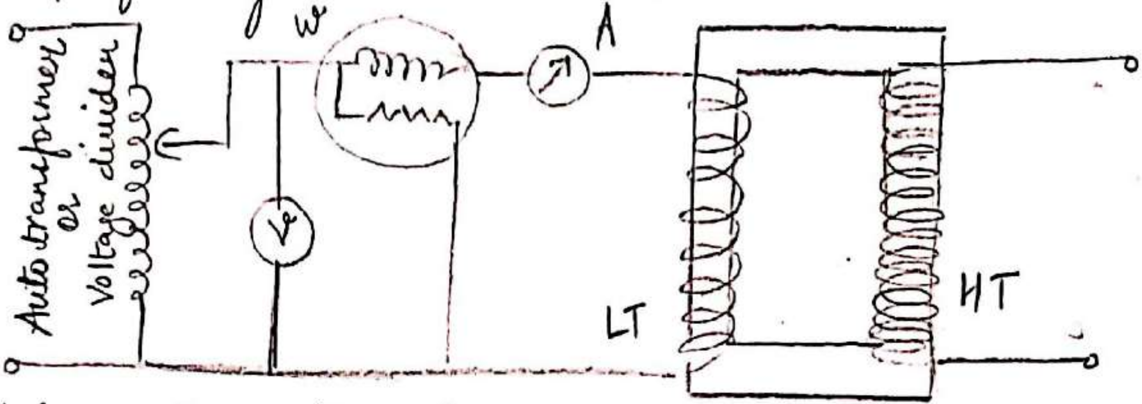
* All day η or energy efficiency or operational η = $\frac{\text{Output in KWh}}{\text{Input in KWh}}$ } over 24 hours

ckt:- circuit

Testing of transformer

a) Open ckt test or No load test.

The open circuit test is performed to find out no load current or iron losses of a transformer. This test is performed on low voltage side. The circuit arrangement for performing such test is as shown below.



The low voltage side of transformer is connected to autotransformer or voltage divider for varying the applied voltage. Ammeter, voltmeter and wattmeter are connected to measure I_0, V_{in} and W_{in} (input power). The secondary side is open circuited

Iron loss P_i = Input power at no load = W_0 watt

No load current = I_0 . Applied Voltage = V_{in}

So. $P_i = V_{in} I_0 \cos\phi_0$

$$\phi_0 = \frac{W_0}{V_{in} I_0} \text{ (Angle lag)}$$

No load current energy component $I_e = I_0 \cos\phi_0 = \frac{W_0}{V_{in}}$

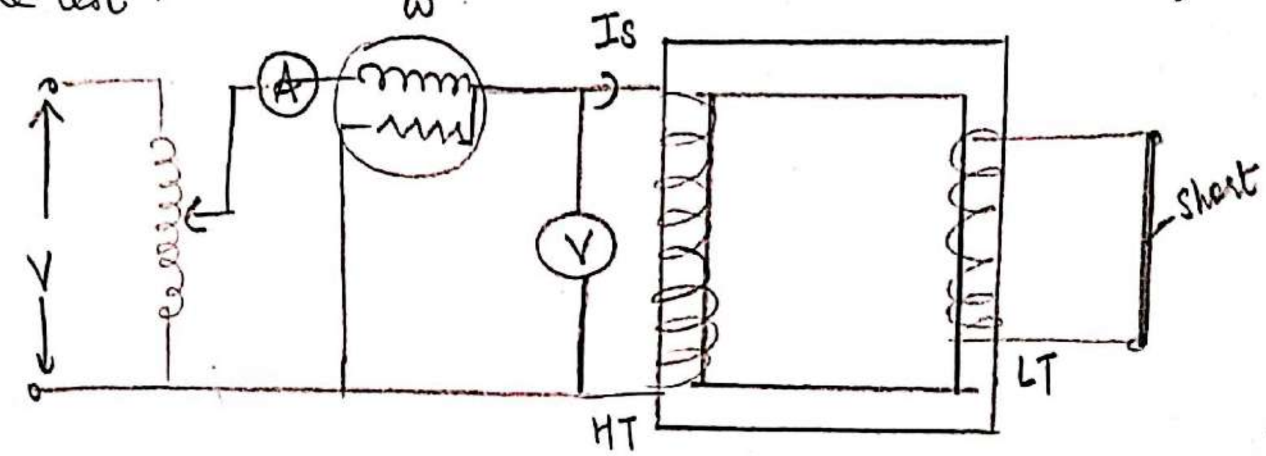
No load magnetizing component $I_m = \sqrt{I_0^2 - I_e^2}$ $I_m = I_0 \sin\phi_0$

Equivalent Circuit parameter

$$R_0 = \frac{V_{in}}{I_e} = \frac{V_{in}^2}{W_0} \qquad X_0 = \frac{V_{in}}{I_m} = \frac{V_{in}}{\sqrt{I_0^2 - I_e^2}}$$

6 Short circuit test / impedance test

This test is perform to calculate the full load Cu loss and equivalent Resistance and reactance referred to metering side. The secondary winding (LV wdg) are short circuit by a thick wire while performing the test.



Let the readings of Voltmeter, ammeter and wattmeter be V_s, I_s and W_s respectively.

full load copper loss $= P_c = I_s^2 R_{eq} \doteq W_s$

Equivalent Resistance $R_{eq} = \frac{W_s}{I_s^2}$

Equivalent impedance $Z_{eq} = \frac{V_s}{I_s}$

Equivalent reactance $X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$

The above values are referred to the metering side only.

entire:

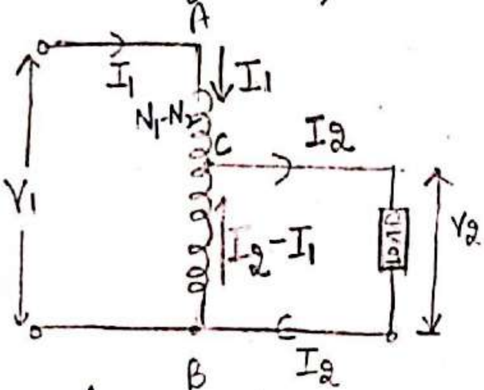
C. Back to back test / Sumpner's test / Regenerative Test.

This test is used to calculate temp rise of T/f by operating two X'former back to back for long period & measuring the temp of oil in periodic interval of time ie upto 1 hour.

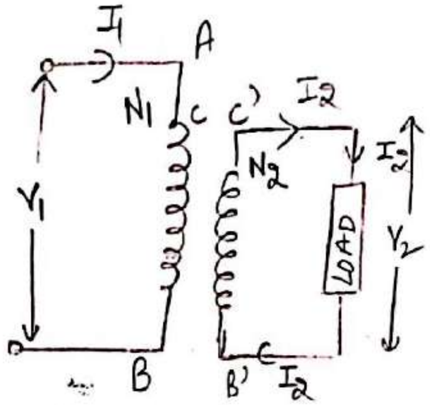
Auto Transformer

The operating principle and general construction of an auto transformer is same as that of conventional two wdg transformer.

(A transformer which has part of winding common to both primary and secondary circuits is called an auto transformer)



Auto Transformer



Conventional 2 winding transformer

Primary wdg. AC I_1 current flow   Secondary wdg BC $(I_2 - I_1)$ flows.

Power delivered to load $= V_2 I_2$

Power in AC winding $= E_{AC} I_1 = (V_1 - V_2) I_1$.

Power transformed (BC winding) $= V_2 (I_2 - I_1) = V_2 I_2 \left(1 - \frac{I_1}{I_2}\right)$

$= V_2 I_2 (1-K)$

Ratio of $\frac{\text{power transformed}}{\text{power delivered}} = \frac{V_2 I_2 (1-K)}{V_2 I_2} = 1-K$

Power conducted directly = Power delivered − Power transformed

$= V_2 I_2 - V_2 I_2 (1-K) = K \underline{V_2 I_2}$ output power

Conductor material required

In an ordinary transformer wt of conductor   As $N_1 I_1 = N_2 I_2$

$\propto (N_1 I_1 + N_2 I_2) \propto 2 N_1 I_1$

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In an auto transformer.

wt. of Cu ∝ wt. of Copper in section AB + wt. of Cu in BC Section.

Weight of Cu in Section AB $\propto (N_1 - N_2) I_1$

" " " " Section BC $\propto N_2 (I_2 - I_1)$

∴ weight of conductor in A.T $\propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$

Ratio of weights = $\frac{\text{wt. of copper in auto transformer}}{\text{wt of copper in two winding transformer}}$

$$= \frac{(N_1 - N_2) I_1 + N_2 (I_2 - I_1)}{N_1 I_1 + N_1 I_1} = \frac{N_1 I_1 - N_2 I_1 + N_2 I_2 - N_2 I_1}{2 N_1 I_1}$$

$$= \frac{N_1 I_1 + N_2 I_2 - 2 N_2 I_1}{2 N_1 I_1} = \frac{N_1 I_1 + N_1 I_1 - 2 N_2 I_1}{2 N_1 I_1} = \frac{2 N_1 I_1 - 2 N_2 I_1}{2 N_1 I_1}$$

$$= \frac{2 I_1 (N_1 - N_2)}{2 N_1 I_1} = \left(\frac{N_1}{N_1} - \frac{N_2}{N_1}\right) = (1 - K) \qquad (1-K) = \frac{Wt \cdot auto}{Wt \cdot 2wdg}$$

∴ Saving in copper = Wt_{2wdg} — Wt_o auto transformer
$= W_{2wdg} - (1-K) W_{2wdg} = K W_{2wdg}$

Advantages of auto transformer

1. Higher efficiency 2. Smaller size 3. lower cost 4. better volltage regulation.

Disadvantages of autotransformer

1. Due to common connection b/w primary and secondary both side are subject to any stress set up distirbance on either side

2. As voltage ratio of autotransformer increases the common coil is much smaller as compared with entire winding. This means that the economy gained is only a small part of transformer, therefore advantage is minimized

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Uses of autotransformer

1. To give small boost to distribution cable to correct voltage drop.
2. Used as regulating transformer
3. to obtain partial line voltages for starting induction and synchronous motor.
4. As furnances transformer.

Compare Characteristics of autotransformer and a two winding transformer

Autotransformer	Two winding transformer
1. This transformer has only one winding, a part of which is common to both primary and secondary wdg.	1. This transformer has seperate primary and secondary winding.
2. These 2 windings are connected electrically.	2. are not connected electrically.
3. It has lower losses & hence better η.	3. losses are more & hence η is less.
4. It is smaller in size	4. It is larger in size
5. It consume less copper	5. It consume more copper
6. Its cost is less.	6. Its cost is more
7. It has better voltage regulation.	7. It has poor voltage regulation

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Three phase Transformer.

A 3ϕ transformer is equivalent to 3 single phase transformer but wound on one core and enclosed with in one common case.

Importance 1. It is cheaper than a bank of 3 single phase transformer due to saving in cost of iron core, tank and oil of the bearings & other auxillary apparatus.

2. More efficient. this is due to the fact that it has shorter magnetic path & volume hence core losses is smaller.

Disadvantages 1. Larger and heavier than one single phase transformer and is difficult to handle, ship & set in place for operation.

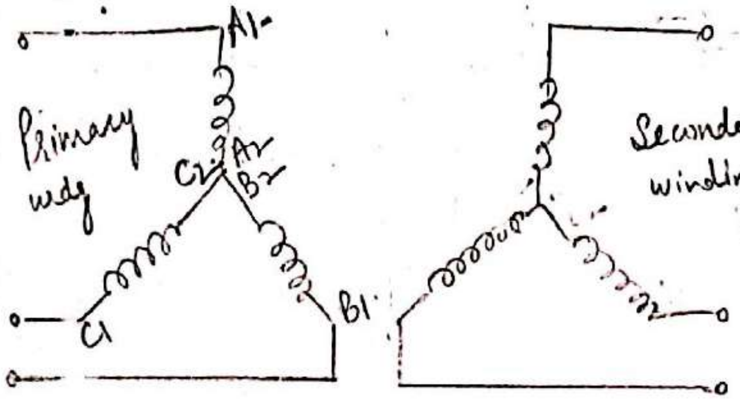
2. Difficult & costly to repair. Moreover in case of breakdown in any coil, the entire unit must be removed from service.

So the advantages of three ϕ transformer such as lesser weight, lower initial cost, lesser space requirement overweights its disadvantages.

Different winding arrangment of 3ϕ transformers are

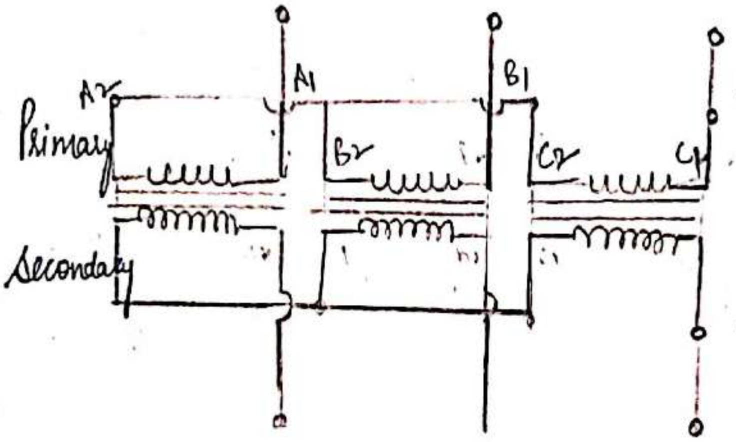
1. Star Star (for high V)
2. Delta Delta (for high I)
3. Delta Star (step up)
4. Star Delta (step down).

1. Star Star connection (Y-Y)



$V_L = \sqrt{3}\, V_{ph}$

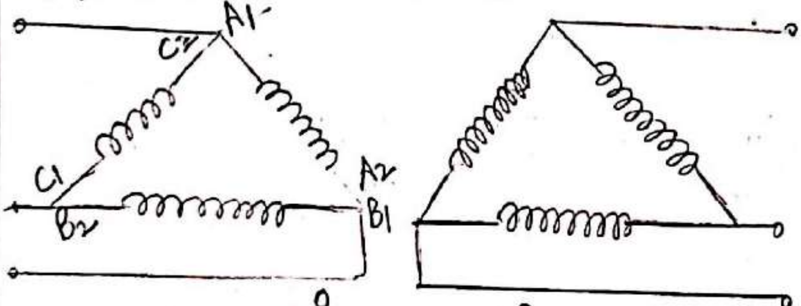
* It is economical for small rating, high voltage transformer as number to turn per phase and amount of installation is less.



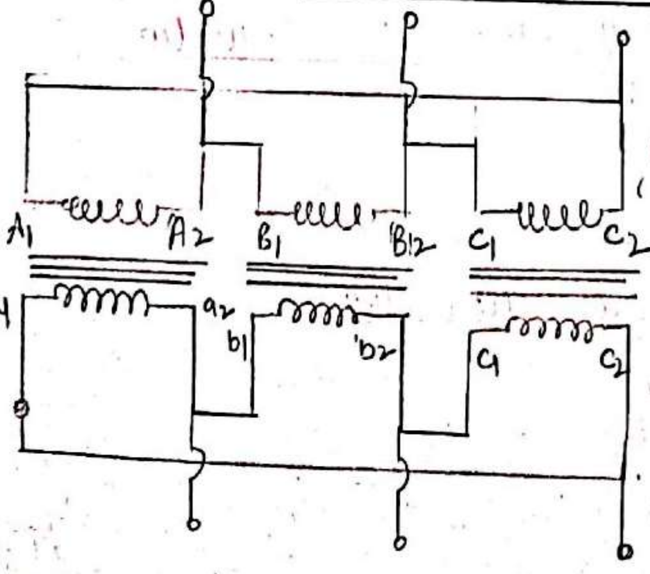
$$V_{ratio} = \frac{V_{L2}}{V_{L1}} = \frac{\sqrt{3}V_{ph2}}{\sqrt{3}V_{ph1}} = \frac{N_2}{N_1}$$

$$\text{Current}_{ratio} = \frac{I_{L2}}{I_{L1}} = \frac{I_{ph2}}{I_{ph1}} = \frac{N_1}{N_2}$$

2. Delta Delta connection.



* Used in s/s which carry large current on low voltage.
* It maintained continuity of service though fault develop in one of the phase.



$$V_{ratio} = \frac{V_{L2}}{V_{L1}} = \frac{V_{ph}}{V_{ph}} = \frac{N_2}{N_1}$$

$$I_{ratio} = \frac{I_{L2}}{I_{L1}} = \frac{\sqrt{3}I_{ph2}}{\sqrt{3}I_{ph1}} = \frac{N_1}{N_2}$$

3: Star Delta

* These connection are used where the voltage is to be stepped down. (in transmission line). The neutral of primary winding is earthed.

$$V_{ratio} = \frac{V_{L2}\ (\text{delta})}{V_{L1}\ (\text{star})} = \frac{V_{ph2}}{\sqrt{3}V_{ph1}} = \frac{1}{\sqrt{3}}\frac{N_2}{N_1}$$

$$I_{ratio} = \frac{I_{L2}}{I_{L1}} = \frac{\sqrt{3}\,I_{ph2}}{I_{ph1}} = \sqrt{3}\frac{N_1}{N_2}$$

4. Delta star

* These connection are used to step up the voltage. (Used in high tension transmission line).

Delta Star

$$V_{ratio} = \frac{V_{L2}}{V_{L1}} = \frac{\sqrt{3}V_{ph2}}{V_{ph1}} = \sqrt{3}\frac{N_2}{N_1}$$

$$I_{ratio} = \frac{I_{L2}}{I_{L1}} = \frac{I_{ph2}}{\sqrt{3}I_{ph1}} = \frac{N_1}{\sqrt{3}N_2}.$$

Also used in distribution s/s. The neutral of secondary wdg is earthed to provide 3ϕ 4 wire system.

Advantages of Star connection over delta connection

Each star connected transformer is wound for only $\left(\frac{V_L}{\sqrt{3}}\right)$ 57.7% of line of line voltage. So smaller transformer built for high voltage than possible with delta connection.

Advantages of Delta connection over star.

When three transformer are connected in delta, ~~one may~~ if one transformer is removed the remaining unit will carry 57.7% of original 3ϕ load and maintain the continuity of supply.

Ideal transformer

It is a transformer which has no ohmic resistance and no magnetic leakage flux i.e flux which produce losses and means all the flux produced in core links with primary as well as secondary hence it has no cu losses, and core losses. so efficiency is 100%. Its end terminal voltage are equal to induced emf and here pure inductor will draw only magnetising current which only produces useful flux.

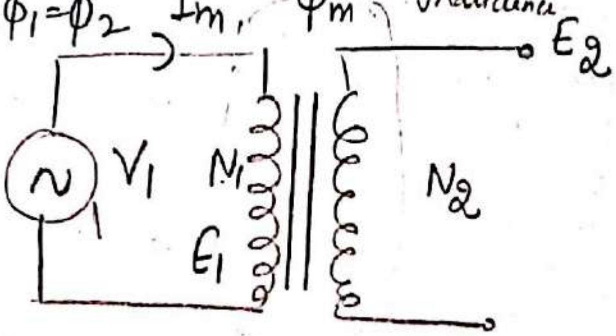
No leakage Inductance

No power losses so i/p = o/p. $\phi_1 = \phi_2$

$$E_2 I_2 \cos\phi_2 = E_1 I_1 \cos\phi_1$$

$$E_2 I_2 = E_1 I_1$$

$$\therefore \frac{E_2}{E_1} = \frac{I_1}{I_2}$$

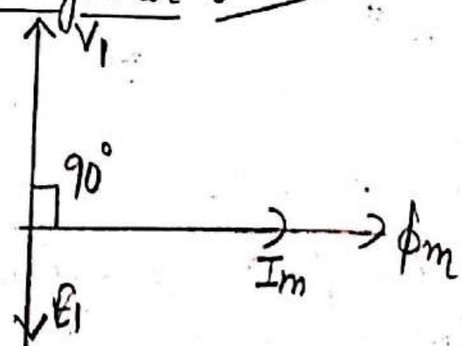


end terminal V = induced emf.

primary and secondary winding behave as pure inductor and draw only useful magnetising current.

Phasor diagram of ideal Transformer

V. Imp



Transformer ON "NO load" condition

1. In actual transformer losses in the wdg cannot be neglected.
2. The current cannot be neglected.

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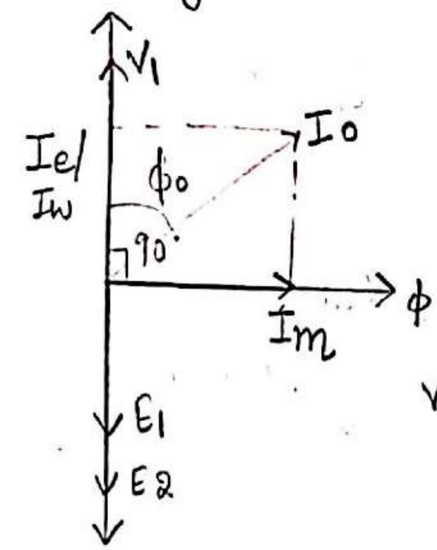
* The current drawn by T/F on No load condition is called no load or exciting current and is denoted by I_0.

4. This I_0 current lags behind voltage V_1 by angle ϕ_0

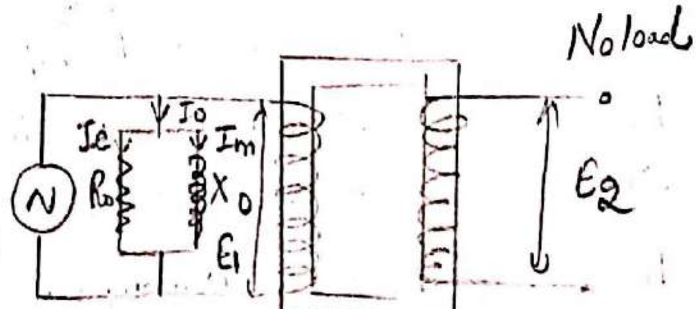
5. The component I_w is called active or working component of current which supplies iron and Cu losses in primary. $I_e = I_w$ (energy component)

6. The comp I_m is called the magnetising component which is in quadrature to supply voltage and it produces flux in the core.



R_0 = exciting resistance

X_0 = " reactance



$$I_e = I_0 \cos\phi_0$$

$$I_m = I_0 \sin\phi_0$$

no load current $I_0 = \sqrt{I_e^2 + I_m^2}$

* At no load the primary Cu losses are so small that it can be neglected so power drawn by the circuit is used to produce only iron losses.

$$\cos\phi_0 = \frac{I_w}{I_0}$$

I_0 is very small 2% 5%

$$P_0 = V_1 I_0 \cos\phi_0$$

(Power at ~~not~~ No Load)

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Transformer on ON load V. Imp

(B)

1. This analysis is done by neglecting wdg resistance and leakage flux.
2. when certain load is connected across sec wdg the current I_2 flows in the wdg.
3. The phase angle of I_2 depends upon the nature of load (resistive, capacitive, inductive)
4. T/f is on No load it draws I_0 current and produce flux in the core.
5. when transformer is loaded the ~~p~~ secondary current I_2 will also produce ϕ_2 in the core which oppose the main flux (ϕ) which is set up by current I_0.
6. As the resultant flux ϕ decreases, the induced emf E_1 also decreases supply Voltage V_1, being the same causes additional flow of current from the supply main. This additional current I_1' is called counter balancing current and it neutralises the effect of flux ϕ_2 by supplying additional flux ϕ_2' in the core which cancel the flux ϕ_2 produced by I_2.

Counter balancing current I_1' will be equal to and opp. to load current I_2.

$$I_1 = I_0 + I_1'$$

Phasor diagram

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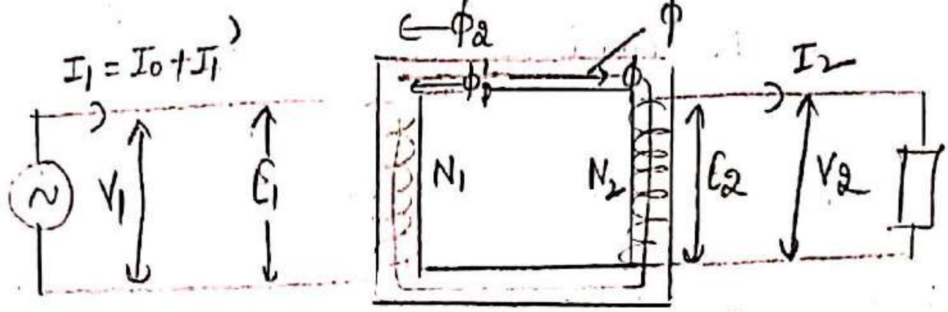
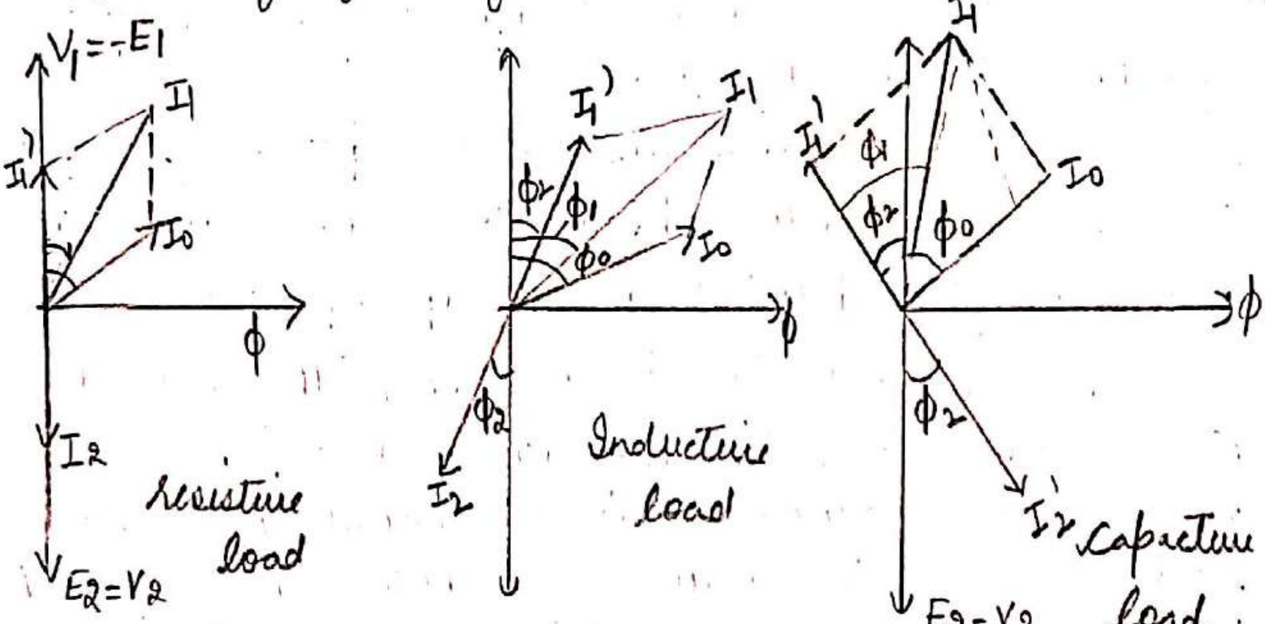


Since no V.D so $V_1 = E_1$ and $E_2 = V_2$.

* I_2 is in phase, lags behind & leads the secondary terminal voltage V_2 by angle ϕ_2 for resistive inductive & capacitive load.



* To primary current

$$I_1 = I_0 + I_1' \quad , \quad I_1 = \sqrt{(I_0^2 + I_1'^2 + 2 I_0 I_1' \cos\theta)}$$

θ is angle b/w I_0 and I_1'.

$$\cos\phi_1 = \frac{I_0 \cos\phi_0 + I_1' \cos\phi_2}{I_1}$$

Power factor

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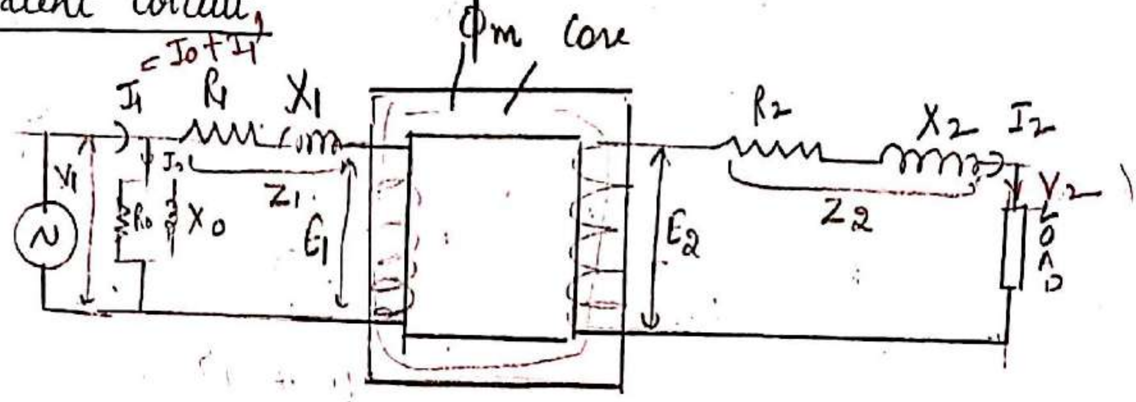
Actual Transformer

An Actual Transformer has 1. primary and secondary resistance 2. primary and secondary leakage reactance 3. Iron & cu losses.

Equivalent circuit,



Voltage drop

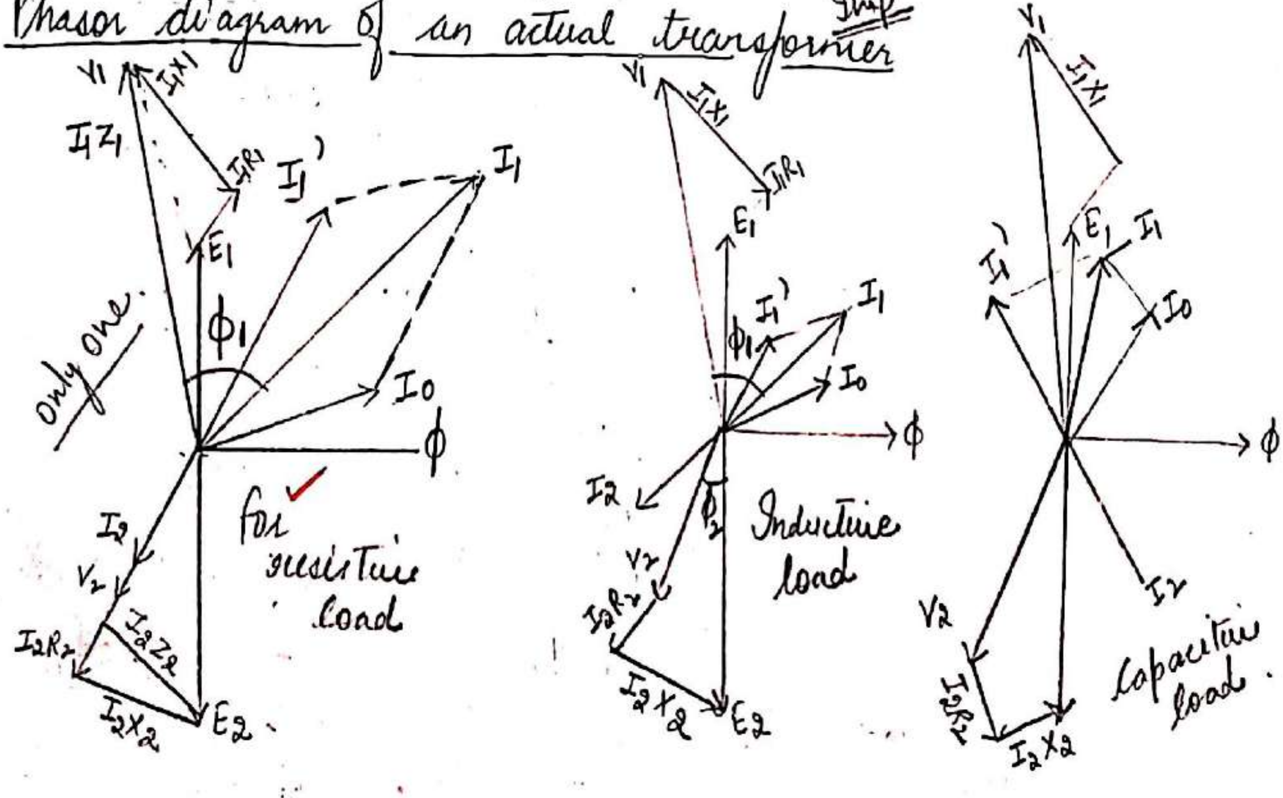
$$E_2 = I_2(R_2 + jX_2) + V_2$$

$$V_1 = E_1 + I_1(R_1 + jX_1) = E_1 + I_1 Z_1 \quad \text{(primary side)}$$

$$V_2 = E_2 - I_2(R_2 + jX_2) = E_2 - I_2 Z_2$$

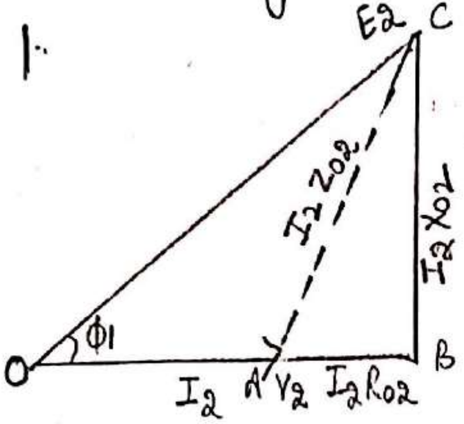
Phasor diagram of an actual transformer

Imp



Expression for NO load Secondary Voltage Extra (imp)

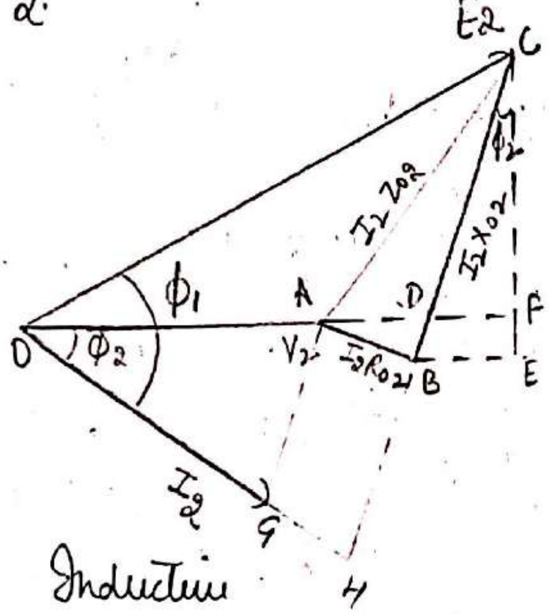
1.



resistive load

$$OC = \sqrt{OB^2 + BC^2}$$
$$= \sqrt{(OA+AB)^2 + BC^2}$$
$$E_2 = \sqrt{(V_2 + I_2 R_{02})^2 + (I_2 X_{02})^2}$$
$$\cos\phi = \frac{OB}{OC} = \frac{OA+AB}{OC} = \frac{V_2 + I_2 R_{02}}{E_2}$$

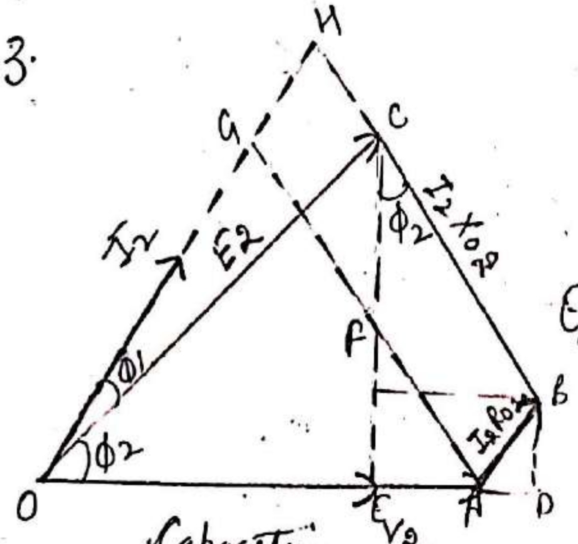
2.



Inductive

$$OC = \sqrt{OH^2 + HC^2}$$
$$= \sqrt{(OG+GH)^2 + (HB+BC)^2}$$
$$= \sqrt{(OG+AB)^2 + (GA+BC)^2}$$
$$E_2 = \sqrt{(V_2 \cos\phi_2 + I_2 R_{02})^2 + (V_2 \sin\phi_2 + I_2 X_{02})^2}$$
$$\cos\phi = \frac{OH}{OC} = \frac{OG+GH}{OC} = \frac{OG+AB}{OC}$$
$$= \frac{V_2 \cos\phi_2 + I_2 R_{02}}{E_2}$$

3.



Capacitive

$$OC = \sqrt{OH^2 + HC^2}$$
$$= \sqrt{(OG+GH)^2 + (HB-BC)^2}$$
$$= \sqrt{(OG+AB)^2 + (GA-BC)^2}$$
$$E_2 = \sqrt{(V_2 \cos\phi_2 + I_2 R_{02})^2 + (V_2 \sin\phi_2 - I_2 X_{02})^2}$$
$$\cos\phi_1 = \frac{HC}{OC} = \frac{OG+GH}{OC} = \frac{OG+AB}{OC}$$
$$= \frac{V_2 \cos\phi_2 + I_2 R_{02}}{E_2}$$

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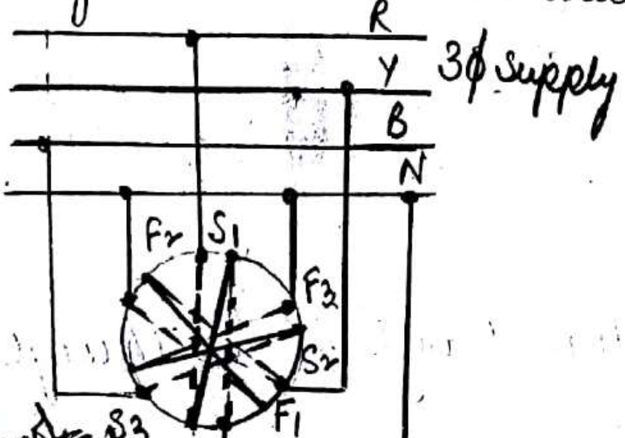
Ch[redacted] Electrical Machines

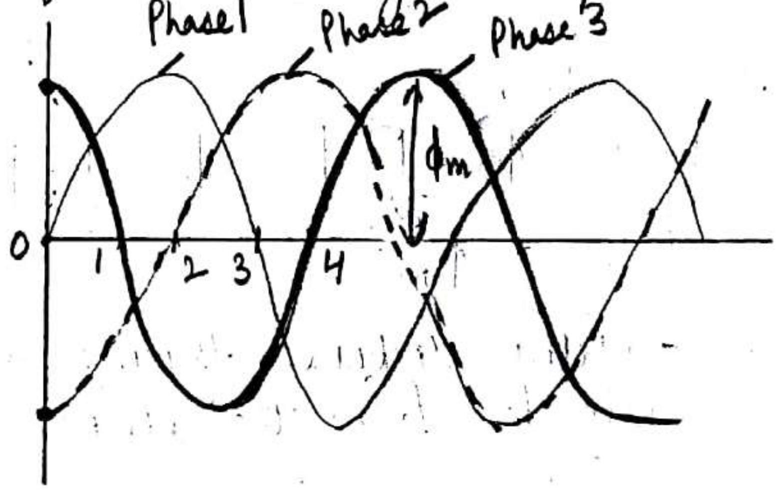
1. Generation of Rotating magnetic field

When stationary coil, wound for 2 or 3 ϕ are supplied by 2 or 3 ϕ supply respectively, a uniform rotating (revolving) magnetic flux of constant value is produced.

Three phase supply

When 3 ϕ wdg displaced in space by 120° are fed by three phase current, displaced by 120°, they produce a resultant magnetic field which rotate in space as if actual magnetic poles were being rotated mechanically.

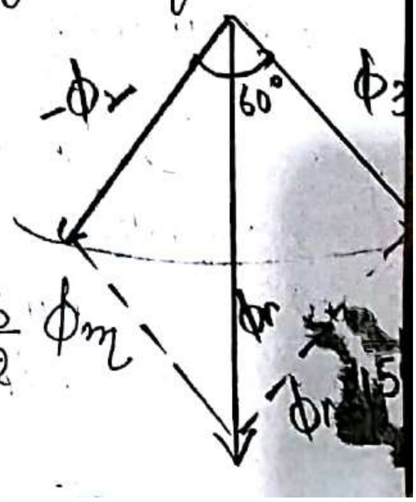




Case I Let max value of flux due to any of 3 phase = ϕ_m

The resultant flux ϕ_r at any instant is given by vector sum of ϕ_1, ϕ_2 and ϕ_3 due to 3 ϕ.

(i) When $\theta = 0$



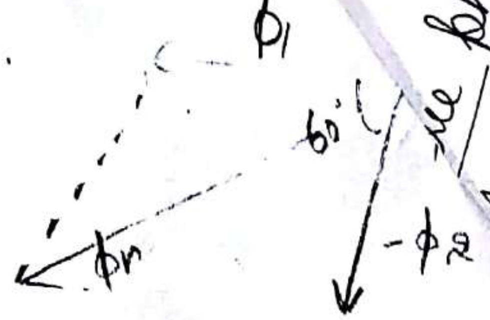
$$\phi_1 = 0 \quad \phi_2 = -\frac{\sqrt{3}}{2}\phi_m \quad \phi_3 = \frac{\sqrt{3}}{2}\phi_m$$

$$\phi_r = 2 \times \frac{\sqrt{3}}{2}\phi_m \cos\frac{60}{2} = \sqrt{3} \times \frac{\sqrt{3}}{2}\phi_m = \frac{3}{2}\phi_m$$

ii) When $\theta = 60°$ (point 1.)

$\phi_1 = \frac{\sqrt{3}}{2}\phi_m \quad \phi_2 = -\frac{\sqrt{3}}{2}\phi_m \quad \phi_3 = 0$

$\phi_r = 2 \times \frac{\sqrt{3}}{2}\phi_m \cos 30° = \frac{3}{2}\phi_m$

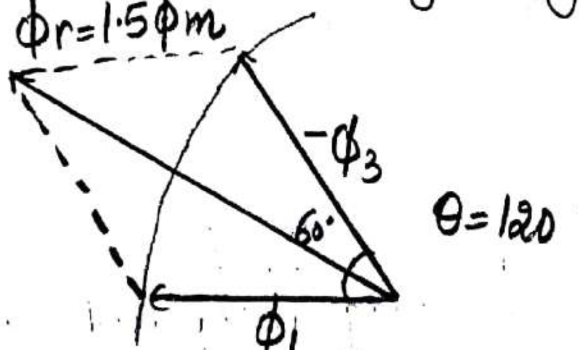


flux is same but has rotated clockwise through angle 6

iii) when $\theta = 120°$ (point 2)

$\phi_1 = \frac{\sqrt{3}}{2}\phi_m \quad \phi_2 = 0 \quad \phi_3 = -\frac{\sqrt{3}}{2}\phi_m$

Again $\phi_r = \frac{3}{2}\phi_m$

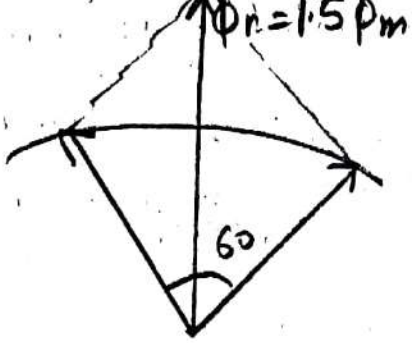


same flux but has further rotated clockwise through an angle of 60°

iv) $\theta = 180$

$\phi_1 = 0 \quad \phi_2 = \frac{\sqrt{3}}{2}\phi_m \quad \phi_3 = \frac{-\sqrt{3}}{2}\phi_m$

$\phi_r = \frac{3}{2}\phi_m$



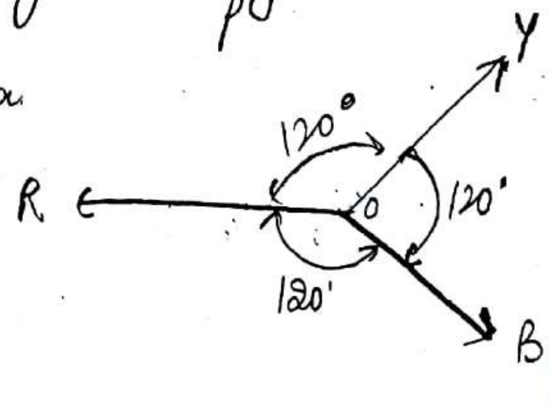
has rotated clockwise through an additional angle 60° or through an angle 180° from the start.

Hence it conclude that :

① The $\phi_r = \frac{3}{2}\phi_m$ ie 1.5 times of ϕ_m due to any pha

② the resultant flux rotates around the stator at synchronous speed given by $N_s = \frac{120f}{P}$.

As seen from position of Resultant flux phasor at interval of 60° only. The resultant flux produces a field rotating in the clock wise direction.



2

Three phase Induction motor

An Induction motor is simply a transformer whose magnetic circuit is separated by an air gap into 2 relatively movable portion, one carrying the primary wdg and other secondary wdg.

Or

An Induction motor derives the name from the fact that the current in rotor conductors is induced by the motion of rotor conductors relative to the magnetic field develop by the stator currents.

* This motor is also known as ~~aschyo~~ asynchronous motor because the rotor does not turn in synchron with the rotating field developed by the stator current

Uses

* These polyphase Induction motors are widely (90%) used ac motor due to its low cost, simple & rugged construction, high reliability, high η, reasonably good p.f and simple starting ~~torque~~ arrangement.

How it is different from other motors?

* It differs from either type of electric motors in that there is no electrical connection from the rotor wdg at any source of supply. It receives current and voltage by induction action and therefore, it is called induction motor.

Ques Why it is called Induction motor or asynchronous motor?

Ans.

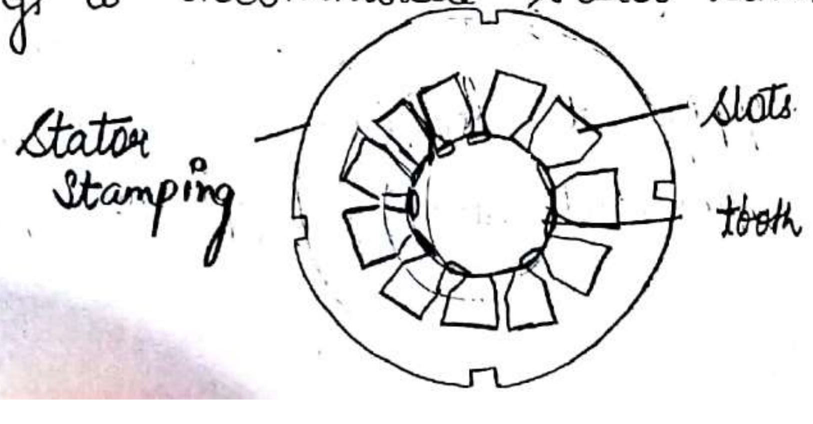
Construction of 3 phase induction motor

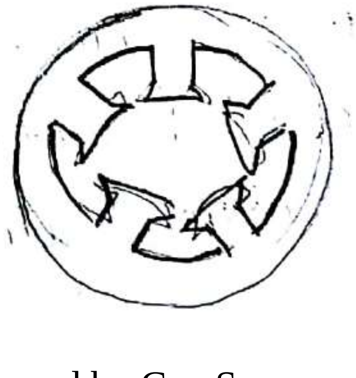
A 3ϕ Induction motor consists of following 2 main parts (1) Stator (2) Rotor.

1) **Stator** It is the stationary part of the motor. It has 3 main parts namely 1) Outer frame, 2) Stator Core 3) Stator winding.

1. **Outer frame**: It is the outer body of the motor. Its function are to support the stator core & wdg and to protect the inner part of the machines. For small m/c, the frame is casted but for large m/c it is fabricated. The end shields, which also carry the bearings are bolted to outer frame.

2. **Stator Core** The stator core is to carry the alternating m.f which produces hysteresis and eddy current losses, therefore, core is built up of high grade silicon steel stampings. The stampings are assembled to the stator frame under hydraulic pressure. Each stamping is insulated from the other with Varnish layer. The thickness of stamping usually varies from 0.3 to 0.5 mm. Slots are punched on inner periphery of stampings to accommodate stator winding.





...agnetic field

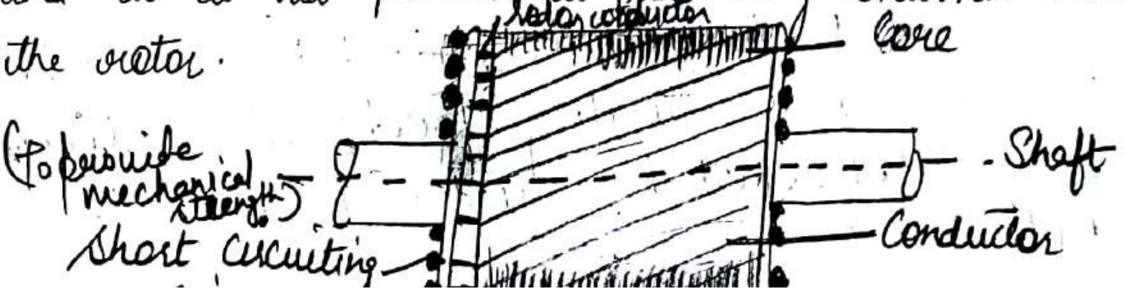
... winding The stator core carries a three phase winding which usually supplied from a three phase supply s/s. The six terminals of winding (2 of each phase) are connected in terminal box of m/c. The speed of the rotor can be determined by $N_s = \frac{120f}{P}$. (P no. of poles i.e. N ...

* 3ϕ wdg are connected in star/delta externally. The wdg are designed to be delta connected for normal running.

(2) <u>Rotor</u> It is the rotating part of the motor. There are 2 types of rotor which are employed in 3ϕ induction motors.

1. Squirrel cage rotor 2. phase wound rotor

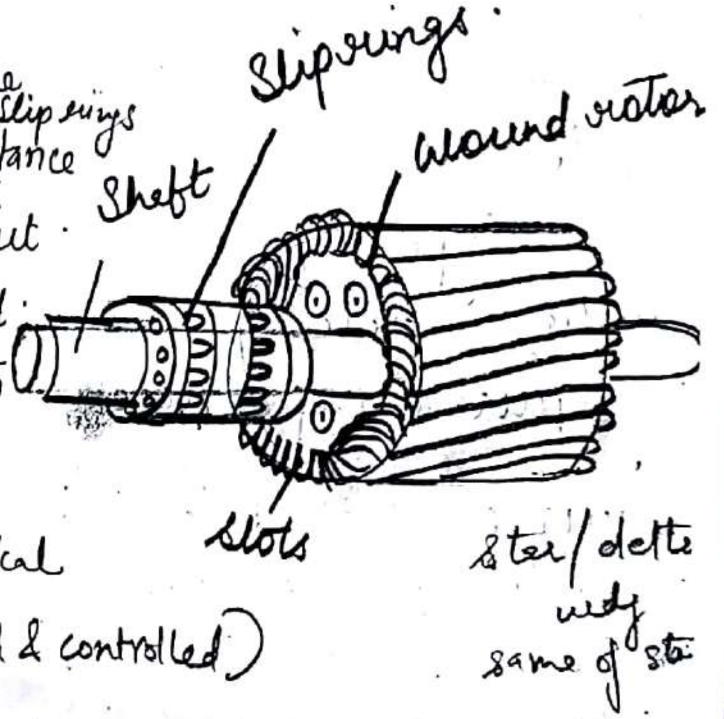
1. Squirrel cage rotor The motor employing this type of rotor are known as squirrel cage IM. most of IM are of this type because of simple and rugged const. of rotor. It consists of laminated cylinderical core having semi closed circular slots at the outer periphery. Cu or Al bar conductor are placed in these slots and joined at each end by cu or aluminum rings, called short circuit rings. Thus the rotor winding is permanently short circuited and it is not possible to add any external resistance in the rotor.



* require less mainten
* drilling m/c
fan etc.

ii) Phase wound rotor: Phase wound rotor is an slip ring rotor and the motors employing this type rotor are known as phase wound or slipring I.M. Its consists of a laminated cylinderical core having semi closed slots at the outer periphery and carries a 3ϕ insulated windi The rotor is wound for the same no. of poles as that of stator. The 3 finish terminals are connected together and the 3 start terminals are connected to 3 Cu slips rings (slip rings) fine on shaft.

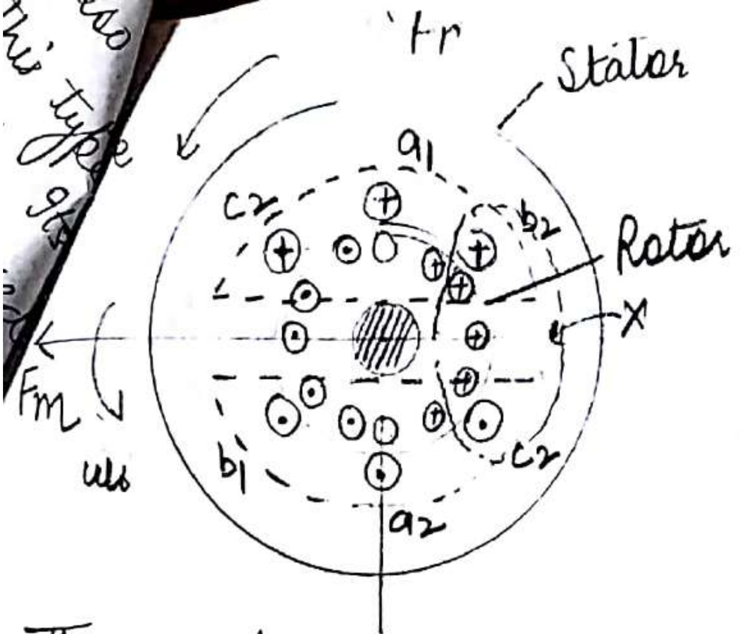
In this case depending upon the requirement of any external resistance (using brushes and slip rings) can be added in the rotor circuit. In this case also rotor is skewed. A mild steel shaft is coupled to the rotor with key. The purpose of shaft is to transfer mechanical power. (Hence speed can be improved & controlled) Const. complicated hence less used.

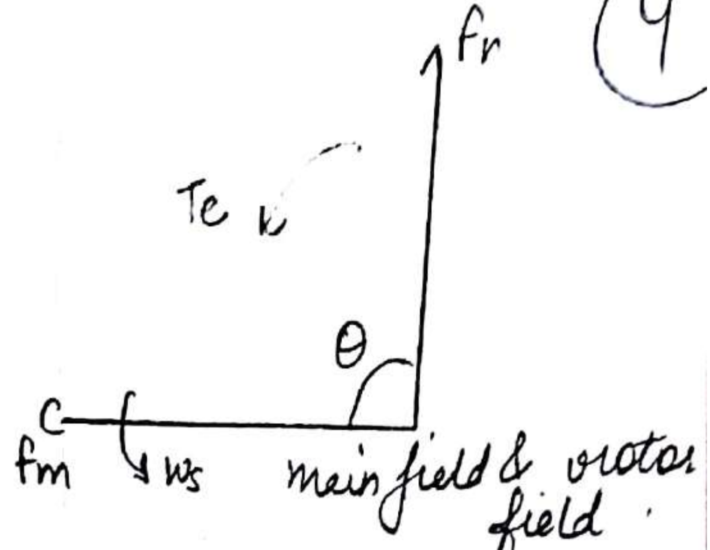


Principle of working of an induction motor

When 3 phase supply is given to the stator of 3 phase wound induction motor, a rotating field is set up in the stator. At any instant, the M.F set up by the stator is sh in fig.

The direction of resultant field is maked by an arrow head F_m. Let this field is rotating ~~field~~ in anti clock direction at an angular speed of ω_s radians per second i.e synchronous speed.





The stationary rotor conductor cut the revolving field and by induction emf is induced in the conductors. As the rotor conductors are short circuited, current flow through them in the direction as marked in fig (b). Rotor current carrying conductor set up a resultant fr by the alignment of the fields an electromagnetic torque is developed in anticlockwise direction. Thus the rotor starts rotating in the same direction in which stator field is revolving.

Since, the principle of operation of this motor depends upon electromagnetic induction, hence the name induction motor.

Imp Can an induction motor run at synchronous speed? Explain.

No, it always run at speed less than synchronous speed. As rotor picks up speed and tries to attain the synchronous speed but speed is always less than N_s. If rotor attains the synchronous speed then relative speed b/w rotating stator field and rotor will be zero, no emf will be induced in rotor conductor. No emf means no current, no rotor field fr and hence no torque is produced. Thus induction motor never runs at synchronous speed.

Imp terms .

1. Slip The difference b/w rotor speed (N) and flux speed is called slip. It is usually expressed as %age of synchronous speed N_s and its represented as s

$$\%\text{age of } s = \frac{N_s - N}{N_s} \times 100$$

$$\text{fractional slip} = \frac{N_s - N}{N_s}$$

1st Rotor speed $N = N_s(1-s)$

2. Slip speed The difference b/w synchronous speed and rotor speed is called slip speed. Slip speed $= N_s - N$

3. frequency of rotor current The frequency of rotor current depend upon the relative speed b/w rotor and stator field. When the rotor is stationary the frequency of rotor current is same as that of supply f. But once the rotor start rotating the frequency of rotor current depend upon slip speed $(N_s - N)$

$$f = \frac{N_s P}{120} \qquad f_r = \frac{(N_s - N)P}{120} \qquad f_r = \left(\frac{N_s - N}{N_s}\right) \times \left(\frac{N_s P}{120}\right)$$

$$\boxed{N_s = \frac{120 f}{P}} \qquad f_r = s f$$

fraction slip

Numerical If emf in stator of an 8 pole I.M has a $f = 50$ and $f_r = 1.5\ Hz$ find speed at which motor is running & its slip

Ans $P = 8$ $f = 50\ Hz$ $f_r = 1.5\ Hz$

Slip $s = \frac{f_r}{f} = \frac{1.5}{50} = 0.03\ Hz$

$N_s = \frac{120 f}{P} = \frac{120 \times 50}{8} = 750$ rpm (revolution)

Motor speed $N = N_s(1-s) = 750(1-0.03) = 725.5$ rpm

Reversal of direction of rotation of 3ϕ I M

The direction of rotation of 3ϕ I.M can be reversed by interchanging the connection of any 2 supply leads at the stator terminals.

Importance of slip: The diff b/w N. and Ns of flux determine the rate at which flux is cut by rotor conductors and hence the emf

emf $e_2 \alpha (N_s - N)$

As. $i_2 \alpha e_2$ $T \alpha i_2$

so $T \alpha (N_s - N)$ $T = K(N_s - N)$

(torque) $T \alpha s$ (slip)

Thus greater the slip greater will be emf induced on rotor current and hence large Torque developed

* No load: Small Torque ∴ slip is small.
* loaded: greater Torque needed to drive load; slip increase so speed decrease slightly

Rotor Emf

$E_1 = 4.44 K_{w1} T_1 f \phi_m$ (stator induced emf).

K_{w1} = winding factor i.e product of coil span factor K_c

T_1 = No. of turns/phase of stator wdg.

f = frequency ϕ_m = max flux value

Rotor $E_2 = 4.44 K_{w2} T_2 f_r \phi_m$ Rotor emf at stationary cond

under stationary condition $f_r = f$ $E_{2s} = 4.44 K_{w2} T_2 f \phi_m$

So $\frac{E_{2s}}{E_1} = \frac{T_2}{T_1} = K$ $\boxed{E_2 = 4.44 K_{w2} T_2 (sf) \phi_m = s E_{2s}}$

Significance of Torque-slip characteristic.

As Rotor Torque $T \alpha \phi I_2 \cos\phi_2$

$E_2 \alpha \phi$

$T \alpha E_2 I_2 \cos\phi_2 \quad T = K E_2 I_2 \cos\phi_2$

I_2 (Rotor current) $I_2 = \frac{s E_2}{\sqrt{R_2^2 + s^2 X_2^2}}$ $\cos\phi_2 = \frac{R_2}{\sqrt{R_2^2 + s^2 X_2^2}}$ Refer JBG

So Torque developed in rotor

$$T = K E_2 \frac{s E_2}{\sqrt{R_2^2 + s^2 X_2^2}} \times \frac{R_2}{\sqrt{R_2^2 + s X_2^2}}$$

under running condition. $T = \frac{s K R_2 E_2^2}{(R_2^2 + s^2 X_2^2)}$

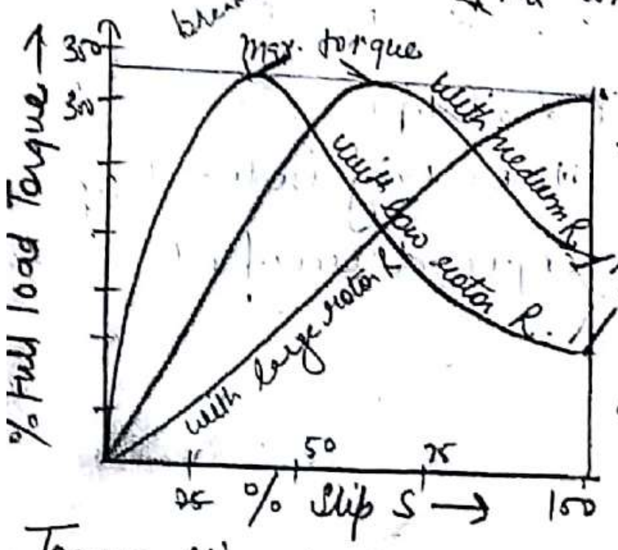
* Condition for max running torque T_{max}

T is max when $\frac{s R_2}{R_2^2 + s^2 X_2^2}$ is

factors are $\frac{R_2}{\sqrt{s}} - X_2\sqrt{s} = 0$

$s = \frac{R_2}{X_2}$

$T_{max} = \frac{K R_2^2 E_2^2 X_2}{R_2^2 + R_2^2} = \frac{K E_2^2}{2 X_2}$



Torque slip curve

* Condition for max Starting Torque. $s=1$ $R_2 = X_2$

1. when speed is synchronous $s=0$ So $T=0$ ∴ curve started from origin O.

2. When speed is near to N_S ie slip is very low the value of sX_2 is very small and neglected ∴ $T \alpha s$ So curve are approx. straight line.

3. As the slip ↑es, the speed ↓es due to increase in load So T ↑ and reaches to max value: when $S = \frac{R_2}{X_2}$ and that Torque is known as breakdown or pull out torque ∴ S_b (breakdown sl

4. If slip ↑es further than T start ↓es and result in slow down and eventually stops. So motor only operate b/w $(0 - S_b)$ slip value.

As Higher the slip R_2 is neglected So $T \alpha \frac{1}{s}$

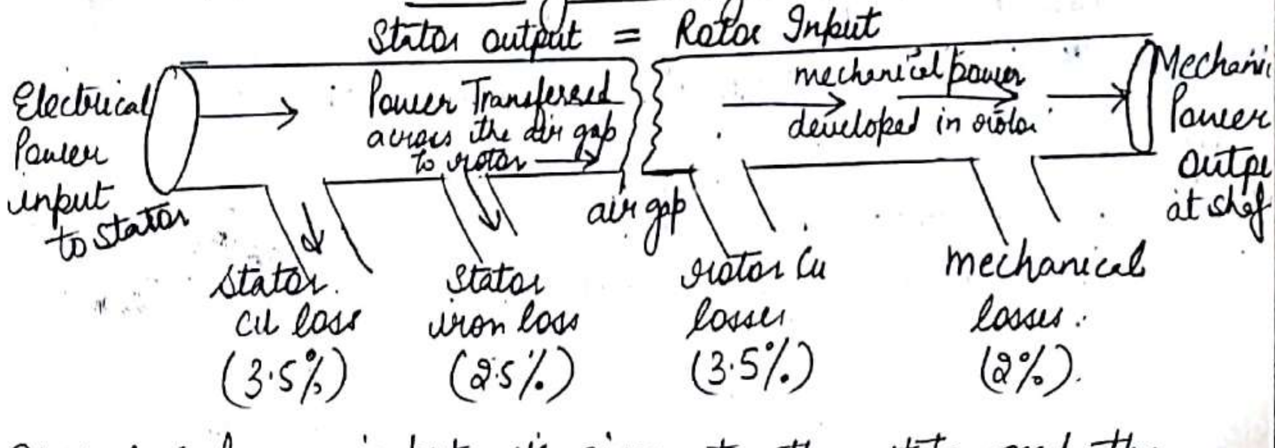
When $R_2 < sX_2$ torque for given slip αR_2

$R_2 > sX_2$ $T_s \alpha \frac{1}{R_2}$ from Graph T_{max} is same but value slip is different for different Resistor

...ses in I.M

1. Stator losses: The losses which occur in the stator of an induction motor are called stator losses.
   i) Stator copper losses: $I_1^2 R_1$
   2) Stator iron losses: These are the hysteresis & eddy current losses
2. Rotor losses:
   Which occur in the rotor.
   i) Rotor Cu losses: $I_2^2 R_2$
   ii) Rotor Iron losses: Since under normal condition rotor frequency is small hence these are neglected.
3. Mechanical losses: force exerted due to friction.
   The sum of windage and frictional losses are called mechanical losses.

Power flow diagram



Electrical power input is given to the stator and the mechanical power output is available at the shaft.

$$\text{Efficiency } \eta = \frac{\text{output power}}{\text{Input power}} = \frac{\text{Mechanical power output (K}}{\text{Electrical power input}}$$

$$\eta = \frac{\text{mechanical power output (kW)}}{P_{mech}\,(kW) + \text{fixed losses in (kW)} + \text{Cu losses in (kW)}} = \frac{P_{mech}}{P_{mech} + P_{const} + P_{cu}} \times 100\ \%$$

* Speed control of 3 ϕ Induction motor :

Running speed of I.M is given by $N = \frac{120f}{P}(1-s)$

from this equation speed of an I.M can be varied by varying following factors.

1. **Frequency Control of speed** This method give wide speed control range but it is difficult to get different supply frequency and hence it is not used commonly.

2. **By changing Number of poles** This method is not used generally to slip rings motors. With 2 independent sets of stator windings, each arranged for pole changing, as many as four Ns can be obtained in squirrel cage motor.

Advantages of simplicity, good speed regulation for each setting highly efficient etc.

Uses. Ventilating fans, conveyors, machine tools etc.

3. **Slip control**

Slip can be controlled by following means:

1. **line Voltage control**: This method of speed control is simple, low in cost and low maintenance cost, but becoz of limitation it cause on max torque (As $T_{em} \propto V^2$) it only used in small squirrel cage motor driving fans.

2. **Rotor resistance control**: This method is used, where speed is reduced for short period because increase in rotor resistance efficiency become less and poor speed regulations.

3. **Secondary foreign Voltage control**: By injecting V at slip freq. (sf) rotor ckt, speed of I.M can be controlled

If emf injected in phase with sec ckt speed will ↑es slip ↓es

If emf injected in opp. phase " " " speed ↓es slip ↑es.

(i)

...d control by cascade arrangement: In this method, 2 motors are required, atleast one of which must have a wound rotor. The 2 motors may be mechanically coupled together to drive a common load.

* The rotor output of first machine is connected to the stator of second machine in such a way that Revolving field of both the machines are in same direction.

$$N_s = \frac{120 f}{P_1 + P_2}$$

f = supply frequency

P_1 and P_2 = no of poles of m/c I and II resp.

* Starting of Induction motor

1. Necessity of a starter

The current drawn by a motor from mains depends upon rotor current $I_2 = \frac{s E_{2s}}{\sqrt{R_2^2 + (s X_2)^2}}$ (under running condition)

when $s = 1$ $I_2 = \frac{E_{2s}}{\sqrt{R_2^2 + (X_2)^2}}$ This current is very large as compared to full load current.

So when I.M directly connected to supply it draws very large current, this is not dangerous as it occur only for short duration of time but it causes following affect.

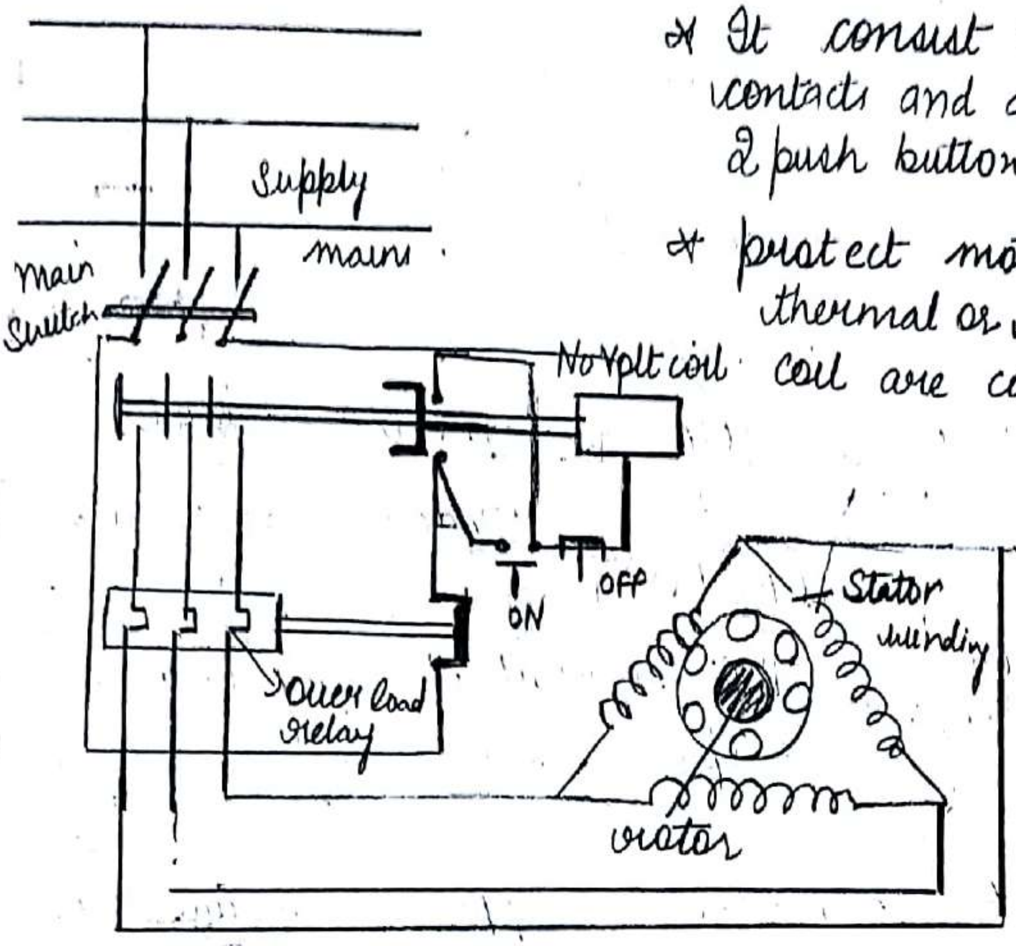
1. produce large V.D in distribution line & thus affect V. Regulation
2. adverse affect on other motor and loads connected to same line.

So such motors should be started by means of some starting device known as starter whose main funtion is to limit the inrush current to a predetermined value.

Starting method of squirrel cage Induction motor

1. Direct on line starter (D.O.L starter)

In this method, the motor is directly fed from main supply, taking 5 to 7 times full load current at start by switching conductor. This causes drop across supply lines for small moments.



* It consist of 4 normally open (NO) contacts and a no volt coil having 2 push button ON and OFF.

* protect motor against overload thermal or magnetic overload coil are connected in each phase.

Working: To Start motor, ON button is pressed which energies the NO volt coil that is connected b/w 2 ϕ. So this coil pull the plunger in such a direction that all NO contacts are closed and motor is connected to supply. To stop motor OFF push button pressed which deenergies the coil.

When the motor is overloaded, the overload relay contact connected in ckt opens thus disconnecting the No volt relay from the supply.

$\therefore$ Starting $T_{st} = T_f \left(\frac{I_{sc}}{I_f}\right) S_f$

T_f full load torque

S_f full load slip

I_{st} = starting current

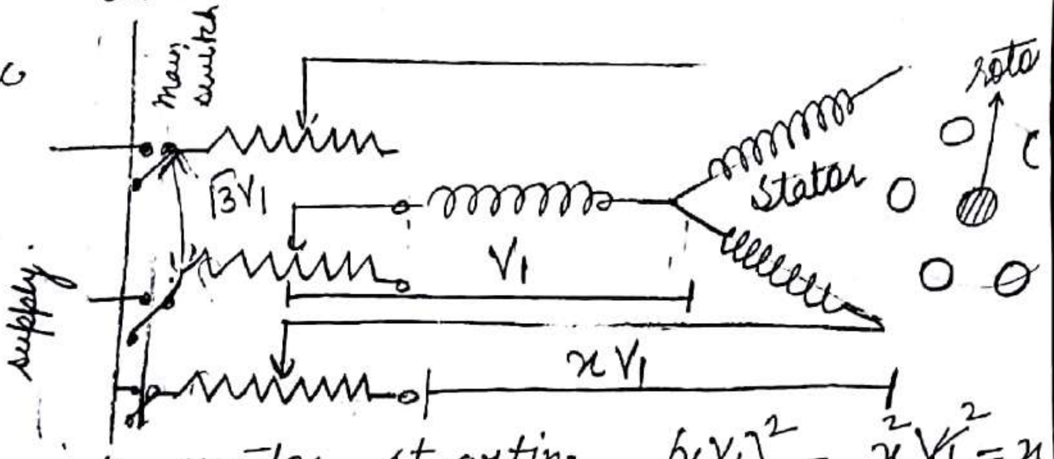
Stator rheostat / resistor / reactor starter

Resistor or reactor is inserted in between motor and supply mains (Series). The V.D in resistor caused a reduced voltage to motor terminals once it pick up the speed resistors are cut out.

$$I_{st} = \frac{x V_1}{Z_1} = x I_{sc}$$

$$\frac{T_{st}}{T_{sfl}} = x^2 \left(\frac{I_{sc}}{I_{fl}}\right)^2 s_{fl}$$

$$T \propto V^2$$



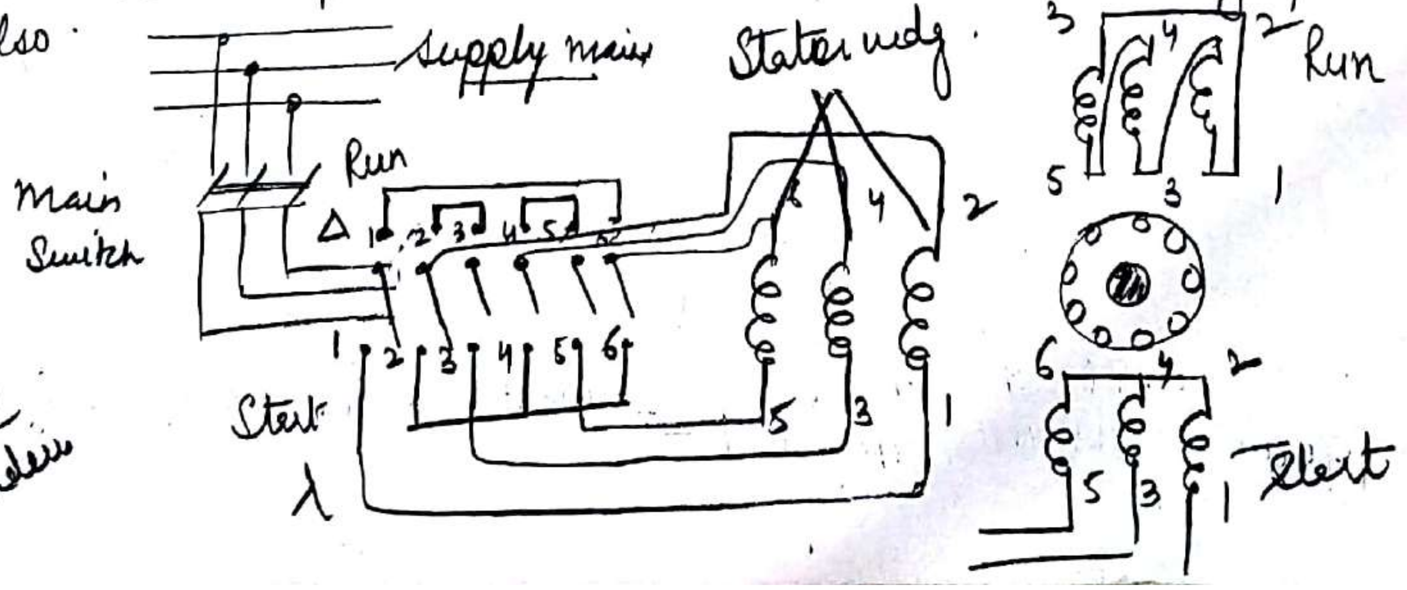
$$\frac{\text{Starting torque with reactor starting}}{\text{Starting torque with direct switching}} = \left(\frac{xV_1}{V_1}\right)^2 = \frac{x^2 V_1^2}{V_1^2} = x^2$$

3. <u>Star Delta Starter</u> (is used for motor to operate normally in delta, to reduce mechanical stress & inrush current at start)

In star connection $V_{ph} = \frac{1}{\sqrt{3}} V_L$ where as the same wdg when connected in delta it will have full line voltage.

So at start, connections of motor are star connected so that reduce V is applied in each wdg.

* When motor pick up the speed the wdg change to delta connection with the help of <u>change over switch</u>.
* The starter is provided with overload and under voltage protection also.



S.K. Sahdev

$\therefore \frac{\text{line current with star delta starter}}{\text{line current with direct switching}} = \frac{I_{sc}/\sqrt{3}}{\sqrt{3} I_{sc}}$

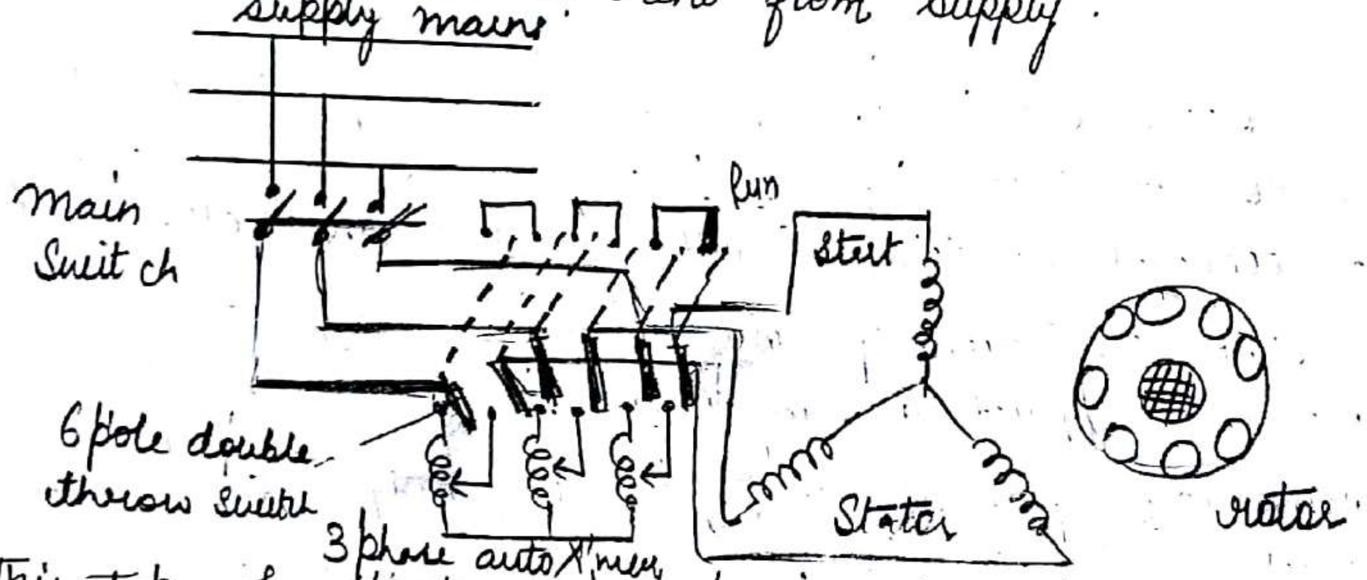
$I_{st(Y)} = \frac{1}{\sqrt{3}} I_{sc}(\Delta)$ $\frac{I_{sc}}{\sqrt{3}}$ (is starting line current)

In this way current drawn by 3ϕ motor is limited to $\frac{1}{3^{rd}}$ of value that it would draw without starter.

$\frac{\text{Starting T with starter}}{\text{Starting T in direct switching in }\Delta} = \frac{\left(\frac{V_L}{3}\right)^2}{V_L^2} = \frac{1}{3}$

4. Autotransformer Starter

The motor is connected to supply through auto X'for at the time of starting a fraction xV_1 of supply voltage V_1 is applied to ~~start~~ stator which reduces the motor current and also current from supply.



This type of starter is expensive but is most suitable for both star connected & delta connected I.M.

Suitable for large motor

Without starter : huge amount of current flow.

Star/Delta starter : reduce to $\frac{1}{3^{rd}}$ value but still cause distrubance to other load connected in lines.

Hence to limit the inrush of current to low values auto transformer starter preferred.

Transformation Ratio

Isc – starting current when normal voltage applied.

So Applied Voltage to stator at Start = KV

Input current $I_s = KI_{sc}$

Supply current = primary current of AT.

$= K \times$ sec. current of AT $= K^2 I_{sc}$

If 20% ie $\left(\frac{1}{5^{th}}\right)$ voltage is applied to motor through auto transformer starter, the current drawn from the main is reduced to $\left(\frac{1}{5}\right)^2$ ie $\frac{1}{25}$ times.

Application of three phase Induction motor

Squirrel cage I.M. : Operate at const speed; high pf and have high over load capacity.

These motor have low starting torque so can not used to pick up heavy loads.

1. printing machinery 2. flour mills 3. Saw mills
4. pumps 5. prime movers with small generators etc.

Slip ring I.M : These motors have all imp. characteristic and have ability to pickup heavy loads

1. Rolling mills 2. lifts and hoists 3. big flour mills
4 large pumps 5. line shaft of heavy industries.

* Comparison b/w Squirrel cage and phase wound I.M.
(V-Pg 53)

Single phase Induction motor

* These days a large number of fractional KW motors are designed to operate from 1 ϕ supply
* A single ϕ motor is not self starting operate on poor pf, lower capacity & reduced η.
* for starting purpose an auxillary wdg are used and hence stator of 1ϕ I.M carries 2 wdg.
1. Main or running winding.
2. Auxiliary or starting winding.

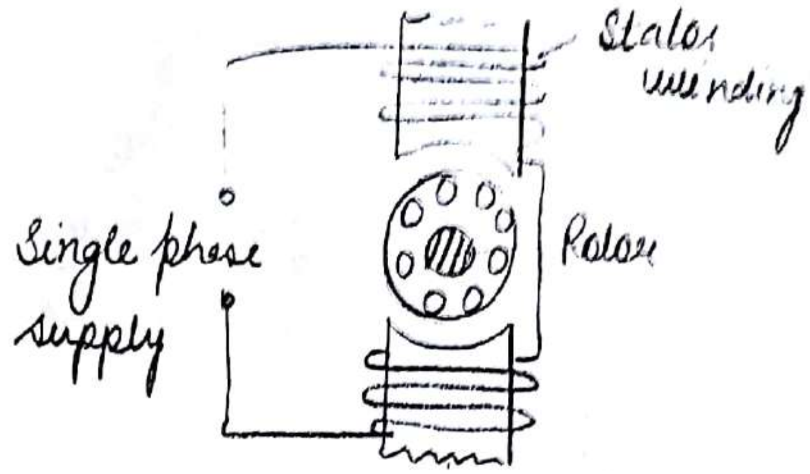
* Types : Split phase Induction mo., capacitor type 1ϕ Induction motor and shaded pole etc.

Constructionally this motor is similiar to 3ϕ I.M except
1. its stator is provided with single ϕ wdg.
2. centrifugal switch is used in some types of motor in order to cut out a winding, used only for starting purposes.

Working When 1ϕ supply is given to stator wdg its produ flux/field which is alternating but not revolving flux. So this alternating flux acting on stationary squirrel cage rotor cannot produce rotation (only revolving flux can do this) so that is why 1ϕ motors are not self starti. But if the rotor of such machine is given an initial star by hand / small motor in either direction, a torque arise, the motor accelerates to its final speed, and the starting device is then removed, the motor continues to rotate in direction in whic

...entary single phase I.M

10



$N_s = \frac{120f}{P}$

it is started. This behaviour of 1-ϕ IM can be explained on the basis of double Revolving field theory.

<u>Double field revolving Theory</u>. (nature of field produced in 1ϕ IM)

This theory is based on "ferraris principle" that pulsating field produced in 1ϕ motor can be resolved into 2 component of half the magnitude and rotating in opp. direction at same synch. speed.

Thus alternating flux which pass across the air gap of single phase I.M at stand still consists of combination of 2 same strength which are revolving with same speed, one in CW direction and other ACW direction. The strength of each one of these field will be equal to one half of max field strength of actual ~~revolving~~ alternating field.

fig1

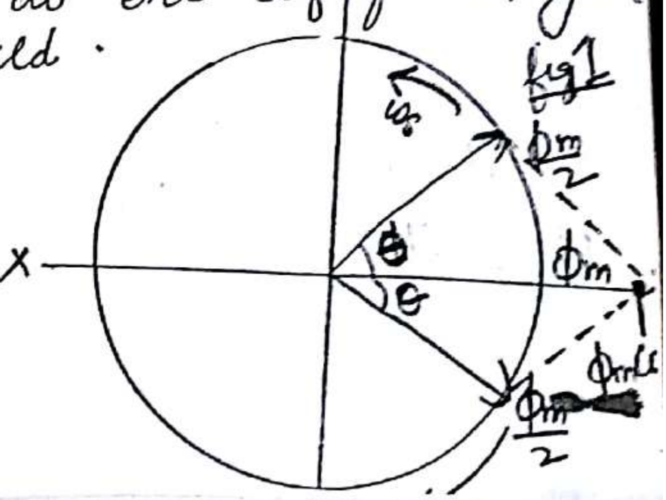
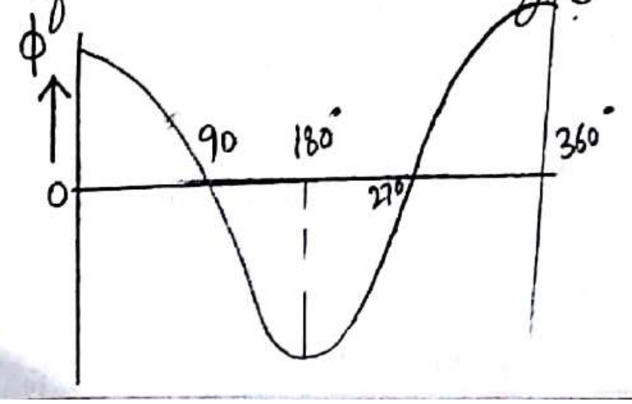


fig2



let ϕ_m be pulsating field which has 2 component of magnitude $\phi_m/2$. Both are rotating at the same angular speed ω (rad/sec) but in opp direction as shown in fig 1

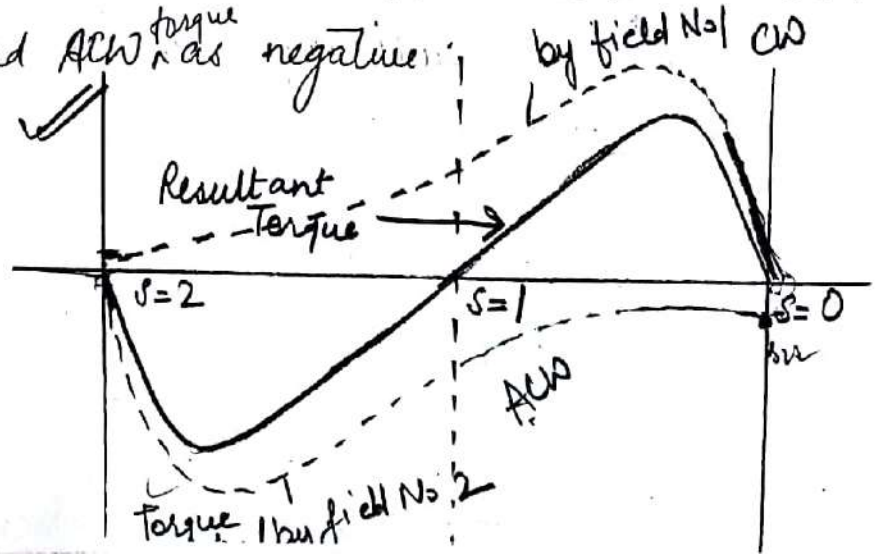
The resultant to the 2 field's is $\phi_m \cos\theta$. Thus the resultant field varies according to cosine of angle θ. The wave shape of R.f is shown in fig 2. Thus an alternating field can be represented by fields each of half the magnitude rotating at same angular speed ω rad/sec but in opp. direction.

* Explain basically a single ϕ I.M is not a self start? or How single phase motor is made revolving.

<u>Ans</u> When single phase ac supply is given to the stator of single phase wound I.M it set up 2 revolving fields of half the magnitude $\frac{\phi_m}{2}$ and these 2 fields revolve in opp. direction at const. speed (N_s).

The 2 revolving field will produce torque in opp direction. let the 2 Rev. field be field no. 1 and field No 2. Let field No 1 rev in CW direction so field 2 revolve in ACW direction. CW torque is ploted as positive and ACW torque as negative.

At stand still slip for both field is one.



...nonous speed in clockwise direction will give (11)
...dition of zero slip for field 1 but it will give slip - 2
for field no 2. Ally N_s in a CCW direction will give stip
condition of zero slip for field 2 but slip = 2 for field No 1.

Now in 2 curves produced by the two revolving field have been drawn and the resultant ie algebric sum of two fields will give the net developed torque or resultant torque. If we look at the resultant torque we see that starting torque is 0 and expect at starting there is always some magnitude of resulte torque, which shows if this type of motor once started in any direction it will develop torque and will function as motor.

Above analysis shows that single phase motor with single w... develops no starting torque but if the machine is started in any direction by some auxiliary means it will develop torque in same direction in which it has been started so the problem is to find out the auxiliary means to give the starting torque to the motor.

The slip of rotor w.r.t forward rotating field f_f,

$$S_f = \frac{Ns - N}{Ns} = S$$

The slip of rotor w.r.t backward rotating field f_b

$$S_b = \frac{Ns - (-N)}{Ns} = \frac{2Ns - (Ns - N)}{Ns} = (2 - S_f) \text{ or } (2 - S)$$

* The forward field and rotor's backward reaction field and vice versa move in opposite direction with relative speeds of double the N_s & develop second harmonic pulsating torque with zero average value. So single motor tend to more noise than 3φ I.M which has no pulsating Torque...

Classification of 1 ϕ I.M (Starting methods and Types)

Some external means are used to start 1ϕ IM. Mechan... Methods are impractical & ∴ motor is started temporarily converting it to 2-ϕ motor (by producing a revolving stator fie...

1ϕ I.M are usually classified according to auxiliary means used to start the motor. They are classified as follow.

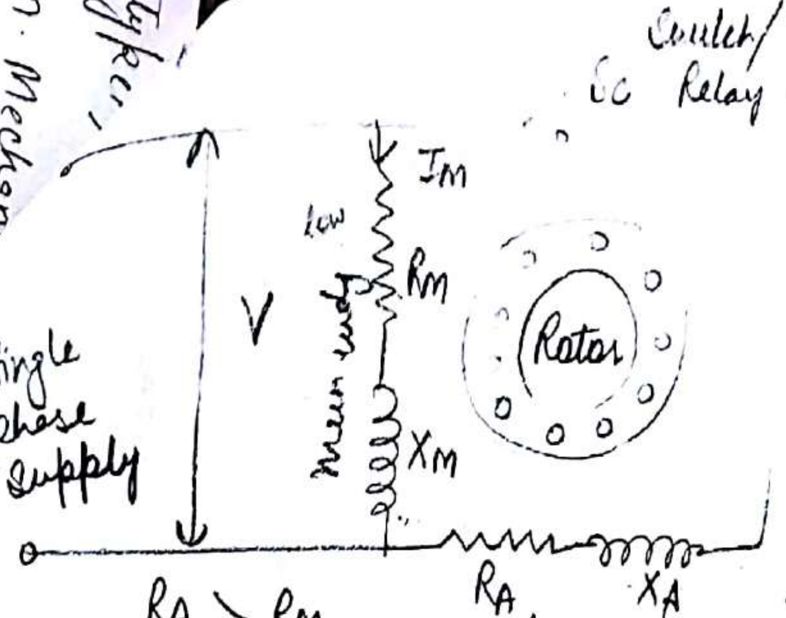
1. Split phase motor
2. Capacitor start motor
3. Cap. start cap run motor (or 2 value cap. motor)
4. Permanent split cap (PSC) motor or (1 value cap motor)
5. Shaded pole motor.

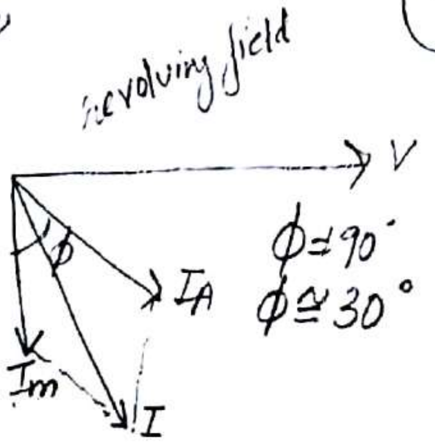
All these starting methods depend upon 2 alternating fie... displaced. The resultant of 2 fields is rotating flds. which react with cage rotor to provide the starting torque. One is produced by main wdg. and other by auxiliary wdg. The auxiliary wdg is also called starting wdg. This splitting of wdg into 2 parts in single phase induction motor is called phase split.

Split phase I.M

- It has a single cage rotor and its stator has 2 wdg – mai... & starting wdg, which are displaced at 90°. Main wdg has very low resistance and high inductive reactance. ∴ Im main wdg current lags behind the supply voltage V by nearly 90°.
- The aux wdg has a resistance connected in series with ...
- It has a high resistance & low inductive reactance. ∴ IA aux. wdg current is nearly in phase with line voltage

Diagram. (Resistance start motor)





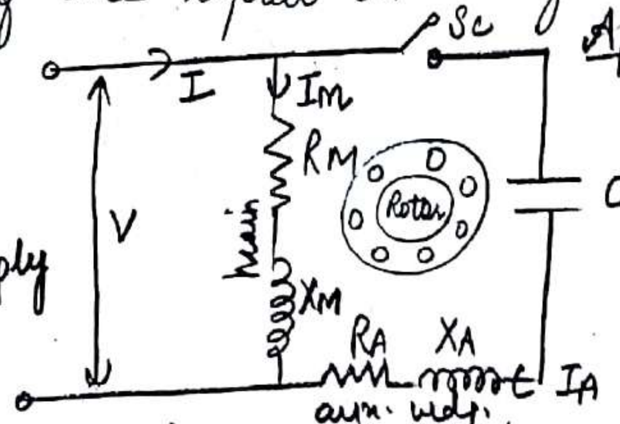
$$\frac{R_A}{X_A} > \frac{R_M}{X_M}$$

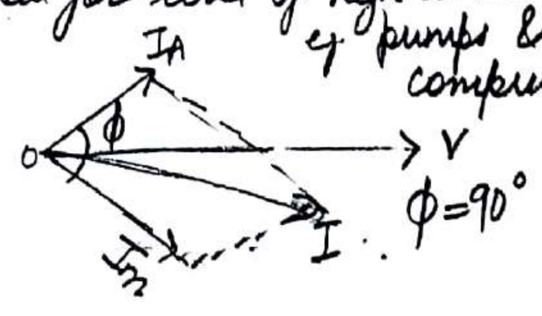
App: blowers, pumps, fans etc because of low starting torque.

2. Capacitor start motor

It has a cage rotor and its stator has 2 wdg namely main & aux. wdg. It employs a capacitor in the auxillary wdg circuit to produce a greater phase difference b/w main wdg current and aux. wdg current. The 2 wdg are displaced at 90°. A capacitor C_s is connected in series with the starting wdg. I_m in the main wdg may be made to lag I_A in aux wdg by 90° ∴ 1-ϕ supply current is split into 2 phases to be applied to the stator wdg. so the wdg are displaced 90° and their mmf are equal in magnitude but 90° apart.

App. used for load of high inertia e.g. pumps & compressors

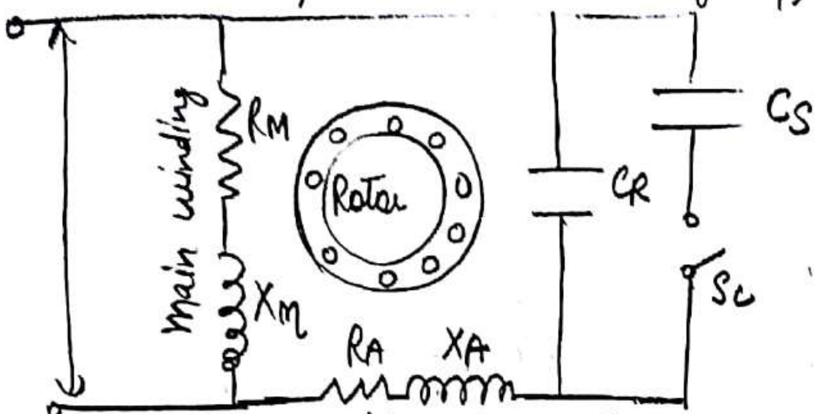




∴ Motor act like balanced 2ϕ motor. As motor approaches to its rated speed, aux wdg & starting C_s are disconnected automatically by centrifugal

Two value capacitor motor (Capacitor start Cap. Run)

It employes a capacitor in the aux wdg. It has a rotor and its stator has 2 wdg namely main wdg & aux. wdg. The 2 wdg are displaced at 90° The motor uses 2 capacitor C_S and C_R. The cap. are connected in parallel at starting. for high starting torque, a large current is required (. C_S starting cap)



Starting (Auxiliary wdg).

App. used in app with high pull out Torque and high η is needed. refrigeration, air compressor etc

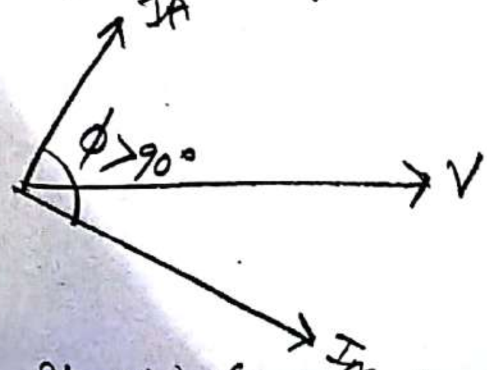
The cap reactance X in starting wdg should be low.

$X_A = \frac{1}{2\pi f C_S}$ Value of C_S should be large.

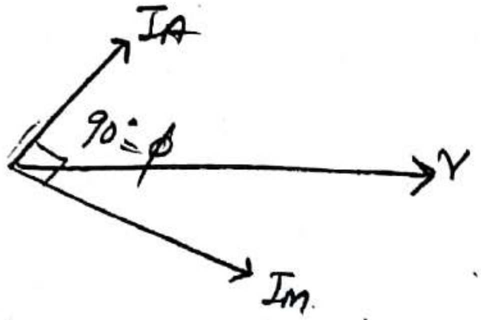
During normal operation rated line current is smaller than the starting current.

$X_R = \frac{1}{2\pi f C_R}$ C_R should be small.

As motor approches N_s, C_s is disconnected by S_C switch. C_R is permanently connected in the ckt.

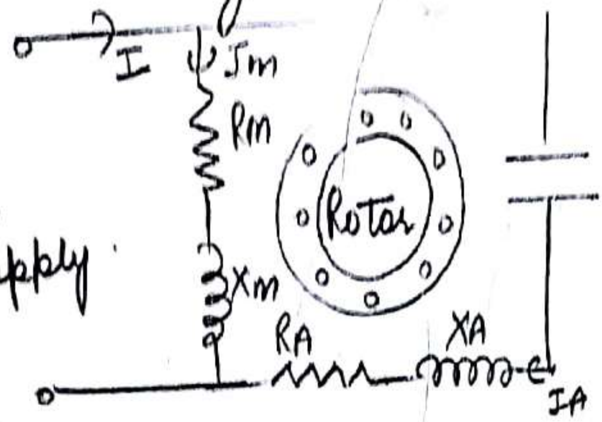


at starting (C_S+C_R) $\phi > 90°$



while running C_R $\phi = 90$.

Permanent split capacitor motor (or single value cap motor)
employs a C in aux wdg to produce phase diff b/w
main and aux. wdg. It has a cage rotor and its stator
has 2 wdg (main & aux). There is one capacitor C which
connected in series with starting wdg and it is
connected permanently.



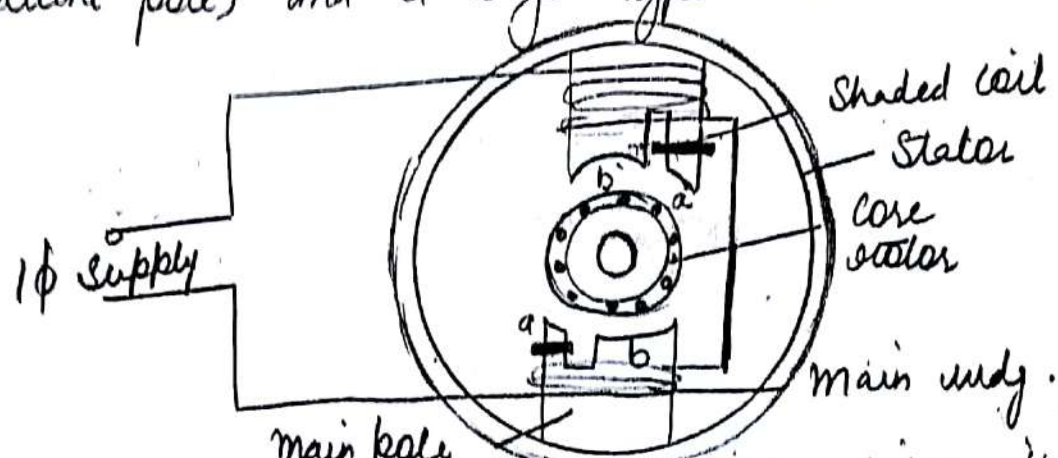
Adv 1 no switch needed
2. higher η

dis. electrolyte cap. can be used for continuous running ∴ paper oil filled type C used whose s is large and very cos

Since C and aux. wdg are always in the ckt ∴ the motor operates as a balanced 2ϕ motor ∴ I_A, I_m ⟹ produ a uniform torque App. used for fans, blowers in heater & also used to drive office machinery.

5 Shaded pole motors

It is a self starting 1-ϕ I.M consisting of a stator (salient pole) and a cage type rotor.



Each pole is slotted on side & cu ring is fitted to the smaller part. This part is sharded pole. The ring is usually a single turn coil & is known as shading coil. [illegible]

3 When a.c flows in field wdg → ac flux (in field core) is produced.

Shading coil causes the flux in shaded portion a lag behind the flux in unshaded portion b of the po[le] main flux & shaded pole flux are displaced at less than 90°

→ R.M.F is set up → starting torque on cage is develope[d]
Direction of field flux is from unshaded to shaded portion of pole ie (Clockwise here)

The shaded pole motor have poor starting torque, poor efficiency (20–50%) & very poor power factor (0.5–0.8 lag) and little overload capacity. App: cooling fan, recorder, electron equipment etc

Application of 1ϕ Induction motor

6 The single phase I.M find use in

1. fans
2. refrigerators
3. Vacuum cleaners
4. washing m/cs.
5. Kitchen equipment.
6. Tools
7. blowers
8. centrifugal pump
9. small farming app. etc.

Separately excited DC motor.

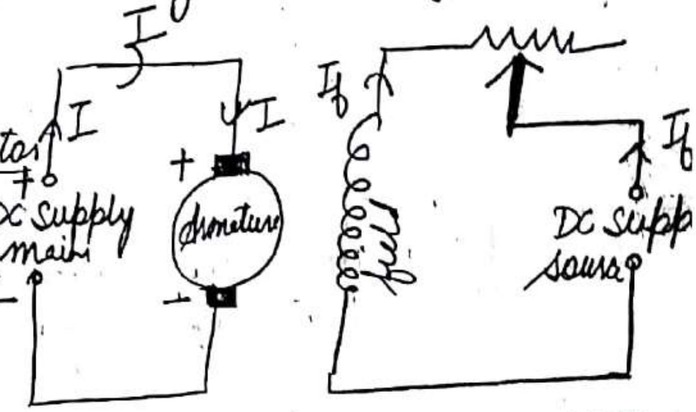
DC motor converts electrical energy into mechanical energy and they work on dc supply.

Types of DC motor

1. permanent magnet type dc motor 2. Seperately excited dc motor 3. Series wound DC motors 4. shunt wound dc motor 5. Compound

Construction 1. Stator (consists of field wdg) 2. Rotor (armature wdg)

These motors have field coils similar to those of shunt wound dc motor but the armature and field coils are fed from different supply sources but may have different voltage ratings.



Separately excited DC Motor

Equation of V, I and power for DC motor

armature current

I_a = line current, I_L; $I_L = I$

$E_b = V - IR_a$

Power drawn from supply $P = VI$

Mechanical power developed

P_m = Power input to armature − power lost in armature

$= VI - I^2R_a = I(V - IR_a) = IE_b$.

~~Operating characteristics~~ **working** If a current carrying conductor is placed in m.f, force is experienced on the conductor and hence conductor moves in direction of force.

When dc motor is connected to supply mains, the armature continues to rotate due to motor action, the armature conductor cut the M. flux & therefore emf's induced in them. The direction of induced emf known as back/counter emf is such that it oppose the applied V. $E_b = \frac{\phi Z N}{60} \times \frac{P}{A}$ Volts Z = Total number of armature conductors

Torque speed characteristics

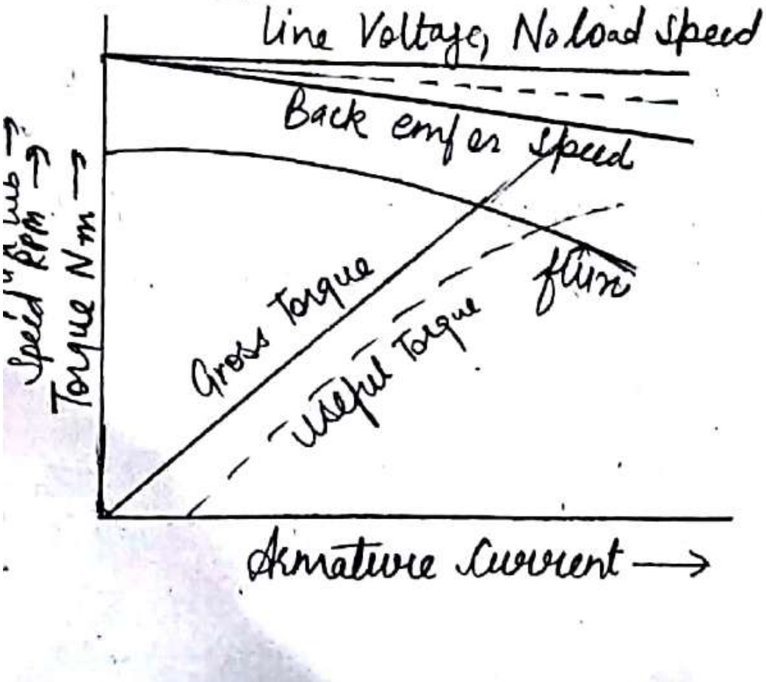
This characteristics gives relation b/w speed N and developed in armature (T). This is also known as mechanical characteristics and this curve is derived from two characteristics curve 1. Torque armature current Characteristic
2. Speed armature current Characteristic

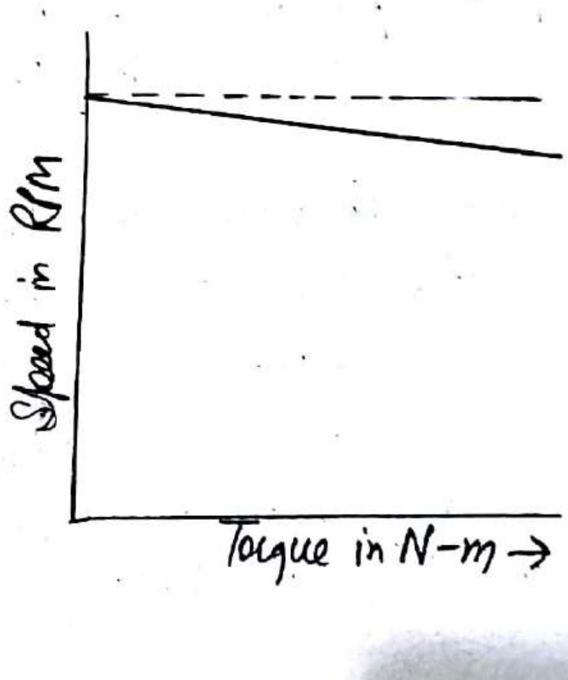
1. (T–Ia) T is prop. to flux and armature current. Neglecting armature reaction flux is const. So $T \propto I_a$. ie the characteristics curve is a straight line passing through origin. So huge current is needed to start heavy load. So this type of motor do not starts on heavy load.

2 (N–Ia) N prop to $\frac{E_b}{\phi}$. When load ↑es Eb and ϕ flux ↓. due to armature resistance drop and armature reaction respectively. However Eb decreases more than ϕ so speed of motor decrease with load.

$E_b = \frac{\phi Z N \times P}{60 A}$

So from above 2 characteristics the speed torque characteristic





...d control of seperately excited dc motor (15)

...ield control method: Weakening of field causes increase in speed of the motor while strengthening the field causes decreases the speed. Speed adjustment of this type of motor is achieved from the following methods. $N = \frac{E_b \times 60 \times A}{P \phi Z}$

a) field rheostat control: A variable resistance is connected in series with the field coil. Thus the speed is controlled by means of flux variation b) Reluctance control involving variation of reluctance of Magnetic circuit of motor c) field voltage control by varying the voltage at field circuit while keeping armature terminal voltage constant. $N = \frac{V - I_a R_a}{K\phi}$

2. Armature control method speed adjustment of seperately excited DC motor by armature control may be obtained by any one of the following methods.

1. Armature resistance control: The speed is controlled by varying the source voltage to armature. Generally, a variable resistance is provided with armature to vary the armature resistance. Poor η, speed & V.R

2. Armature terminal Voltage control Armature terminal Voltage control involving variation of voltage in armature circuit. (adjustable voltage generator)

Application of DC motor

these motors have industrial application. They are often used as actuators. This type of motor is used in train and automatic traction purpose.

Synchronous Generator

A synchronous generator is a synchronous m/c which receives mechanical energy from prime mover (steam turbine)(hydraulic turbine or diesel turbine) to which it is mechanically coupled and delivers electric energy.

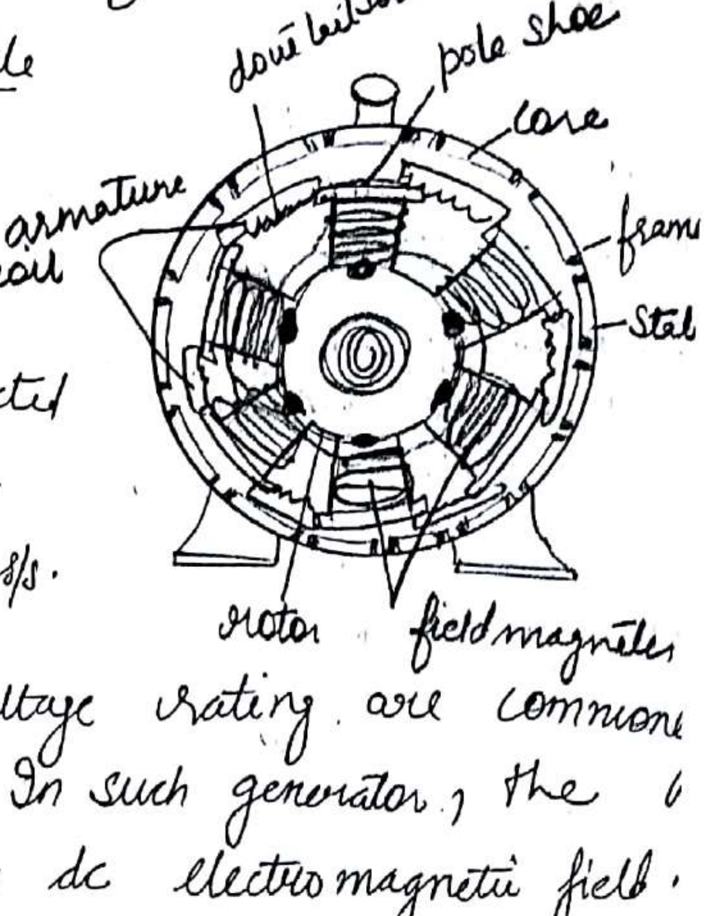
The synchronous m/cs may be single, 2 or 3ϕ types. The Generator is also known as alternator which convert M.E into E.E at desirable 50 Hz.

Construction & working principle

It consist of 2 part

1. Rotor (Armature)
2. Stator (field magnet s/s)

An alternator may be constructed with either the alternator or field structure as the revolving s/s.



Small ac generator of low voltage rating are commonly made of rotating armature. In such generator, the required M.F is produced by dc electromagnetic field placed on the stationary member called stator & the current generated is collected by means of brushes and slip rings on revolving member called the rotor. Practically all large rating generator are made of revolving field.

such generators & if structure or rotor has slip rings and brushes for supply of excitation current from outside dc source & stationary armature, which is made of thin silicon steel lamination securely clamped and held in place of steel frame, accomodate coils or windg in slots. The slots are provided on the stator core and of mainly 2 Types 1. Open Type 2. semi closed type.

* The excitation is usually provided from a small dc shunt or compound generator, called exciter) mounted on shaft of alternator shaft.

<u>Types of rotor used</u>

1. Salient pole type These rotors are used almost entirely for slow and moderate speed alternator & cannot employed in high speed generators such rotor have large diameter and small axial length.

2. <u>Non salient or smooth cylindrical type</u> These rotor are used in very high speed alternators such rotor have small diameter and long axial length $f = \frac{PN}{120}$

<u>Emf equation</u> $E_{rms}/phase = 4.44 K_d K_p \phi f N$ volts. (N = speed)

K_d = distribution or breadth factor $= \frac{\sin \frac{m\beta}{2}}{m \sin \frac{\beta}{2}}$

K_p = coil span factor or pitch factor $= \cos\frac{\alpha}{2}$

* α = angle by which coil span fall short. $N_s = \frac{120f}{P}$

ϕ = useful flux

N = no of turns.

Electrical Installation

V.V. Imp

Switchgear The apparatus used for switching, controlling and protecting the electrical circuits and equipment is known as switchgear.

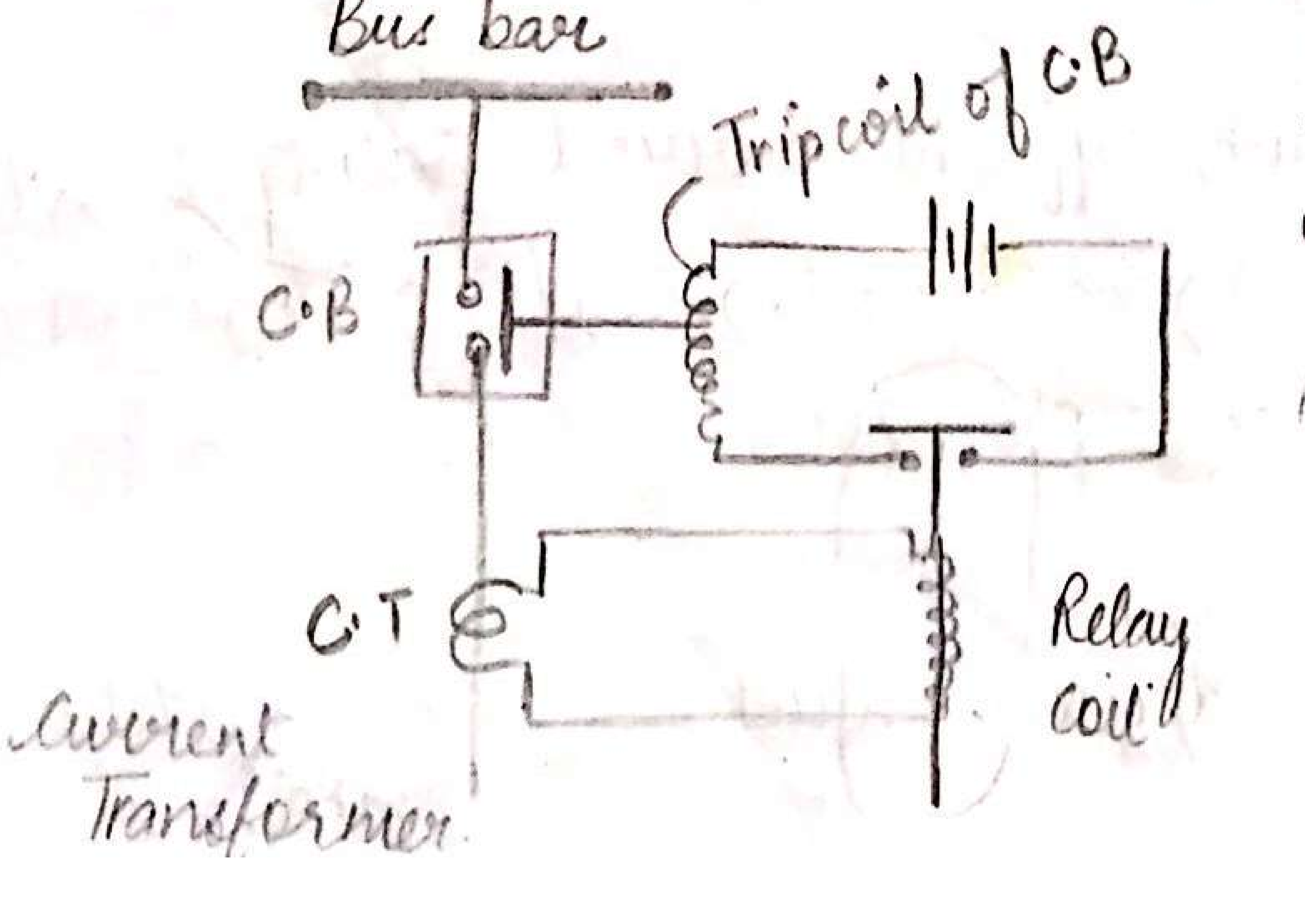
Component of LT switchgear

1. **Switches** A switch is a device which is used to open or close an electrical circuit in a convenient way but it cannot interrupt the fault current.
   a) air break switch b) oil pressure switch.

2. **Fuses** A fuse is a short piece of wire which melts when excessive current flows through it for sufficient time. It is connected in series with the circuit to be protected. (Round type fuse unit, Kit Kat type/Rewirable fuse unit, cartridge type fuse unit, HRC fuse unit, Semiconductor fuse)

3. **Circuit breaker** A circuit breaker is an equipment which can open or close a circuit under all condition i.e no load, full load and fault condition.
   eg. MCB, ELCB and MCCB

4. **Relay** A relay is a device which detect the fault and supply information to breaker for circuit interruption.



Under normal load emf of sec winding CT is small & current is less to close the relay contacts. This keep trip coil of CB unenergised.

eg. Thermal relay, electromagnetic relay

Buchholz relay (X'former)

1. Switch fuse Unit (SFU)

A suitable switch is provided immediately after the meter board its protect the circuit against excessive current. The linked main switch and fuse unit may be provided as one unit or as seperate unit.

Switch fuse is combined unit & known as iron clad switch. 2 types 1. DPIC (Double pole Iron Clad) for controlling 1ϕ 2 wire circuit (240V, 16A)

2. TPNIC (Triple pole neutral Iron clad) for controlling 3 phase 4 wire circuit. (500V, 32A)

V. Imp 5 marks.

2. Miniature Circuit Breaker (MCB) Imp

This is the device that provide protection to the wiring installations and equipment against overcurrent and short circuit faults.

Operation. Thermal operation is achieved with bimetallic strip which deflect when heated by any overcurrents flowing through it. So it release the latch mechanism and cause the contact to open. Inverse time current characteristics result, i.e more the Overload current, shorter time required to operate the MCB. On the occurrence of a short circuit, the rising current energizes the solenoid, operating the plunger to strike the trip lever causing sudden release of latch mechanism which further causes the opening of contacts.

Ratings

These MCB are available with different current rating 0.5, 1, 2, 2.5, 3, 4, 5, 6, 7.5, 10, 16, 20, 25, 32, 35, 40, 63, 100, 120, 160A and voltage rating 240/415V ac upto 220V dc

Uses

It is used to protect the devices such as air conditioners, refrigerators & computers etc.

3. Earth leakage Circuit breaker (ELCB) imp

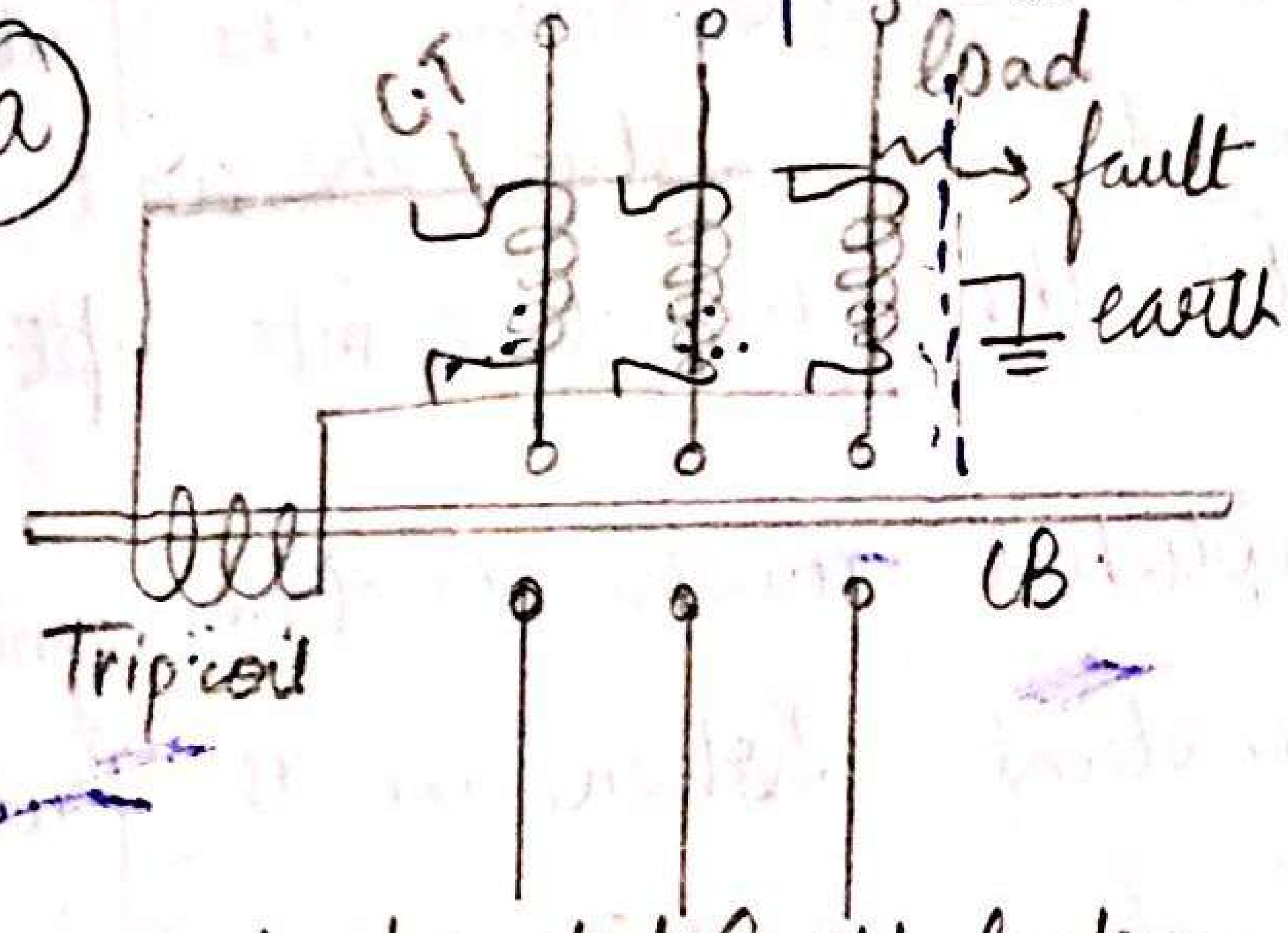
The device which provides the protection against earth leakage.

2 Types

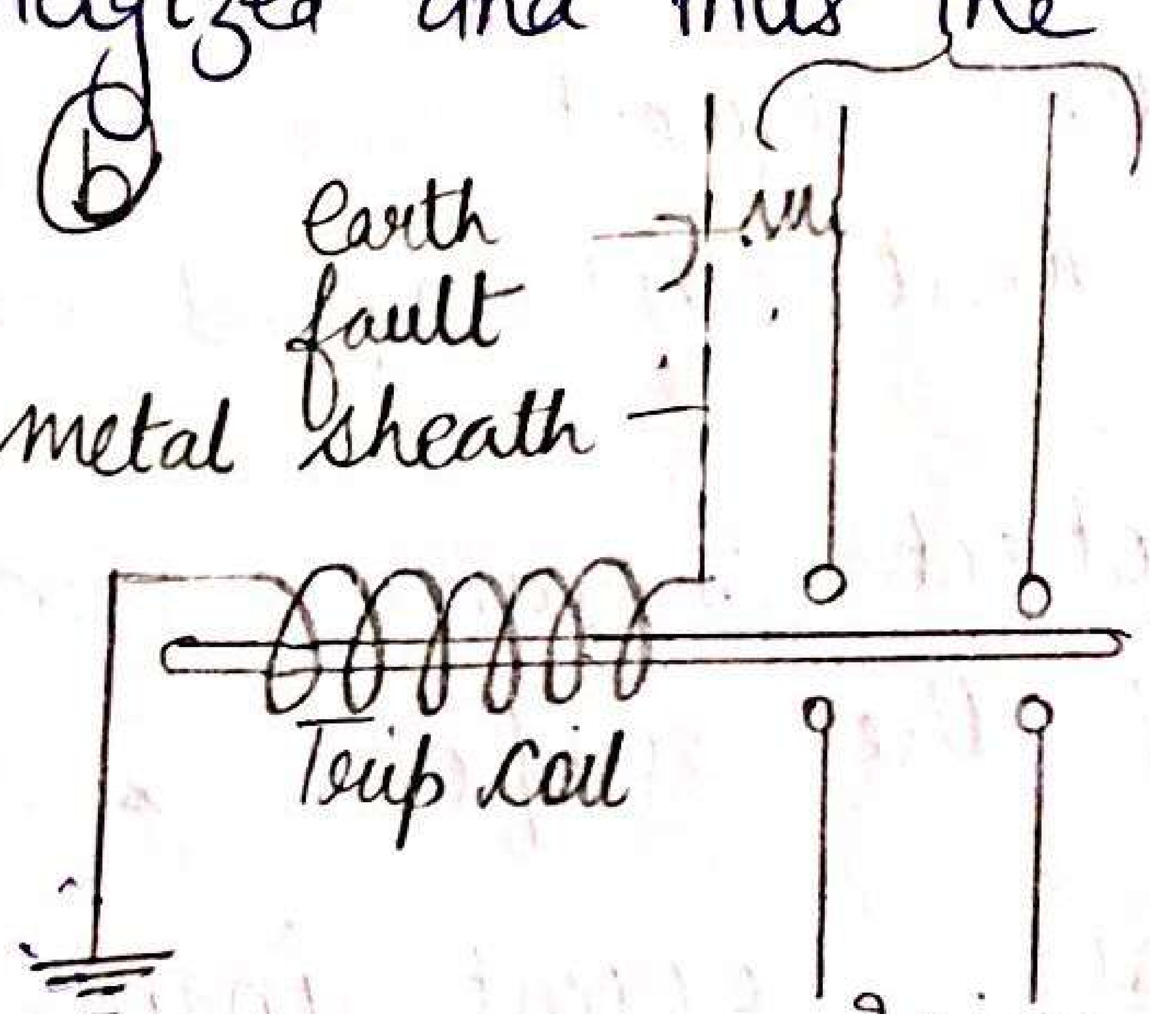
1. Current operated earth leakage CB.

Condition if product of the operating current in A and the earth loop impedance in Ω does not exceed 40 then this type of CB used.

Operation A earth leakage protection is applied to 3ϕ 3 wire s/s. If there is no earth leakage the sum of all the current in 3 coils of CT = 0 and no current flow through the trip coil. But in case of any earth leakage, the currents are unbalanced and the trip coil is energized and thus the CB is tripped.



Current operated Earth leakage Trip



Voltage operated Earth leakage Trip.

2. Voltage operated earth leakage CB

Suitable when earth loop impedance exceeds the values applicable to current operated earth leakage CB.

Operation An earth leakage trip in 2 wire circuit. When the V b/w the ECC and earth electrode rise to a sufficient value, the trip coil will carry the required current to trip the CB.

ECC (Earth continuity conductor)
A 3rd conductor with Line & neutral in main distribution s/s bonded to earth.

4. Molded case circuit breaker (MCCB)

A molded case CB is a protection device that can be used for wide range of voltages and frequencies of both 50 Hz and 60 Hz.

Difference b/w MCCB and MCB It have high current rating upto 2500 A, and its trip settings are normally adjustable.

Main function
1. Protection against overload
2. Protection against electrical faults.
3. Switching a circuit ON & OFF.

Operation It is based on the same principle used by all types of thermal magnetic C.B.

1. Overload protection is done by means of thermal mechanisms. It has a bimetallic contact which expands and contracts in response to change in temperature. So whenever the fault occur (or the current exceeds the adjusted trip value) the contact will start to heat and expand until the circuit is interrupted.

2. The fault protect is also accomplished with electromagnetic induction, and the response is instant. Whenever the fault occur, the high current induces a magnetic field in a solenoid coil located inside the breaker - this magnetic induction trip contact and current is interrupted.

V. Imp

MCB	MCCB
1. Miniature Circuit breaker with optimum protection facilities of overcurrent only. These are manufactured for fault level of upto 10KA only with operating current 0.5 to 63A. These are used for smaller loads.	Molded case Circuit breaker with protection facilities of overcurrent, earth fault. Has variable range of 50% to 100% operating current. They can be wired for remote as well as local operation both. fault level 16KA to 50KA operating R 25A to 30… larger power requirement.

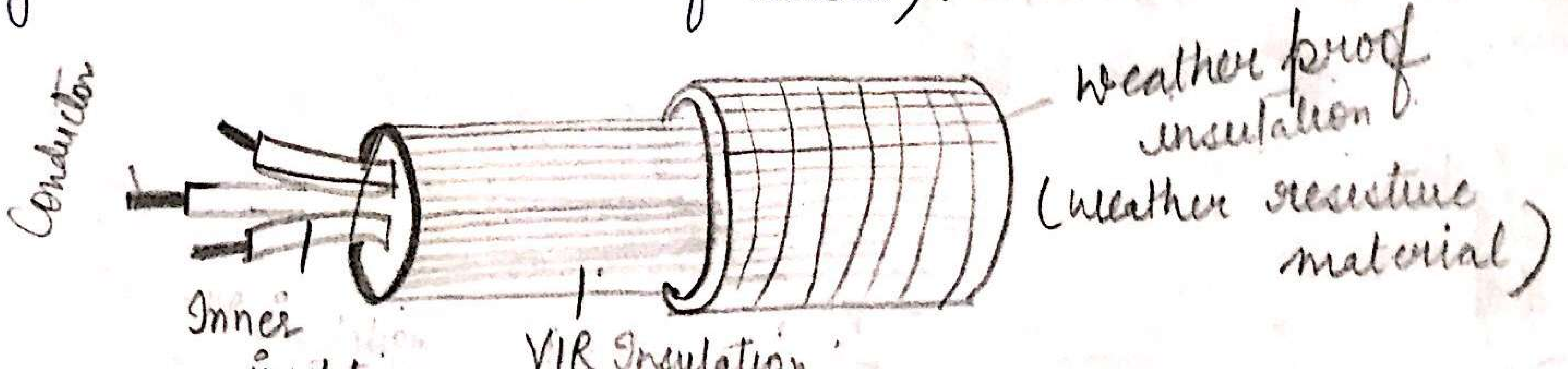
Types of wire and cables

The wires used for internal wiring of building may be divided into groups according to

1. Conductor used a) Cu conductor cables b) Al conductor cables
2. Number of cores used a) single core b) Twin core c) 3 core cables
3. Voltage grading a. 250/440V b. 650/1100V (Voltage a conductor can withstand)
4. Type of insulation used:
   a. Vulcanized Indian Rubber (VIR) cables 240/415V Cu, cotton tape sheathed
   b. Tough rubber sheathed (TRS) cables VIR cable with outer protecting covering of TRS provide additional insulation, corrosion
   c. Lead sheathed cables VIR conductor covered with lead sheath provide protection against moisture.
   d. Polyvinyl chloride PVC cables
   e. Weather proof cables (outdoor)
   f. Flexible cords and cables (consist of wires silk/cotton/plastic covered)
   g. Multi strand cables (↑ no. of strands)
   h. XLPE cables (Cross linked polyethylene) (↑ current rating, longer life)

* Single wire, may be bare or covered with insulation is called wire while several wires stranded together is called cable.

* PVC insulation is most widely used for covering wire/cables used in internal wire (as it provides better flexibility, has better insulating qualities, has no chemical effect on metal of wire and gives smaller diameter of cable).



Earthing — Equipment grounding
— System grounding

Earthing means connection of neutral point of supply system or the non current carrying parts of electrical apparatus, such as metallic framework, metallic covering of cables etc to the general mass of earth in such a manner that at all times an immediate discharge of electrical energy take place without danger.

Earthing is provided

1. to ensure that no current carrying conductor rise to a potential with respect to general mass of earth than its designed insulation.
2. to avoid electric shock to human beings.
3. to avoid risk of fire due to earth leakage current through unwanted path.

Various method of earthing

1. Strip or wire earthing. (Horizontal buried rocky soil 25 mm X 1.6 mm Cu 0.5 depth)
2. Rod earthing (12.5 mm dia 2.5 m l) vertical buried sandy soil
3. pipe earthing (size depend upon current to be carried & type of soil)
4. plate earthing (dimension 60 cm X 60 cm X 3 m Cu plate)

The most common and best system of earthing is pipe earthing which is suitable for the same earth & moisture conditions.

(read pipe earthing imp)

Batteries

A source of emf (dc) in which chemical energy is converted into electrical energy is called an electric cell. The emf developed and current supplied by single cell is very small i.e only 1.5 V and 0.125 A resp. There are many app. where higher V/I is required. So In order to obtain high V & I no. of cells are connected in series, parallel or series-parallel combination. Such combination of cells is known as batteries.

Types of batteries

1. **Primary batteries**: Primary batteries can be used only once because the chemical reaction that supply the current is irreversible eg. Voltaic cell, daniel cell, drycell etc. In these cells during discharing, one of the plates (-ive plate) consumed which cannot be recovered by reversing the direction of flow of current through the cell. Thus chemical action in this case is not reversible and the cells cannot be recharged. This fact makes batteries more expensive so rarely used in commercial applications.

2. **Secondary batteries** (Storage batteries or accumulators) The batteries can be used, recharged and reused. The chemical reaction that provide current from the battery are readily reversed when current is supplied to the battery eg. lead acid, nickel iron alkaline cell, nickel cadmium alkaline cell etc.

In these cells no electrode is consumed during discharging however the chemical composition of plates is charged.

when the direction of flow of current through the cell is reversed the plate and electrolyte regain their original composition. So action is reversible and cell can be recharged. While recharging E.E is converted into chemical energy which is stored in the cell itself i.e it is called storage batteries.

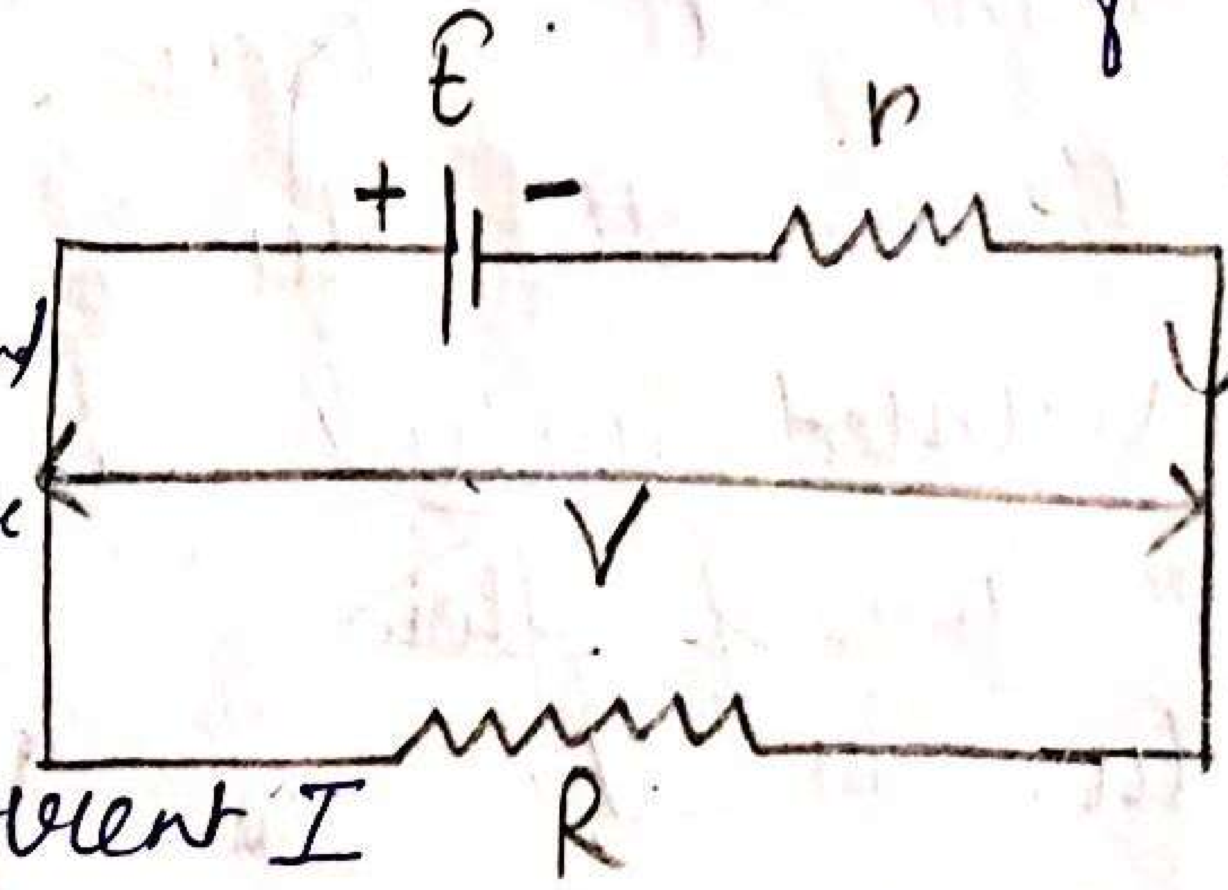
* Usually a no. of cells connected in series placed in single container is called a battery.

Important Characteristics for batteries (V. Imp)

The 3 important characteritics of an accumulator are -

1. Voltage

a) Emf (electromotive force) of a cell: The energy supplied by a cell to one coulomb of charge is called Emf of cell. It is also defined as potential drop b/w the 2 electrodes of a cell on open ckt. (E)



b) Terminal Voltage The p.d across the terminals of cell at load is known as terminal voltage (V).

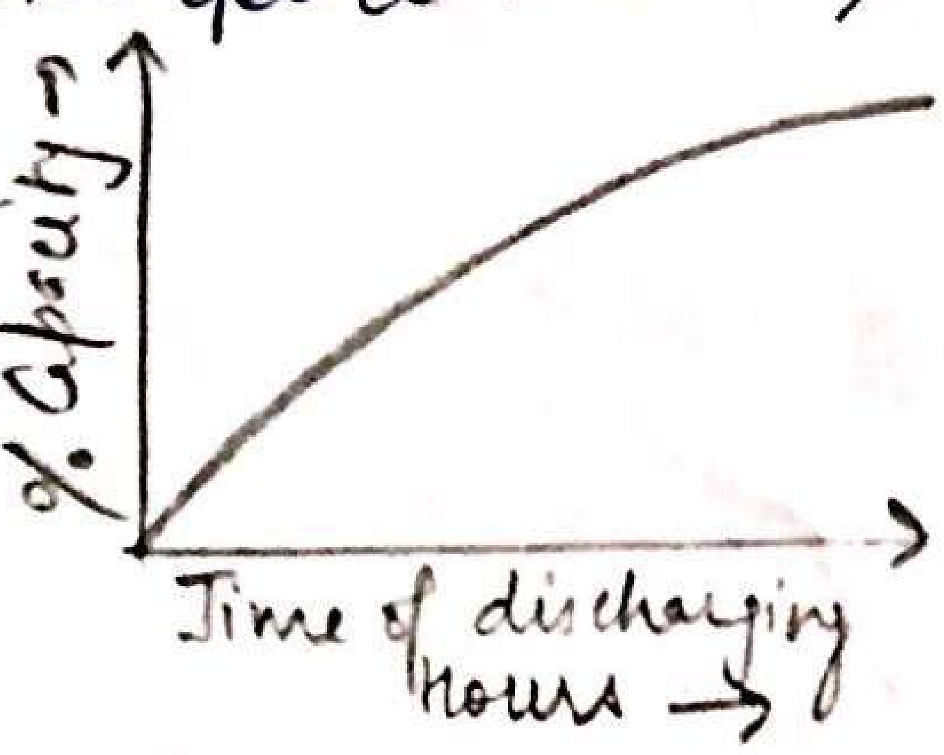
When load is applied, it delivers current I to external resistor (R) as shown. The p.d across the terminals reduces to V becoz V.D ($I \times r$) in internal resistance.

Thus $V = E - I \times r$ (if battery discharges;
$V = E + Ir$ if battery charges)

2. Internal resistance of cell The opp. offered to flow of current by internal composition of cell itself is called internal R (r).

3. Capacity (Backup) The ability of an accumulator to last & provide current is called the rated output or capacity/Backup

So the quantity of electricity which a battery can deliver during single discharge until its terminal Voltage falls to 1.8 V/cell is called capacity of battery. It is expressed in A-H (ampere hours)



Capacity of battery or cell = $I_d \, T_d$ (discharging)

I_d = Current, T_d = Time

4. Efficiency of a battery (elementry Calculation for energy consumption)

a. Quantity or (A-H) η The ratio of output A-H during discharging to A-H during charging gives η of batteries

$$\eta_{AH} = \frac{I_d T_d}{I_c T_c}$$

I_d = dis. current
T_d = dis. Time
I_c = charging Current
T_c = Charging Time

b. Energy or W-H η The ratio of output Watt-hours during discharging to the input watt hours during charging of battery is called energy / W-H η.

$$\eta_{WH} = \frac{I_d T_d V_d}{I_c T_d V_c}.$$

V_d = dis. Voltage.

5. Battery ratings.

The standard adopted by both The industry and government are

1. Ampere hour capacity Rating..
2. Reserve capacity.
3. cold ratings
4. cold cranking power ratings.

Elementry Calculation for energy consumption.

(write equation) ↑ here.

numericals *

Numerical A discharge battery is put on charge of 5A for 3½ hours at a mean charging Voltage of 13.5V. It is then discharged in 6 hours at a const terminal Voltage 12 V through R ohms. Determine i) R for an A-H η 85% ii) watt hour η of battery.

Sol Given $I_c = 5A$ $T_c = 3.5$ $V_c = 13.5V$
$T_d = 6$ hours $V_d = 12V$

$\eta_{AH} = 85\%$
$= 0.85$

$$\eta_{AH} = \frac{I_d T_d}{I_c T_c}$$

$$I_d = \frac{0.85 \times 5A \times 3.5}{6} = 2.48A$$

$$R = \frac{V_d}{I_d} = \frac{12}{2.48} = 4.48\,\Omega \quad 4.84$$

$$\eta_{WH} = \eta_{AH} \times \frac{V_d}{V_c} = 85 \times \frac{12}{13.5} = 75.55\% \text{ Ans}$$

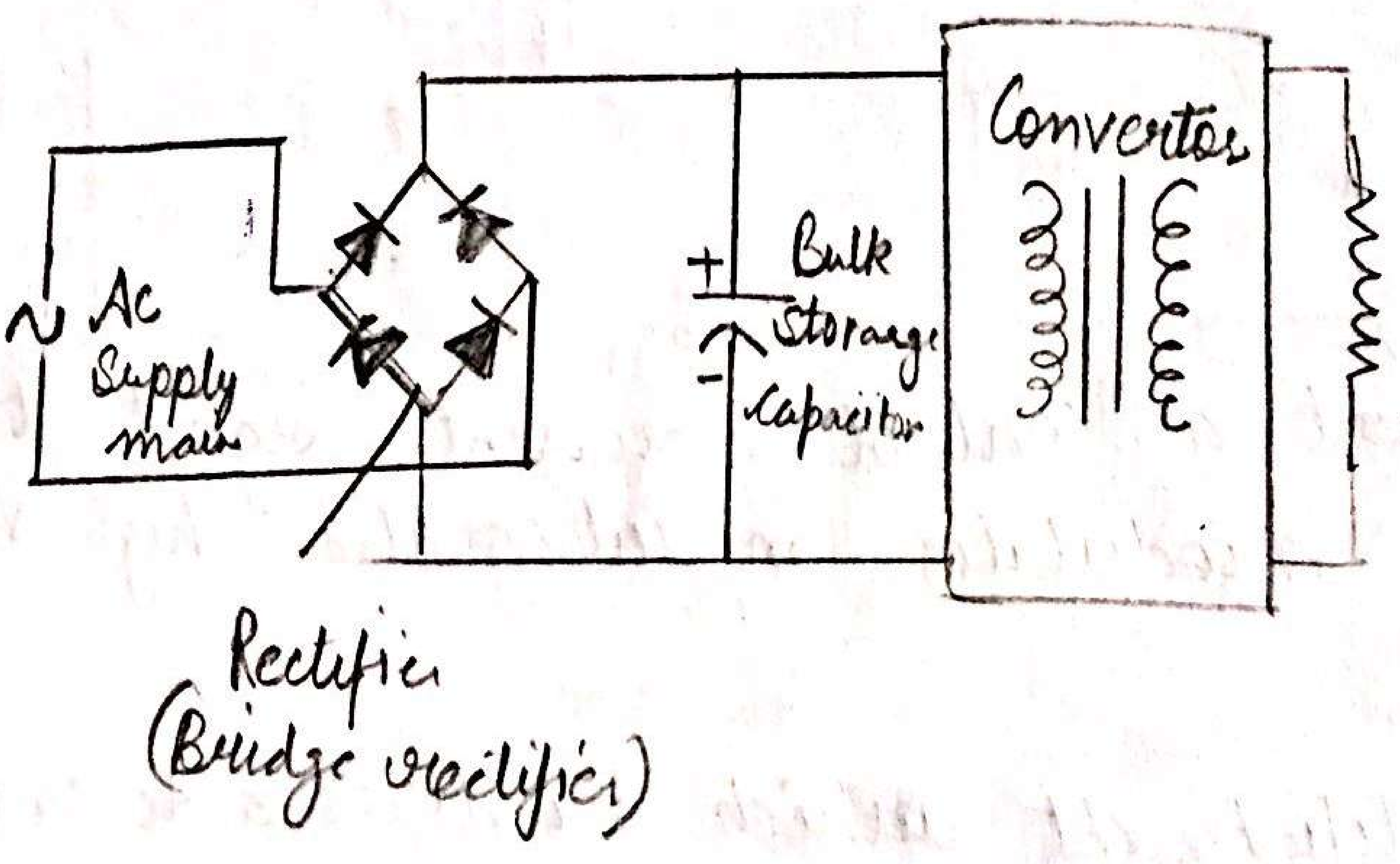
Power factor improvement (V. Imp)

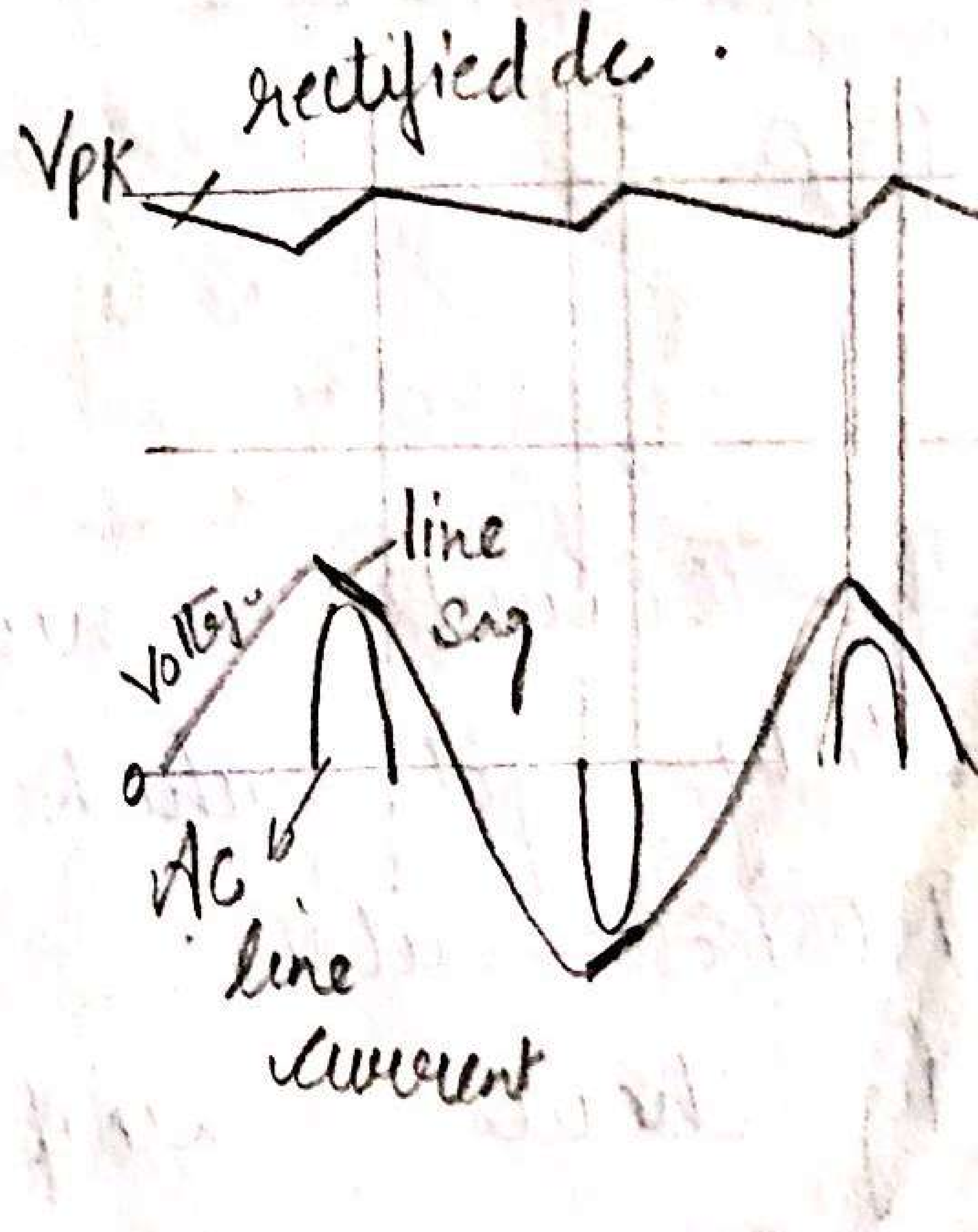
Power factor improvement can be achieved with the use of either a passive or active input circuit. Passive circuit usually contain a combination of large capacitors, inductor and rectifiers that operate at supply line frequency. Active ckts incorporate some form of high f. switching convertor for the power processing with the boost converter being the most popular topology. Since active input circuit operate at a frequency much higher then that of supply line frequency they are smaller in size, light wt. and more efficient than a passive circuit that provide similar ckts. 6

With proper control of the preconvertor, almost any complex load can be made to appear resistive to the ac supply line, thus significantly reducing the harmonic current eg MC3368 active pf controller, TOPS switch.

Why pf correction is needed?

The simple rectifying circuit draws ~~pwf~~ power from the ac supply main when the instantaneous ac voltage exceed the capacitor Voltage. This occur near the supply line voltage peak and result in high current spike as shown in fig since power is only drawn near the supply line V peaks, the resulting spikes of current are extremely non sinusoidal with a high current of harmonics. This result in poor power factor condition where apparent input power is much higher then the true power. This reason that pf correction is required in power supplies.





1. MC 3368: An active pf controller whose function is to boost preconverter in off line power supply line app, has low power & high density also low power dissipation.

It features a (1) watchdog timer (to initiate output switching), (2) one quadrant multiplier (to force line current to follow the instantaneous Voltage)

(3) detector (to ensure critical conduction of operation)

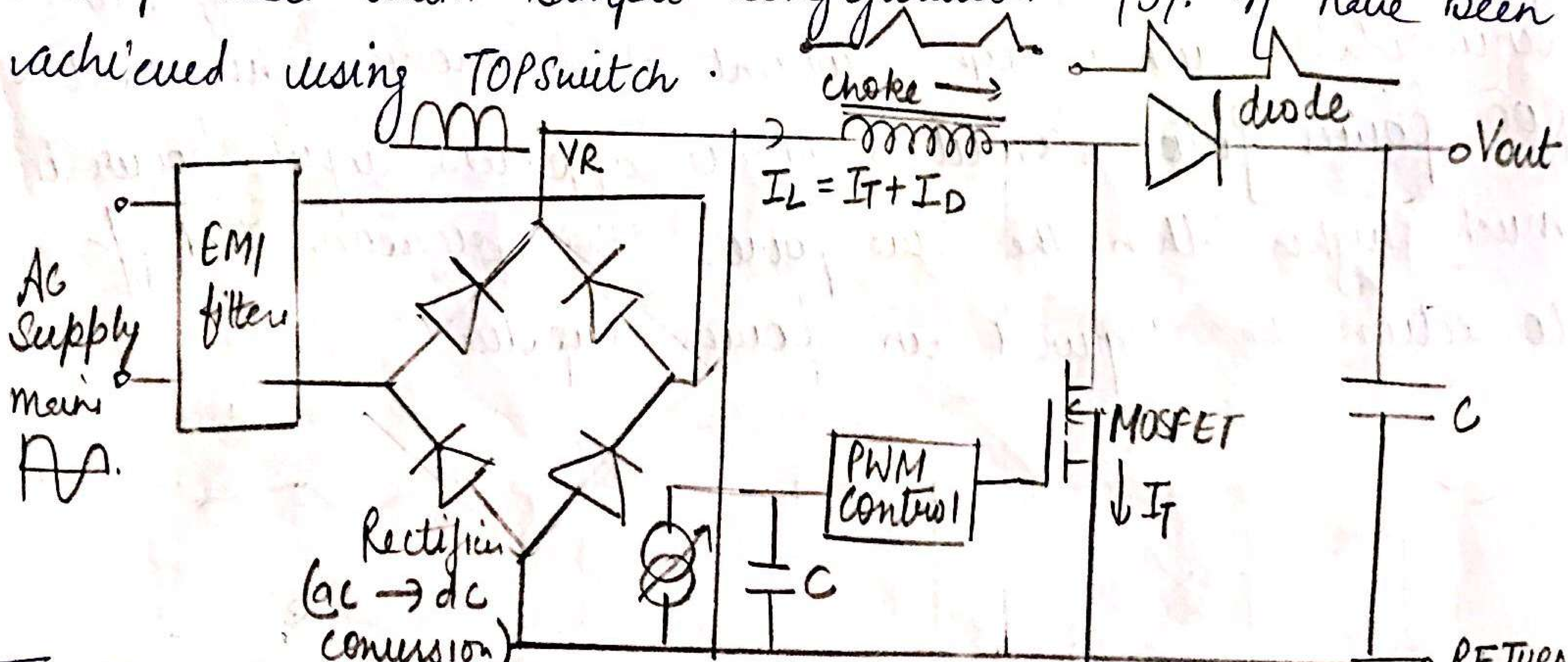
(4) A transconductance error amplifier.

(5) current sensing comparator

(6) 5.0V reference, (7) an under Voltage lockout circuit which monitor Vcc

(8) CMOS driver for driving MOSFET's.

2) <u>Using TOPSwitch</u> It is 3 terminal PWM switch integrated circuit implements a new, fixed frequency pf correction ckt using few as 17 components. Output power level upto 150 watts are possible with simple configuration. 93% η have been achieved using TOPSwitch.



The TOP Switch convert a control current signal to a duty cycle which modulates an integrated high voltage MOSFET switch.

fig shows a simplified ckt which produces a dc voltage of higher than the peak of full wave rectified ac supply voltage. Proper control of the switch duty cycle over line freq. period generates a filtered sinusoidal input current waveform that is in phase with input voltage waveform.

Construction/Characteristics/ merits & demerits / App of

1. Nickel cadmium cells.

It was developed by Swedish scientist Waldemar Jungner in 1899.

Const: Anode $Ni(OH)_4$ Cathode Cd (cadmium)
electrolyte – KOH (potassium hydroxide) of specific gravity

Its const. is similar to nickel iron cell with the difference that its extreme plates are +ive. moreover the plates are electrically connected to the container.

Chemical action during discharging. Diagram (last Page)

At cathode $Cd + 2OH \rightarrow Cd(OH)_2$

At anode $Ni(OH)_4 + 2K \rightarrow 2KOH + Ni(OH)_2$

no change in specific gravity of electrolyte.

Recharging At anode $Ni(OH)_2 + KOH \rightarrow Ni(OH)_4$

cathode $Cd(OH)_2 + 2K \rightarrow 2KOH + Cd$

regain their original composition.

Characteristics 1) Emf :- fully charge. 1.4 V which decreases to 1.3 rapidly.

2. $\eta = 80\%$ AH and 65% W.H

3. Internal resistance very low, less than lead acid cell.

advantages very long life ... can be stored in any condition as there is no change in specific gravity and these cells can be charged for short period.

disadvantages 1. Very costly 2. low average emf therefore more cells are required for particular voltage.

2. Nickel Iron alkaline cell/ batteries

Also known as Edison cell, developed by American Scientist Thomson edison in 1909.

Const. Consist of 2 plates :- Anode & cathode. The active material of anode is $Ni(OH)_4$ and cathode is fe (iron) when fully charged. These plate immersed in electrolyte KOH. A small quantity of LiOH (lithium hydrate) is also added to electrolyte which ↑es the capacity and life of cell. The specific gravity is 1.2 and the container made of nickel plated iron to which negative plates are connected.

Working. Diagram (last page)

When cell is fully charge its positive plate $Ni(OH_4)$ and -ive plate fe. KOH is electrolyte is dissociated into K^+ and OH^- ions

Discharging

$$Fe + 2OH \rightarrow FeOH_2 \quad \text{cathode}$$

$$Ni(OH)_4 + 2K \rightarrow 2KOH + Ni(OH)_2 \quad \text{anode}$$

recharging

$$Fe \cdot Ni(OH)_2 + 2OH \rightarrow Ni(OH)_4$$

$$Fe(OH)_2 + 2K \rightarrow Fe + 2KOH$$

When cell is put on charging the OH^- ions moves toward anode and potassium ions move toward cathode.

Electrical characteristics

1. emf of fully charged cell is 1.4V which decreases to 1.3V rapidly however the avg emf is 1.2V which decreases to 1.0V when fully discharge.
2. internal R is high nearly 5 times to that of lead acid cell.
3. A-H η is 80% & W-H η is 60%

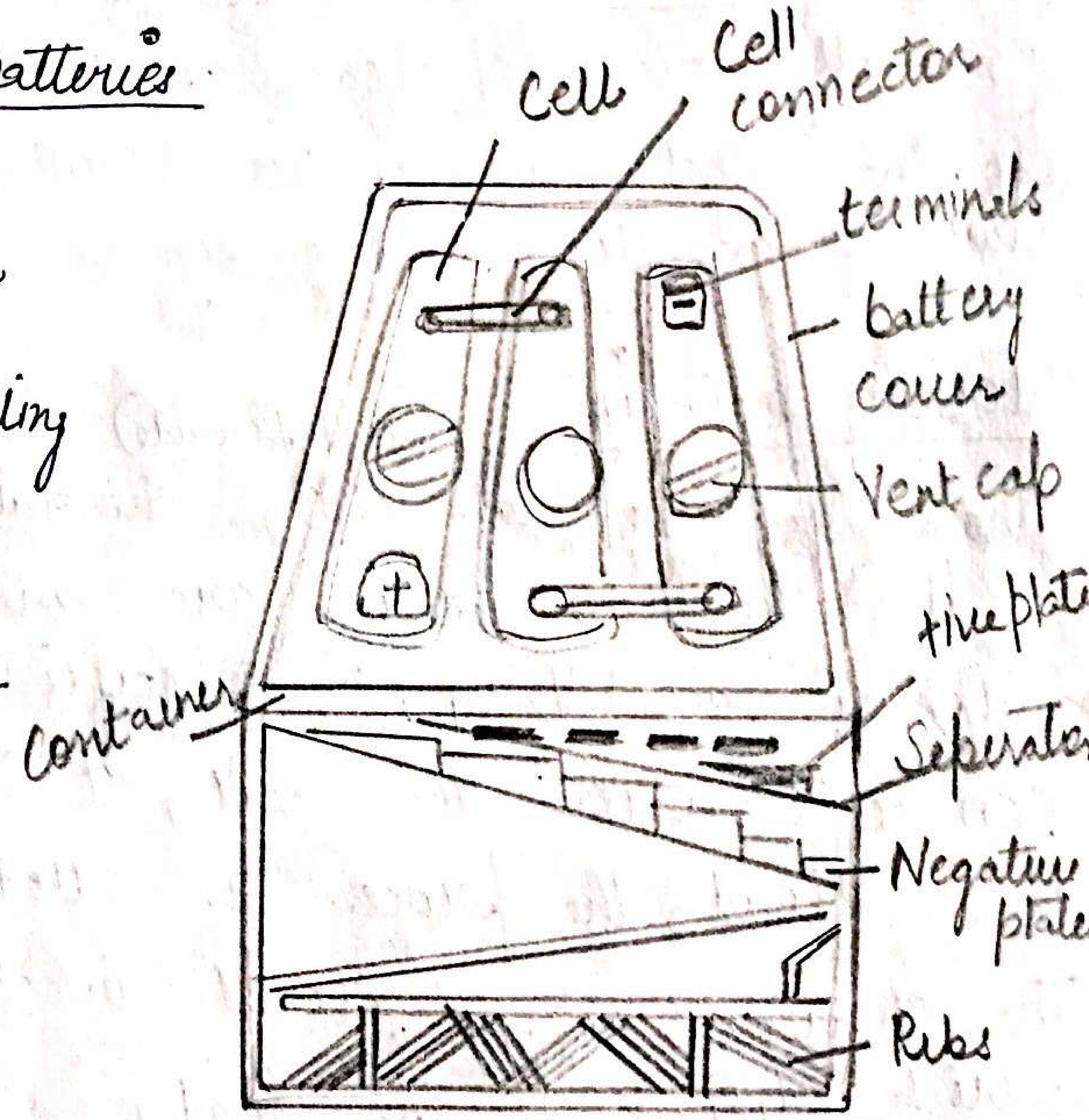
advantages 1. longer life
2. KOH is not harmful if spilled away.
3. lower weight nearly half of lead acid cell.
4. can withstand higher temperature.

Disadvantages 1. higher cost nearly double
2. lower efficiencies.

lead acid batteries.

The important parts of batteries

1. Container
Outer body, made up of hard rubber or plastic and is sealed at top to prevent spilling of electrolyte.



2. plates
Alloys of lead antimony sheet covered with lead peroxide & spongy lead forming +ve and -ve plates respectively are used as electrodes

3. Seperator
To reduce internal resistance of cell and to save the space the plates are placed close 2 each other

... plates are placed alternately with separators of ... they are separated by rubber sheet (non conducting material) (8)

4. **Electrolyte** H_2SO_4 is used as an electrolyte in lead acid batteries. This added to water in such a proportion that with fully charged battery its specific gravity is about 1.28 to 1.29.

5. **Battery cover** each cell is covered with molded hard rubber and sealed with an acid resistant material.

6. **Vent caps** it has hole that allow the free exit of gases formed in the cell during charging. It's can be easily removed for adding water.

7. **Inter cell connector** cells are connected in series with a lead alloy link (in one container)

8. **Cell terminals** Each cell has 2 terminals which are generally made of lead as it does not corrode due to the electrolyte. The +ive terminal of the battery is marked with red colour or +ive sign.

Working principle

When the +ive plate PbO_2 (lead peroxide) - chocolate brown colour and -ive plate of (Pb) spongy lead - grey in colour are immersed in a dilute sulphuric acid (H_2SO_4) of specific gravity 1.28 and load is connected across the cell, it start delivering current to the load, the process is called discharging of cell. The chemical energy stored in cell is converted into EE which delived to the load.

Chemical action during discharging

At cathode $SO_4^{--} - 2e \rightarrow SO_4$ (radical)
(sulfate)

~~At anode~~ $Pb + SO_4 \rightarrow PbSO_4$ (lead sulfate)
(grey colour) whitish colour

At anode $2H^+ + 2e \rightarrow 2H$

$PbO_2 + 2H \rightarrow PbO + H_2O$
Chocolate brown

$PbO + H_2SO_4 \rightarrow PbSO_4 + H_2O$
(sulfuric acid) whitish colour.

Explain these chemical reaction as follow ↓

(Hydrogen gas liberated at anode acts chemically with anode material PbO_2 and reduces it to PbO which further reacts with H_2SO_4 forming $PbSO_4$)

Chemical action during recharging

- **At anode** $SO_4^{2-} - 2e \rightarrow SO_4$ (radical)

$SO_4 + H_2O \rightarrow H_2SO_4 + O$

$PbSO_4 + O + H_2O \rightarrow PbO_2 + H_2SO_4$

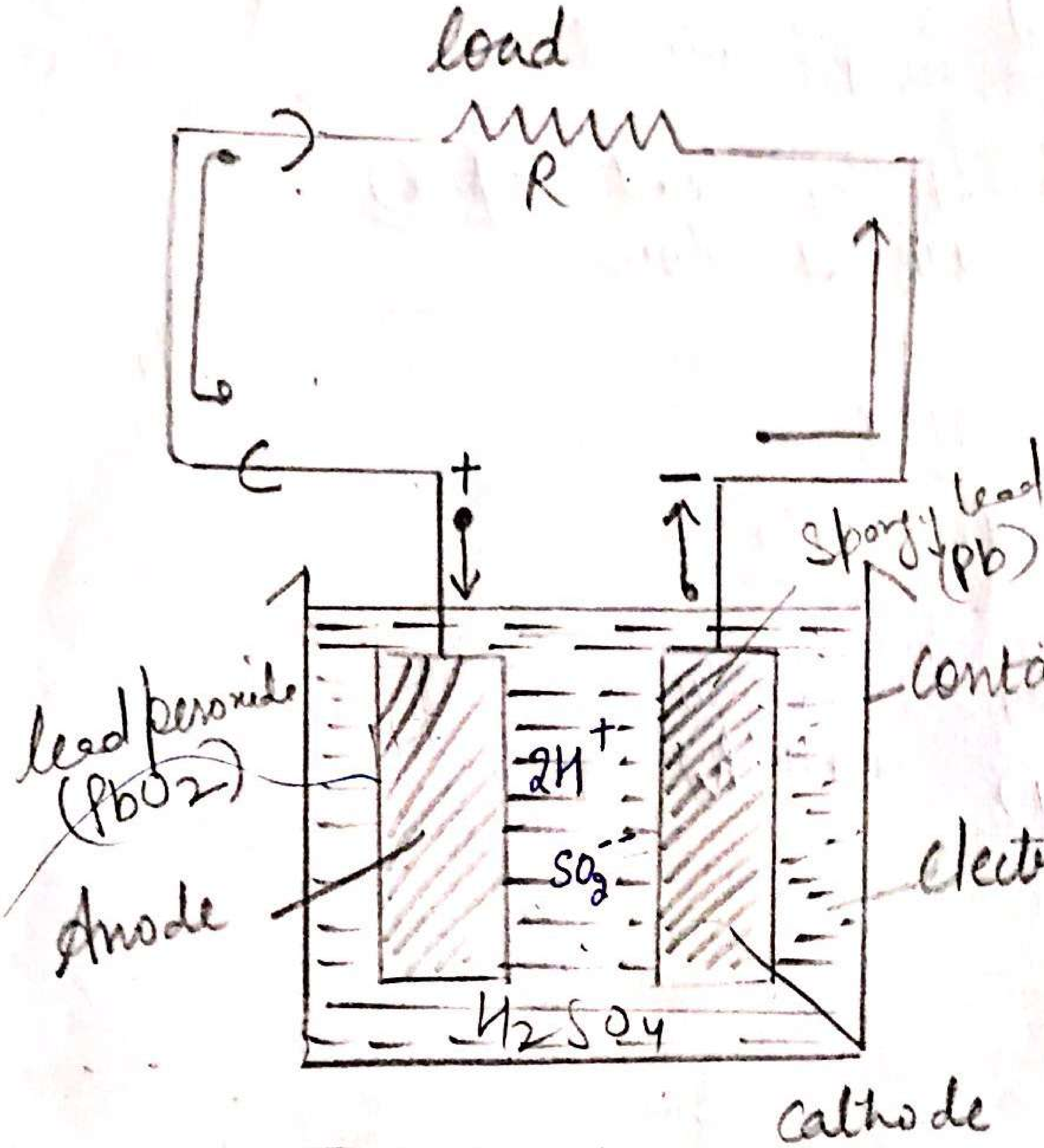
At Cathode $2H^+ + 2e \rightarrow 2H$

$PbSO_4 + 2H \rightarrow Pb + H_2SO_4$.

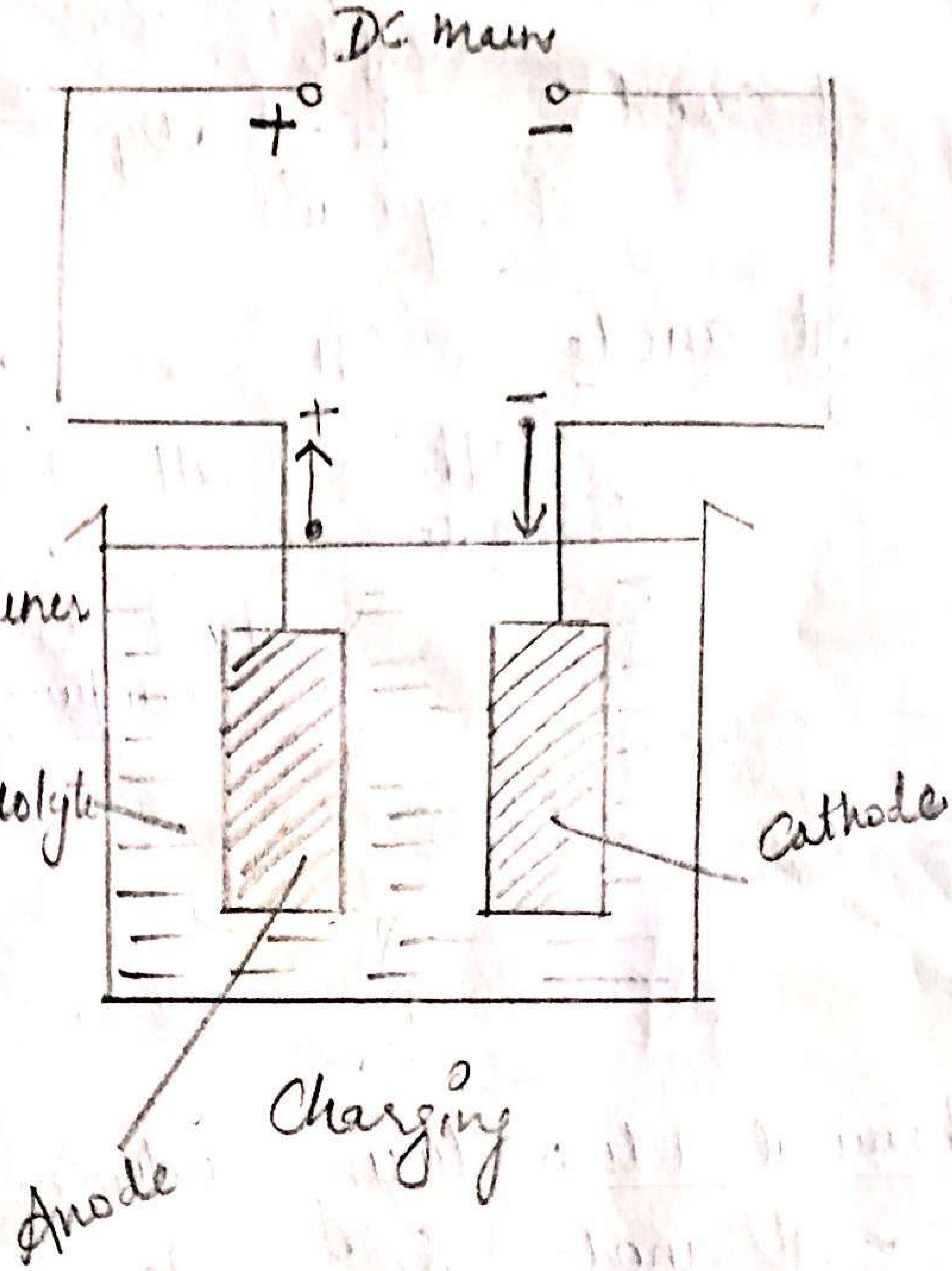
Here. Electrical energy is converted in Chemical energy

The average life of a lead acid battery is 2 to 4 years

Application 1. Used in automobiles for starting & lighting.
2. for lighting on steam and diesel railway trains
3. Used at Telephone exchange.
4. Used for lighting purpose in remote areas.
5. Used at generating station & substation for operation of protective devices and for emergency lighting.



Discharging



Charging

Nickel Iron Alkaline cell

Nickel Cadmium cell.

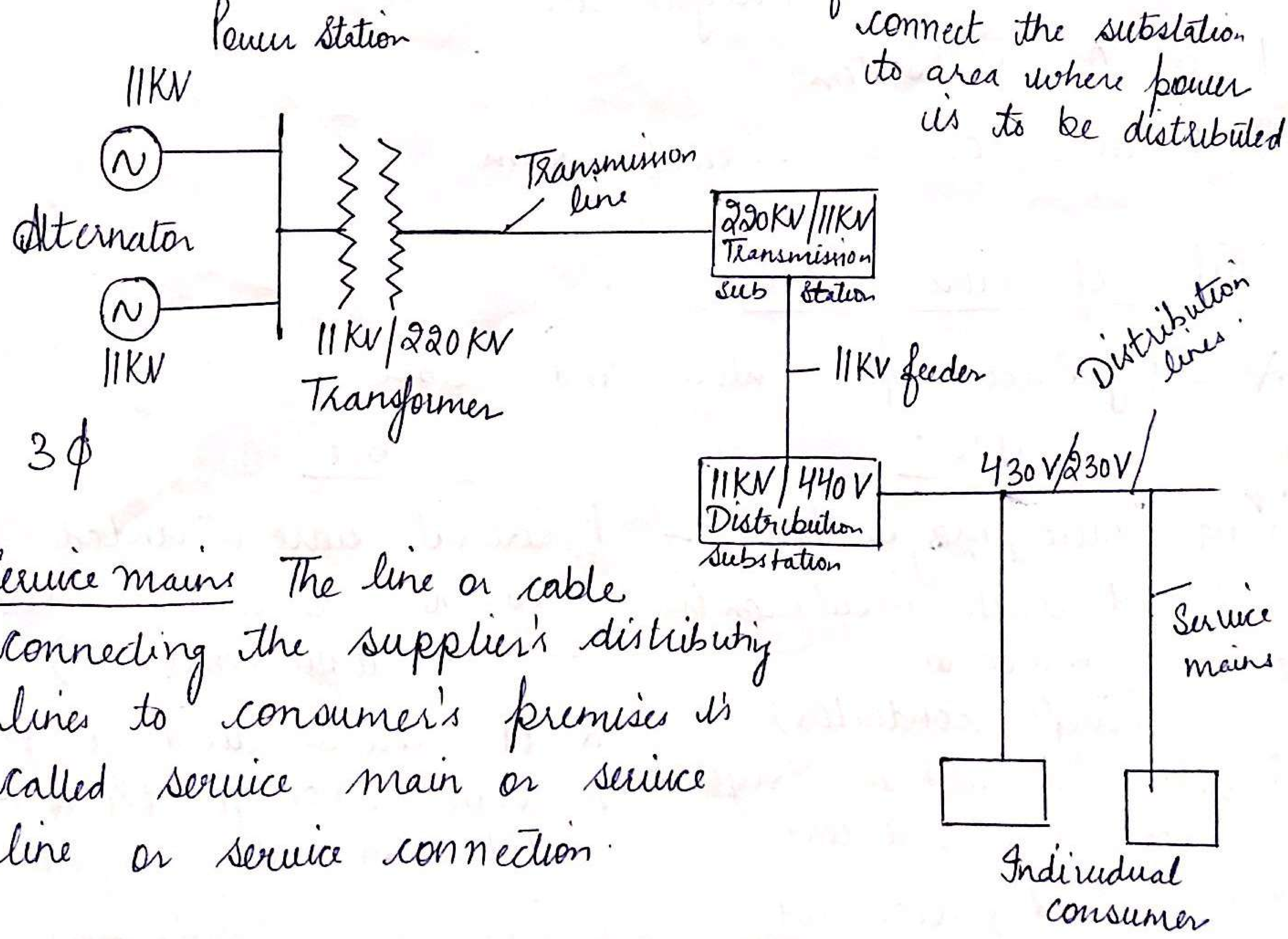
CHS Electrical Installation

Transmission lines Power is transmitted from generating station to the utility centre by the means of transmission lines.

Distributed lines from the utility centre power is distributed through distributors/distribution lines. The consumer are provided power supply by tapping connection from distribution lines.

electric power s/s

feeder Conductor which connect the substation to area where power is to be distributed



Service mains The line or cable connecting the supplier's distributing lines to consumer's premises is called service main or service line or service connection.

3 pipe earthing

An electrical supply s/s consist of 3 principal component the power station, transmission line and distribution system. Electric power is produced at power station which are located at favourable places, generally quite away from consumer. It is then transmitted over large distance to load centre with the help of conductors known as transmission line. Finally, it is distributed to large number of small and big consumer through distribution network.

Electrical Supply s/s can be classified into

1. AC or DC system.
2. Overhead or underground system

line used to transmit electrical energy.

Types of wire & cables

* Difference b/w wire and cable

wire	cable
1. Single wire, may be bare or covered with insulation is called wire i.e. (Single conductor)	1. Several wire stranded together is called cable. (multiple conductor)
2. A wire is used to carry electricity, to bear mechanical loads.	2. A cable is used for power transmission for ~~telecommunication~~ telecommunication signals or to carry electricity.
3. Types Solid, Standard	3. Twisted pair, multi conductor, coaxial cable

Fuse.

A fuse is a short piece of metel, inserted in the circuit which melts when excessive current flows through it and thus breaks the circuit.

Low Voltage fuse

Semienclosed rewireable fuse, HRC cartridge fuse (High rupturing capacity).

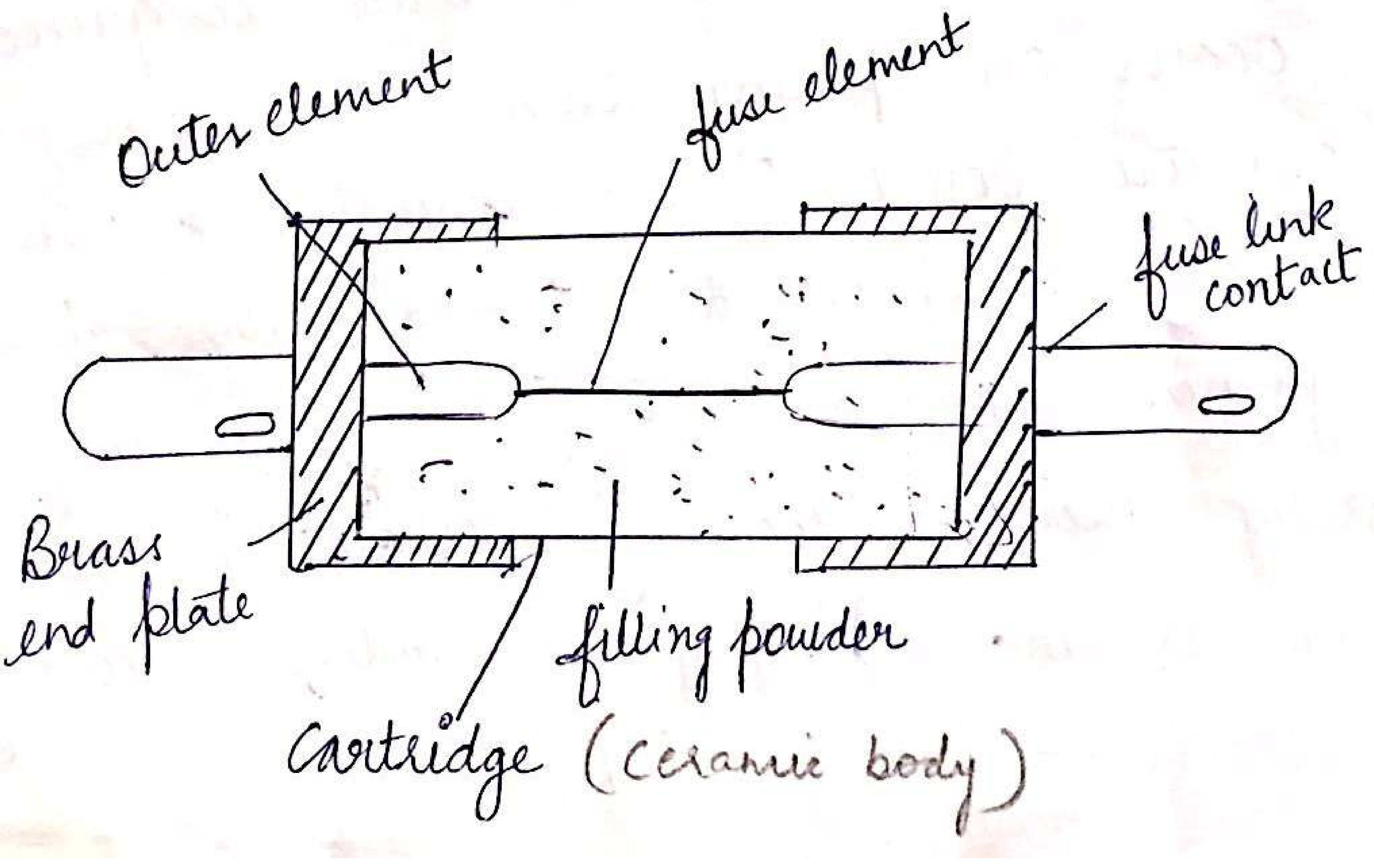
High Voltage fuses

cartridge type, liquid type, metal clad fuses.

v. Imp

High Rupturing capacity cartridge fuse

It consist of a heat resisting ceramic body having metal end caps to which welded silver current-carrying element. The space within the body surrounding the element is completely packed with filling powder. The filling material may be chalk, plaster of pairs or marble dust acts as arc quenching and cooling medium.
∴ carries normal current with overheating.



when a fault occurs, the current increases and the fuse element melts before the fault current reaches its first peak. The heat produced in the process vapourise the ~~metal~~ melted silver element. The chemical reaction b/w the silver vapour and the filling powder results in formation of a high resistance substance which helps in quenching the arc.

<u>Advantage</u> 1. High speed of operation.
2. longer life & require no maintenance.
3. They are cheaper then other circuit interrupting devices of equal breaking capacity.

<u>Disadvantages</u> 1. They have to replaced after each operation.
2. Heat produced by the arc may affect the associated switches.

<u>Switch</u> <u>Air break switch</u> These switch are designed to open a ckt under load. In order to quench the arc that occur on opening such as switch, special <u>arcing horn</u> are provided (where arc is formed). As switch opens these horns are spread farther moved and farther apart. The arc is lengthened, cooled & interrupted. Air break switches are generally used outdoor for circuits of medium capacity such as line supplying an industrial load from a main transmission line or feeder.

Earthing Or Grounding ~~easy~~

The process of connecting the metallic frame (i.e non current carrying part) of electrical equipment or some electrical part of system (eg neutral point in a star connected system, one conductor of the secondary of transformer etc) to earth / soil is called grounding or earthing.

Advantage

If grounding is done systematically in the line of the power system, it prevent accidents and damage to the equipment of power s/s and at the same time continuity of supply can be maintained.

Grounding / earthing may be classified as

1. Equipment grounding: The process of connecting non current carrying metal part of electrical equipment to earth.
2. System grounding The process of connecting some electrical part of the power system to earth.

* Neutral grounding The process of connecting neutral point of 3 phase system to earth either directly or through some circuit element (eg resistance, reactance etc) is called neutral grounding.

Various method of earthing are

1. Strip or wire earthing.
2. Rod earthing.
3. Pipe earthing
4. plate earthing.

Pipe earthing. The most common and best s/s of earthing as compared to other systems suitable for same earth and moisture condition.

A galvanised steel and perforated pipe of approved length and diameter is placed upright in permanently wet soil. Size of pipe depend upon current to be carried and type of soil. Usually dia = 40 mm and l = 2.5 m for ordinary soil or greater length in case of dry & rocky soil. depth = 3.75 m at which pipe is buried. The pipe at bottom is surrounding with broken pieces of charcoal for a distance about 15 cm around pipe. Alternate layer of coke and salt are used to increase the effective area of earth and decrease the earth resistance respectively.

Another pipe d = 19mm l = 1.25 m is connected to the top of pipe. As in summer season the moisture in the soil decreases which cause increase in earth resistance. So concrete work is done to keep the water arrangment accessible to have effective earth, 3/4 buckets of water are put through funnel (dia = 19mm) connected to pipe.

1. Define the following terms,

(a) Bare conductor

(b) Wire

(c) Cable.

ns :

Bare conductor: An electrical conductor without any insulation on it is referred as bare conductor.

Wire: A long thin flexible piece of conductor (ex: aluminium, copper etc) may be bare or covered with insulation that carries electric current is called as wire. Usually they are present inside the cable.

Cable: When two or more insulated wires are wrapped in one jacket then it is called as cable. Generally cables are provided with different protective layers such as bedding, metallic sheath and armouring to protect the cable from mechanical injuries and moisture.

6. **Define fuse.**

s : A fuse is a short piece of metal, inserted in the circuit, which melts en excessive current flows through it and thus breaks the circuit.

The fuse element is generally made of material having low melting point, high conductivity and least deterioration due to oxidation.

The materials used for fusing elements are silver, copper, zinc etc.

It is inserted in series with the circuit to be protected.

Figure below represents the symbol of a simple fuse,

Figure

Q14. What are batteries?

Ans : Batteries are the electrochemical power sources which convert chemical energy into electrical energy. These are also considered as store houses for electrical energy.

Batteries are generally classified into two types. They are,

(i) Primary battery

(ii) Secondary battery.

Q15. **What are the applications of batteries?**

Ans : Batteries are used as a source of D.C power where convenience is of major importance and where electrical power is not readily available.

The various applications of batteries are,

1. Batteries are used in industrial and military applications where high reliability and long life are required.
2. These are used for starting aircraft and motor cars.
3. These are also used for train lighting and emergency power supplies.
4. These are used in equipments where standby power is of major concern (such as emergency light, telephone exchange, laptops, cellular phones, electric vehicles and pacemakers).

Q16. Differentiate between primary and secondary cells.

Ans : The differences between primary cell and secondary cell are,

Primary Cell		Secondary Cell	
1.	Primary cells are irreversible.	1.	Secondary cells are reversible.
2.	These cells are not chargeable.	2.	These cells are rechargeable.
3.	Primary cells are cheap, light weight and small in size.	3.	Secondary cells are expensive, heavy and large in size.

Q17. List the applications of lead acid cell.

Ans :

Applications

(i) Lead-acid cell is used in Uninterrupted Power Supply (UPS), because of its recharging capability.

(ii) These cells are also used in,

(a) Automobiles and railway trains

(b) Hospitals

(c) Telephone exchanges

(d) Gas engine ignition.

Q18. Define capacity of a battery.

Ans : The capacity of a battery is defined as the product of current (in Amperes) and the time (in hours). It is measured in Ampere-hours (Ah).

Mathematically, it is expressed as,

$$\text{Capacity} = I \times T$$

Where,

I - Current (in Amperes)

T - Time (in hours).

...What is UPS? State the need of UPS.

...ns : A device that provides continuous power supply without any ...nterruption is known as "Uninterrupted Power Supply (UPS)". This provide ...ackup power during power failure and the more sophisticated UPS even ...rovide power conditioning.

Basically, critical loads such as computers, biomedical instruments, ...rgical equipments must function without any interruption (or power ...ilure). To achieve this, continuous power must be supplied to the load ...hich can be accomplished using a UPS. For instance, a computer turns off ...ickly when the power supply is switched off. Due to this, the data which ...s not been saved will be lost. In such cases, UPS is used, as it supplies ...interrupted power to the system thereby preventing loss of data.

Moreover, UPS also protects the computer from harmful electrical ...rges.

...0. Classify the different UPS.

...s : An Uninterrupted Power Supply (UPS) is classified into static UPS ...d hybrid UPS. The static UPS is further classified into on-line and off-line ...S as shown in figure.

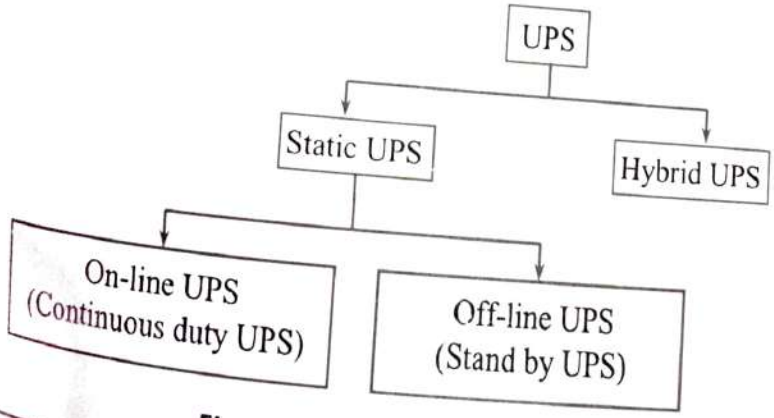


Figure: Classification of UPS

...1. What is meant by electrical energy consumption?

...: The consumption or utilization of electrical energy is known as ...trical energy consumption. It is the demand of energy made on the supply ...ectricity. The electrical energy consumed is measured in watt-hours. ...hematically, it is given as,

Energy = Power × time

$E = P \times t$

Q19. What is UPS? State the need of UPS.

Ans : A device that provides continuous power supply without any interruption is known as "Uninterrupted Power Supply (UPS)". This provide backup power during power failure and the more sophisticated UPS even provide power conditioning.

Basically, critical loads such as computers, biomedical instruments, surgical equipments must function without any interruption (or power failure). To achieve this, continuous power must be supplied to the load which can be accomplished using a UPS. For instance, a computer turns off quickly when the power supply is switched off. Due to this, the data which has not been saved will be lost. In such cases, UPS is used, as it supplies uninterrupted power to the system thereby preventing loss of data.

Moreover, UPS also protects the computer from harmful electrical surges.

Q20. Classify the different UPS.

Ans : An Uninterrupted Power Supply (UPS) is classified into static UPS and hybrid UPS. The static UPS is further classified into on-line and off-line UPS as shown in figure.

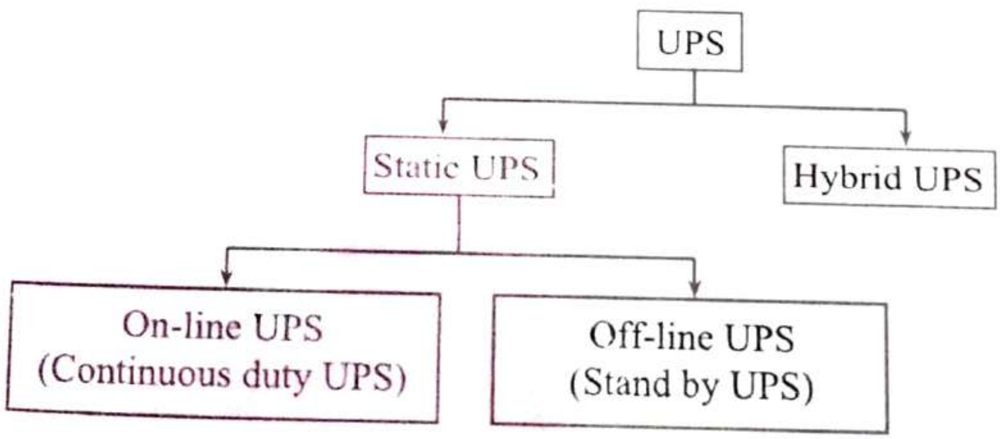


Figure: Classification of UPS

Q21. What is meant by electrical energy consumption?

Ans : The consumption or utilization of electrical energy is known as electrical energy consumption. It is the demand of energy made on the supply of electricity. The electrical energy consumed is measured in watt-hours. Mathematically, it is given as,

$$\text{Energy} = \text{Power} \times \text{time}$$

$$E = P \times t$$

Q22. **Write about switch fuse unit.**

Ans :

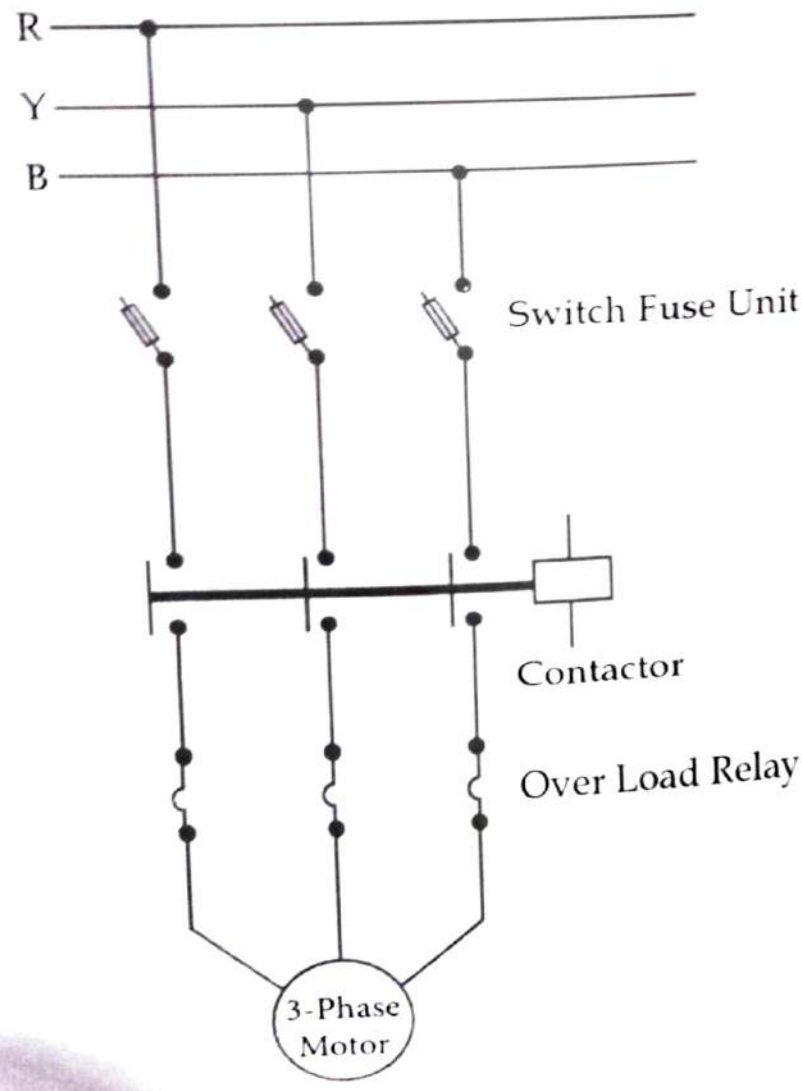
Switch Fuse Unit : Switch fuse unit is formed when fuse base is integrated with switch. These units are available in three pole (TP) and three pole neutral (TPN) form up to a rating of 1000 A, 415 V with breaking capacity of 50 kA.

Switch fuse units are of two types,

(i) SFU where fuse is stationary and

(ii) SFU where fuse is mounted on moving assembly

Both the units are in use, however the unit with stationary fuse are more reliable and has less deterioration of electrical joints compare to the unit with movable fuse. The power circuit of motor using switch fuse unit is shown in figure.



Figure

Q23. What is miniature circuit breaker and mention its use? Give the specifications of miniature circuit breaker.

Ans :

Miniature Circuit Breaker (MCB) : Miniature Circuit Breaker (MCB) is a type of circuit breaker which are used only at low voltages. It is an electro mechanical device which provides protection under overloads and short-circuit conditions. Unlike fuses, they do not need servicing and rewiring. They comes into operation when current in the circuit reaches predetermined value. MCB's are more efficient, faster and are easily manageable.

It other words, miniature circuit breakers or micro circuit breakers is a switch which automatically goes in off state when the current in the circuit flows more than the limited value. It detects the fault in an electrical circuit by interrupting the current flow.

Uses : Miniature circuit breakers are widely used nowadays by replacing the typical rewirable fuses. They find applications in the following areas,

1. Residentials
2. Shops
3. Distributions boards
4. Offices
5. Power loads
6. Industries
7. Lighting circuits
8. Control circuits
9. Sub-distribution circuits
10. Building applications etc.

Q32. Explain the need of earthing of electrical equipment.

Ans : The process of connecting non-current carrying metal parts of an electrical systems to earth is known as earthing of electrical equipment or equipment earthing. The need of earthing of electrical equipments is explained as follows,

1. **Protection from Shocks:** Earthing provides safety against electric shocks to any person or animal when they are in contact with the metal parts. Though some of the systems have fuses or circuit breakers for protection from the fault current or short circuit, the person may receive a shock at the operating point of fuse or breaker. Thus, earthing is necessary for the protection against shock.

2. **Controls Constant Line Voltage:** Earthing controls the constant line voltage in unbalanced load condition.

3. **Prevention of Equipment from Damage:** Without earthing the parts of the electrical equipment may damage either due to fault currents short circuits or the undetected part which causes fire.

4. **Protection against Lightning:** Earthing guards the buildings, towers, machines which are supplied from overhead transmission lines against lightning and thunder storms. Lightning arises because the surge current follows the path of two or more ground connections. The conductors of the lightning must have direct connection to earth in order to prevent from lightning.

5. **Achieves Required Performance:** The earthing installations ensure the desired performance of the earthing systems. It is cost effective process and achieves reliable and improved service. It also provides a drainage path for the currents which are undesirable.

Q34. Explain the construction and working of pipe earthing with a neat sketch.

Ans :

Construction : Pipe type earthing consists of a galvanized iron (GI) pipe of specified length and diameter, mixture of salt and charcoal and an earthing wire. The pipe acts as an earth electrode. The pipe has funnel, nuts and bolts. The pipe is of circular cross- section and so large leakage currents can be carried out for the same size of electrodes. The top section of the pipe is covered with cement work in a cast iron box to avoid mechanical damage. The arrangement of pipe earthing is shown in figure.

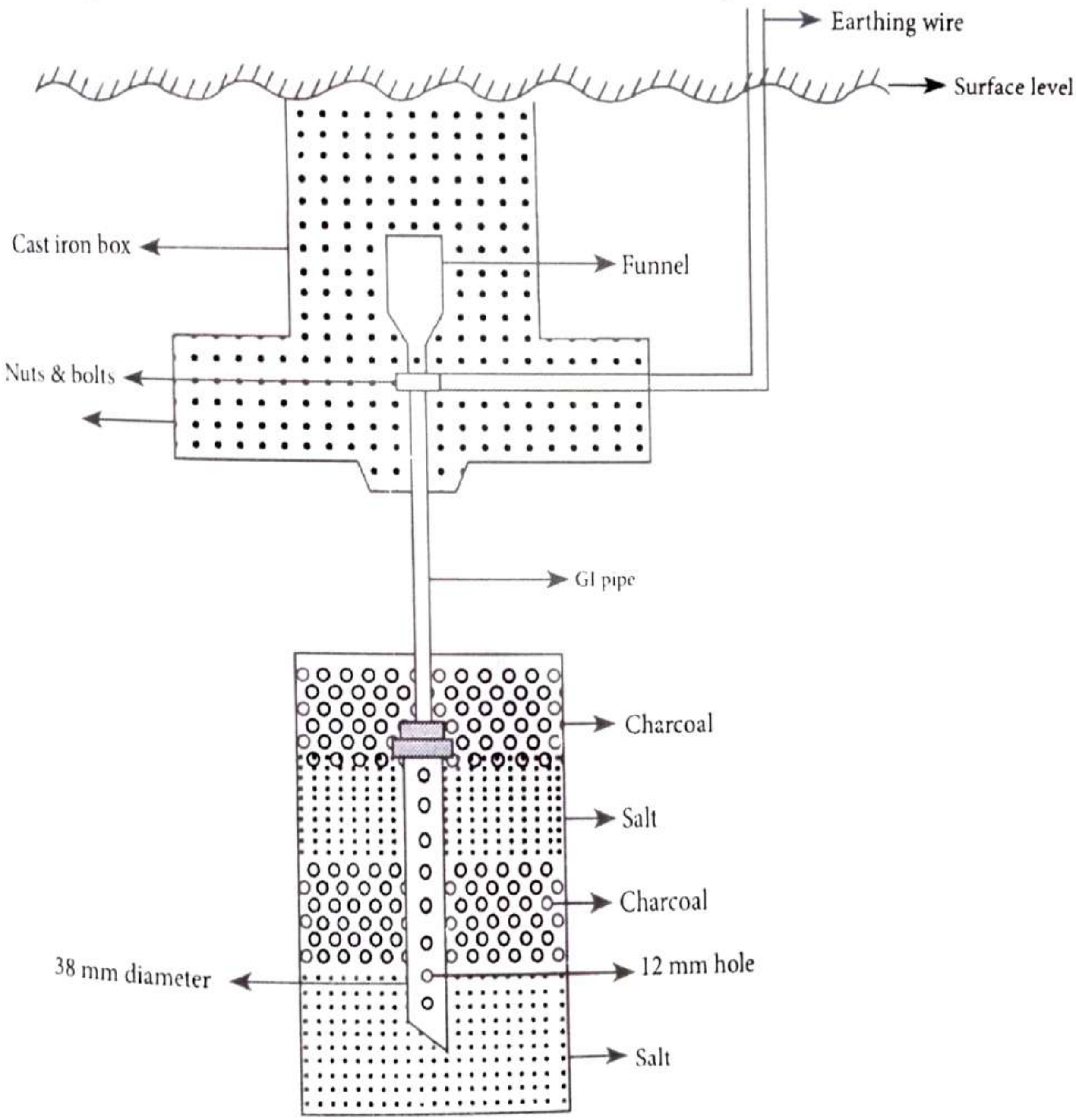


Figure: Pipe Earthing

0. **A house has the following loads:**

(a) **5 lamps 60 W each working for 8 hours a day**

(b) **4 lamps of 100 W each working for 5 hours a day**

(c) **2 heaters of 1000 W each working for 3 hours a day**

(d) **5 fans of 80 W each, working for 12 hours a day**

Calculate the January bill if rate of charge is rupees 0.50 per unit. Add rupees 10 as a meter rent per month.

s : Arranging the given data in tabular form.

Load	Wattage W	Quantity (Q)	Total Wattage $W_T = W \times Q$	Working Hours (t)	Energy Watt Hour/Day $E = W_T \times t$
Lamps	60 W	5	300 W	8 hr	2400 Wh/day
Lamps	100 W	4	400 W	5 hr	2000 Wh/day
Heaters	1000 W	2	2000 W	3 hr	6000 Wh/day
Fans	80 W	5	400 W	12 hr	4800 Wh/day
					$\Sigma E = 15.200$ kWh/day

Total energy consumed in the month of January is,

$$= 15.2 \times 31 = 471.2 \text{ kWh}$$

Given, Cost per unit = ₹ 0.50

Meter rent = ₹ 10/month

Monthly bill = Total number of kWh consumed × Cost per unit + Meter rent per month

$$= 471.2 \times 0.50 + 10 = ₹\ 245.6$$

Q42. Discuss about, Improvement of power factor.

Ans :

Improvement of Power Factor : Improvement of power factor results in net annual saving for the consumer. This is so because, a consumer is charged for his maximum kVA demand and the units he consumes.

An improvement in power factor reduces the maximum kVA demand. Since, they are inversely proportional to each other.

$$\text{Maximum kVA demand} = \frac{\text{kW}}{\cos\phi}$$

On low power factor, the maximum kVA demand is large and hence the charges are increased. Improvement of power factor means less kVA demand and hence less charges resulting in net annual saving.

Q46. **With a block diagram, explain the working of online UPS.**

OR

List and explain the different types of UPS.

Ans :

Types of UPS : The classification of an Uninterrupted Power Supply (UPS), is as follows

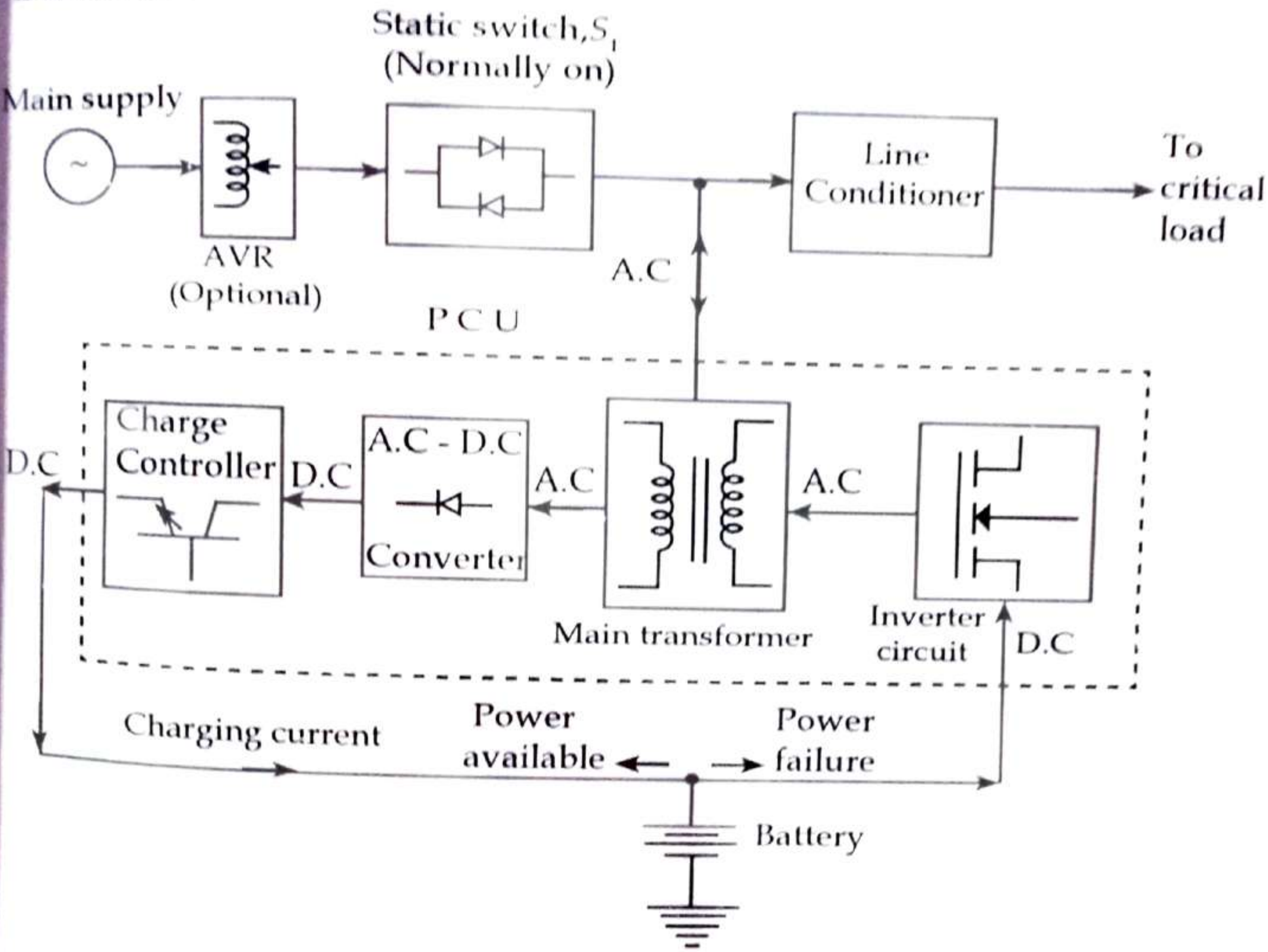


Figure (1)

1. **Static UPS :** A static UPS system stores energy in electrochemical batteries by using power electronic equipments. It can be further classified as,

   (a) **On-line UPS :** On-line UPS is the system in which the batteries are always connected to the inverter. This arrangement provides continuous regenerated clean A.C power to the load. It is also known as double conversion UPS or inverter preferred UPS.

The block diagram of online UPS is shown figure as follow,

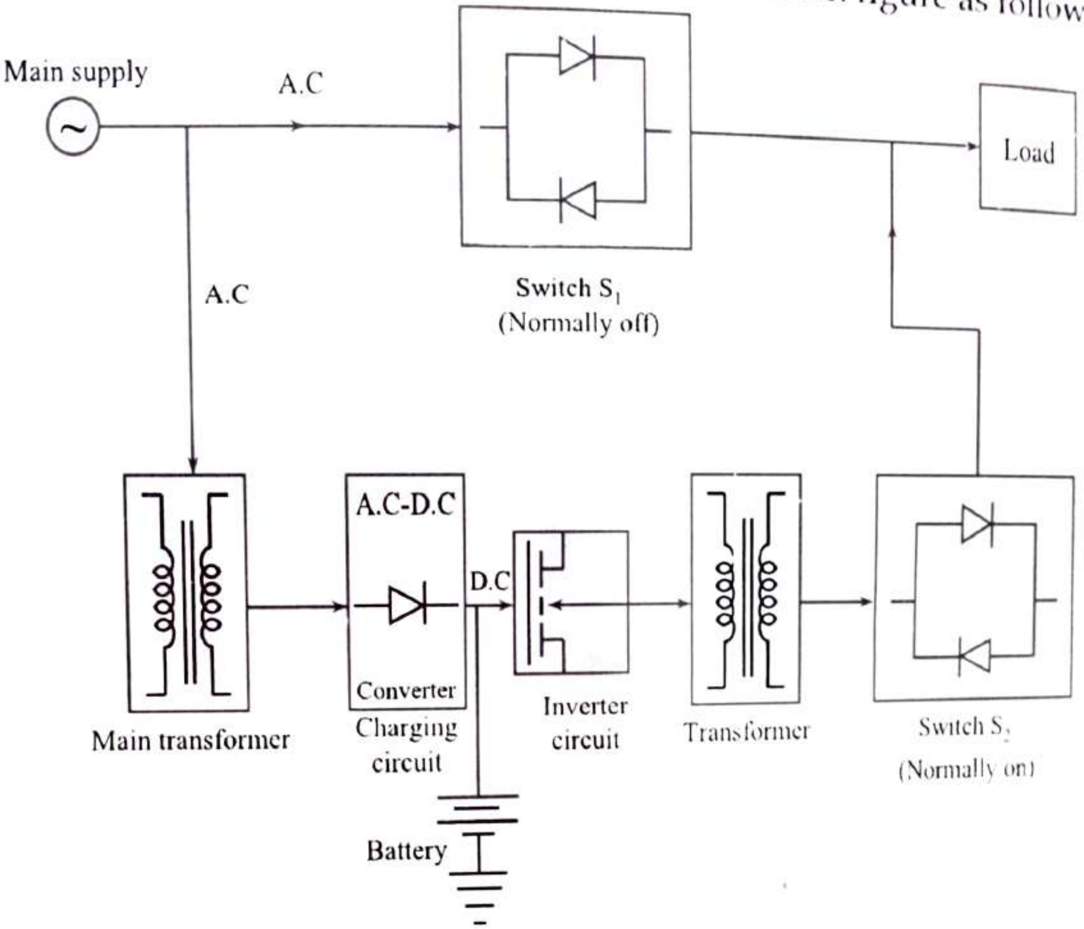


Figure (2): Block Diagram of On Line UPS

(b) **Off-line UPS** : Off-line UPS is a form of backup UPS which normally operates in off-line state and connects the load to the mains. It is also known as standby UPS or line-preferred UPS.

2. **Hybrid UPS** : Hybrid UPS is analogous to an off-line UPS, but it contains an additional ferroresonant or electric line conditioner. This extra circuitry provides regulation of voltage and acts as a storage unit for energy.