Basic Electrical Engineering

NOTES by
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Book: B.L. Thereja

Syllabus :

1. Electric Circuits

Introduction to linear and non-linear circuits, circuit elements, various sources and source transformation, star delta transformation, solution of D.C. circuits using Kirchoff's laws, signal wave forms and passive elements specifications, basic theorems, generation of A.C. sinusoidal voltage and currents, average and r.m.s. values, form factor and peak factor, phasor representation, phasor in polar, rectangular and exponential forms, Terminal relationship for pure passive elements & their combination in series and parallel. Analysis of single phase series, parallel and series-parallel circuits. Active and reacting power p.f. and volt-amperes, frequency response and Q-factor. Analysis of balanced three phase a.c. circuits – Introductory concepts, voltage, current and power in three phase balanced circuits.

Introduction to Domestic Electric ~~Wri~~ Wiring & Storage Batteries.

2. Electromagnetic and Transformer.

Magnetic circuit concept, B-H curves characteristics of magnetic materials, practical magnetic circuits, magnetic circuits with DC and AC excitation, hysterisis and eddy current losses.

3. Measuring Instruments

Introduction to galvanometer (Moving coil and Moving Iron), ammeter, voltmeter, wattmeter, energy meter, use of shunt and multiplier

4. Electrical machines

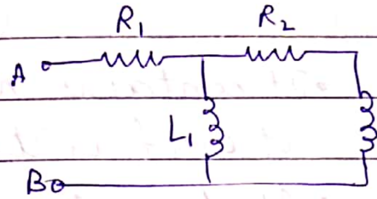
Fundamentals of DC & AC machines.

Magnetic force, self and mutual inductance, faraday's laws, Lenz's laws, statically & dynamically induced emf's, energy stored in magnetic fields, Principle of Transformer operation, construction & equivalent circuit of transformer.

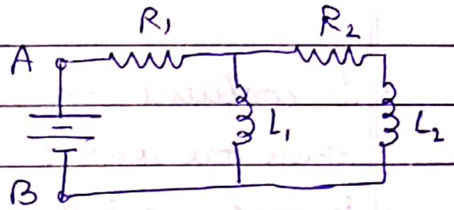
Ch-2 DC Network Theorems

2.1 **Network**- It is the interconnection of different circuit elements R, L, and C

Circuit - It is a closed energised network where current flows or intended to flow.



Network

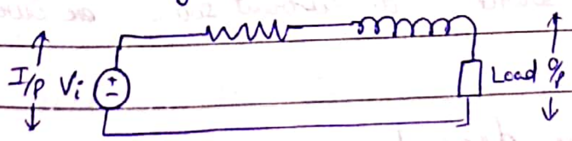


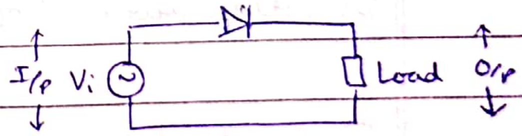
Circuit

Classification of Circuits

1.

Linear circuit	Non-linear circuit
• It is determined by R, L and C, waveforms and frequency	• It contains transistor, diode, transformer
• Have linear V and I characteristics	• Non-linear V and I characteristics
• Linear input and output characteristics.	• non-linear I/P and O/P characteristics.
• It obey's Ohm's law.	• Does not follow Ohm's law.





2.

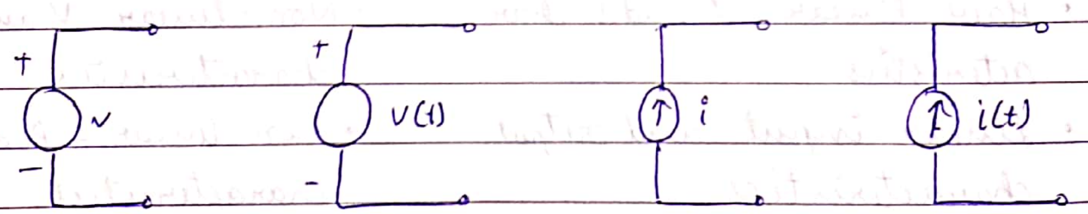
Bilateral element	Unilateral elements
Its properties or characteristics are the same in either direction.	Its parameters or characteristics change with the direction of its operation.
e.g. transmission wires	e.g. diode

Simple wire has only resistive and inductive elements but transmission wire has resistive, capacitive and inductive elements.

3. Active network | Passive network

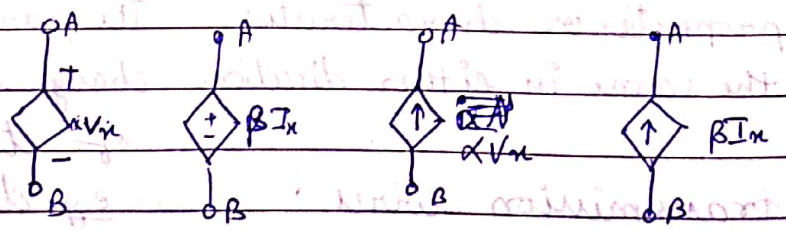
Active network	Passive network
• It contains one or more than one source of e.m.f.	• It contains no source of e.m.f. in it.
• It needs active elements like DC generator, AC generator, Batteries, photoelectric cell	• It does not contain active elements but contain passive like, R, L, C, diode, transistor

2.9 Independent sources- Those voltages or current sources, which do not depend on any other quantity in the circuit are called independent sources. e.g. generator, batteries, alternator.

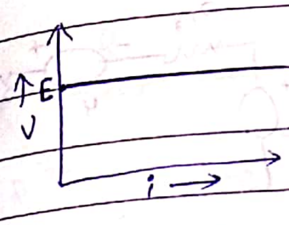


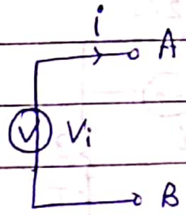
independent DC voltage source | independent ac voltage source | independent dc current source | independent ac current source

Dependent sources- These depend on some other quantity in the circuit which may be either a voltage or a current e.g. transistor, op-amp.

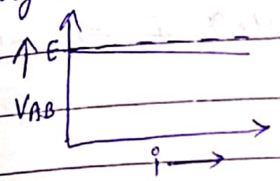


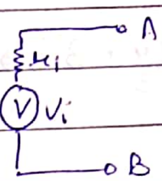
Ideal Source- There are no internal loses in source & it supplies the marked value.



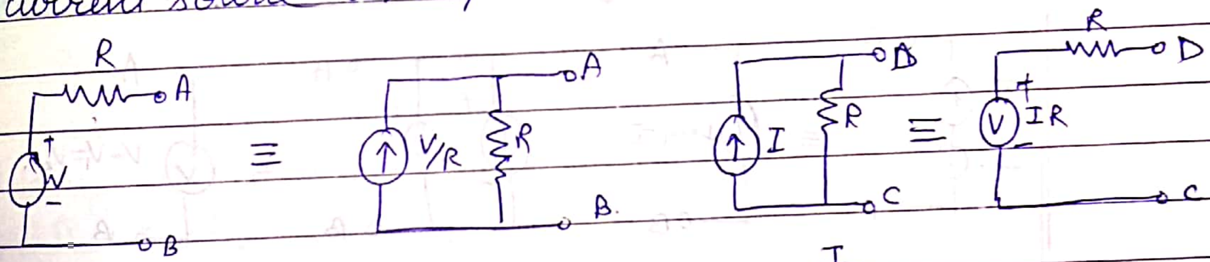


Practical Source - It has some internal resistance due to which voltage drop takes place, and it causes the terminal voltage to reduce

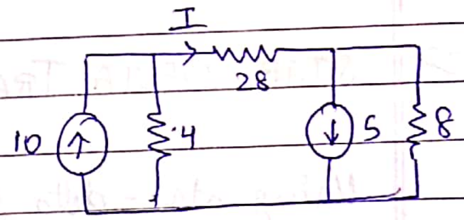




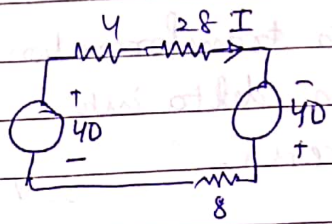
Source Conversion - A given voltage source with a series resistance can be converted into (replaced by) an equivalent current source with parallel resistance. and vice versa.



Find the value of I



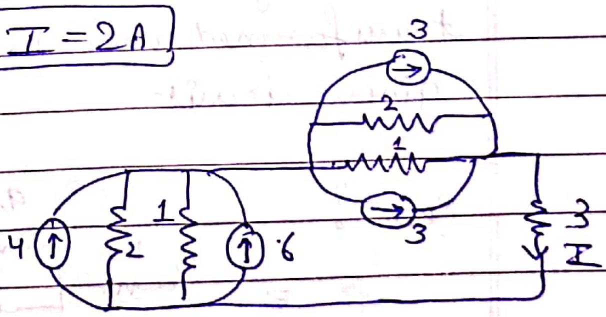
The given equivalent circuit is this by the method of source conversion



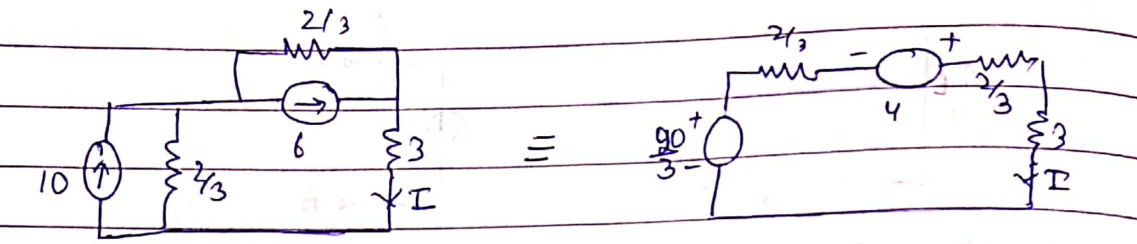
Now Applying KVL $40 - 4I - 28I + 40 - 8I = 0$

$\Rightarrow 80 = 40I \Rightarrow \boxed{I = 2A}$

Find the value of I



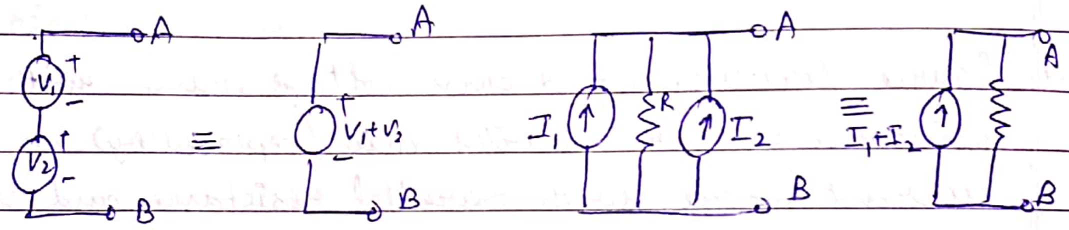
We apply source conversion on the given network after applying additive property

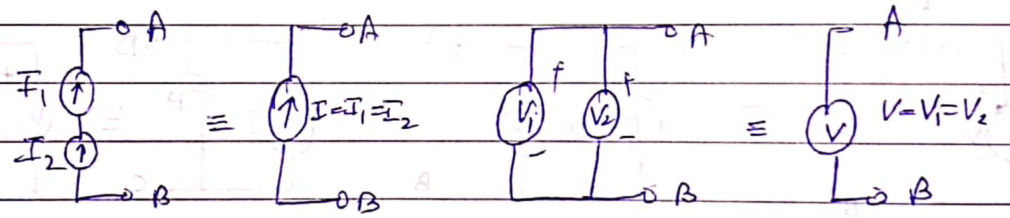


Applying KVL, $\frac{20}{3} - \frac{2}{3}I + 4 - \frac{2}{3}I - 3 = 0$

$\Rightarrow \frac{20}{3} + 4 = \left(\frac{4}{3} + 3\right)I \Rightarrow 20 + 12 = (4+9)\,I \Rightarrow I = \frac{32}{13} = 2.46\ A$

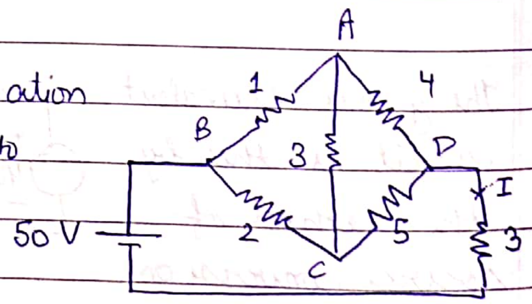
NOTE :



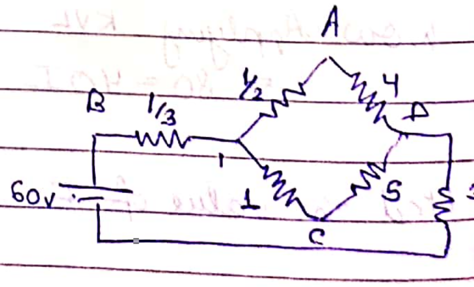


2.22 STAR-DELTA TRANSFORMATION

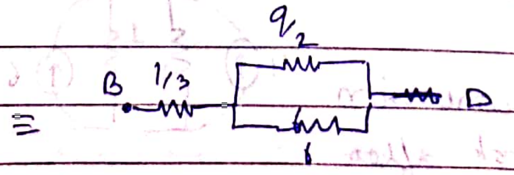
Using star-delta transformation we can convert a delta into a star & vice versa.



Thus the given circuit is transformed into the given circuit



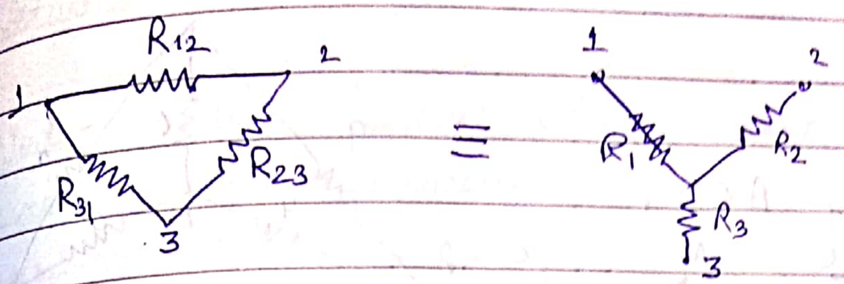
$R_{BD} = ?$



$\equiv \frac{9 \times 2}{7} + \frac{1}{3}$

$= \frac{18}{7} + \frac{1}{3} = \frac{54+7}{21} = \frac{61}{21} = 2.9$

$R_{BD} = 2.9\,\Omega$



Delta   Star

Resistance between node 1 and 2 :

$$R_1 + R_2 = R_{12} \parallel (R_{31} + R_{23}) = \frac{R_{12}(R_{31} + R_{23})}{R_{12} + R_{23} + R_{31}} \quad -①$$

Resistance between node 2 and 3 :

$$R_2 + R_3 = R_{23} \parallel (R_{12} + R_{31}) \quad -②$$

Resistance between node 3 and 1 :

$$R_3 + R_1 = R_{31} \parallel (R_{12} + R_{23}) \quad -③$$

Adding all the three equations, we get :

$$R_1 + R_2 + R_3 = \frac{R_{12}R_{31} + R_{12}R_{23} + R_{23}R_{31}}{R_{12} + R_{23} + R_{31}} \quad -④$$

Subtracting ① from ④ :

$$R_3 = \frac{R_{23}R_{31}}{R_{12} + R_{23} + R_{31}}$$

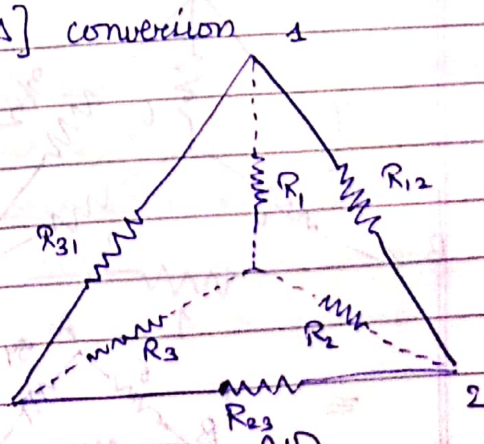
Similarly : $R_1 = \dfrac{R_{12}R_{31}}{R_{12} + R_{23} + R_{31}}$, $R_2 = \dfrac{R_{23}R_{12}}{R_{12} + R_{23} + R_{31}}$

From Star to Delta   [Y − Δ] conversion

$$R_{31} = R_3 + R_1 + \frac{R_3 R_1}{R_2}$$

$$R_{12} = R_1 + R_2 + \frac{R_1 R_2}{R_3}$$

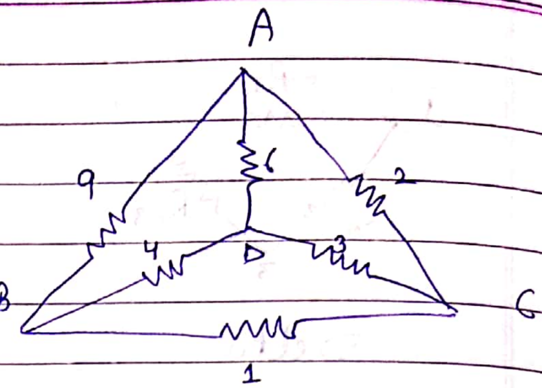
$$R_{23} = R_2 + R_3 + \frac{R_2 R_3}{R_1}$$



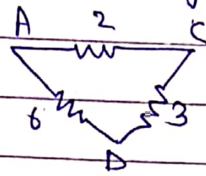
MEMORY — AID

Example 2.92

Q. Find R_{AB}



Considering ACD,



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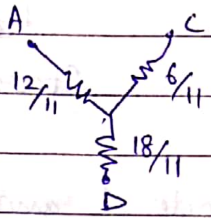

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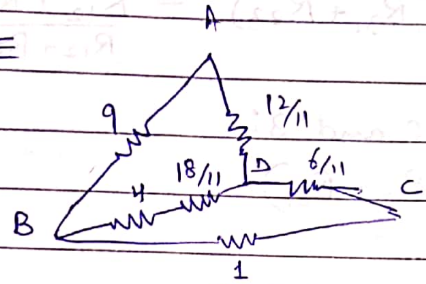

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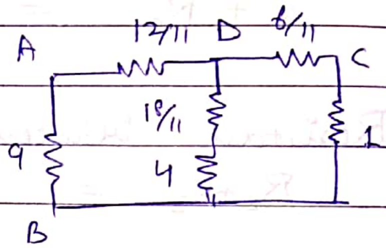

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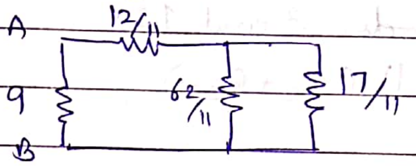

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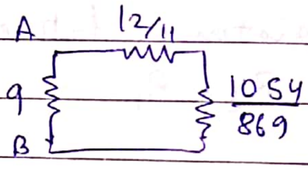
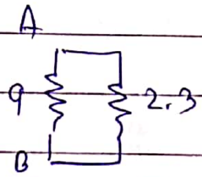


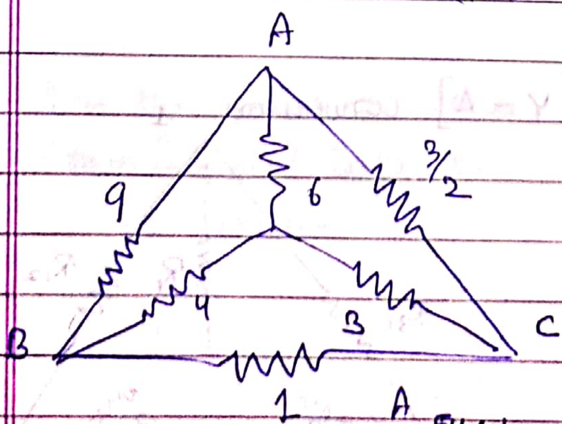
$$\frac{\frac{17}{11} \times \frac{62}{11}}{\frac{62+17}{11}} = \frac{1054}{79 \times 11} \Rightarrow \frac{1054}{869} \qquad \frac{1054}{869} + \frac{12}{11} = \frac{\cancel{948}\ 2002}{869} = 2.3$$

$\Rightarrow$



$$R_{AB} = \frac{9 \times 2.3}{9 + 2.3} = \frac{20.7}{11.3} = 1.83\Omega$$

(OR)



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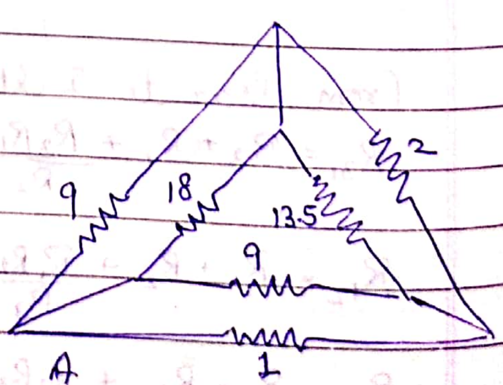

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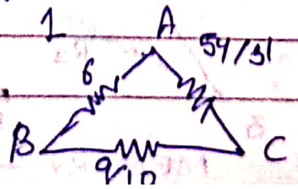

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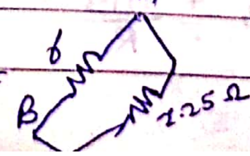
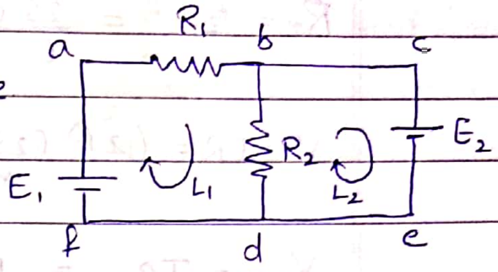


$\Rightarrow R_{AB} = 1.8$

Network Terminology:

1. Node - A node is a common point where at least two components are connected like connecting wire, resistor, battery etc. e.g. a, b, c, d, f, e



2. Junction - A common point having at least three components connected to it. e.g. b, d.

3. Branch - It is that part of a network which lies between two junctions. e.g. bafd, bced, bd.

4. Loop - It is a close path in a circuit in which no element or node is encountered more than once. e.g. abdfa, bcedb, abcedfa

5. Mesh - It is a subpart of a loop. It is the smallest loop which can not be subdivided. e.g. abdfa, bcedb

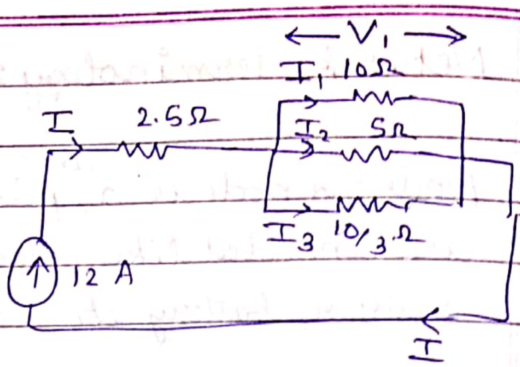
2.2 Kirchhoff's law

1. Kirchhoff's Current Law, KCL - Sum of all the incoming/entering current is equal to outgoing current.

2. Kirchhoff's Voltage law, KVL - The algebric sum of products of currents and resistances in each of the conductors in any closed path (or mesh) in a network plus the algebric sum of the emfs in that path is zero.

$$\sum IR + \sum e.m.f. = 0$$

Q. Calculate I_1, I_2, I_3.



$R_T = \frac{5}{2} + \frac{5}{3} = \frac{25}{6}\ \Omega.$

$V = IR = (\overset{2}{\cancel{12}}\ A)\left(\frac{25}{\cancel{6}}\ \Omega\right) = 50V.$

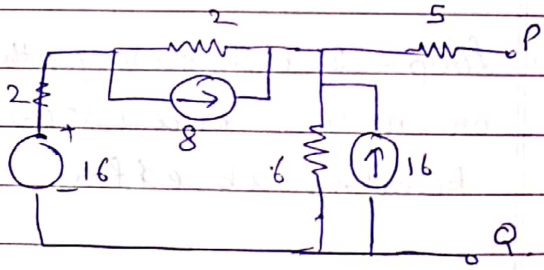
$V_{2.5} = IR_{2.5} = 12 \times 2.5 = 30V.$

$\Rightarrow V_1 = 50 - 30 = 20V.$

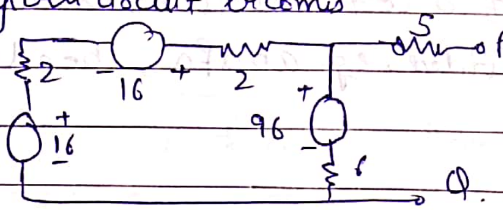
$I_1 = \frac{V_1}{R_1} = \frac{20}{10} = 2A.$ $\qquad I_3 = \frac{V_1}{R_3} = \frac{\overset{2}{\cancel{20}}}{\cancel{10}/3} = 6\ A$

$I_2 = \frac{V_1}{R_2} = \frac{20}{5} = 4A.$

Q. Find single voltage source equivalent of the foll. circuit.



A. Given circuit becomes



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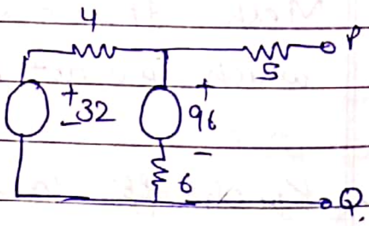

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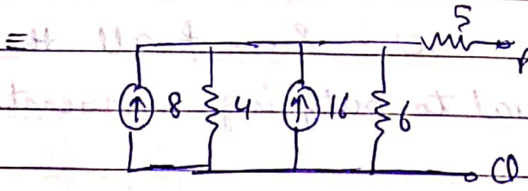

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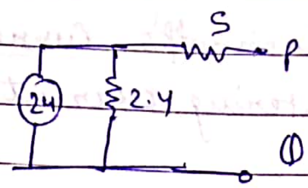

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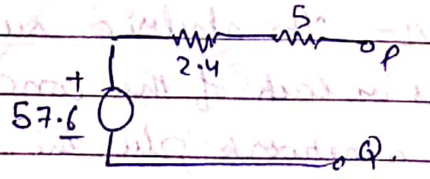

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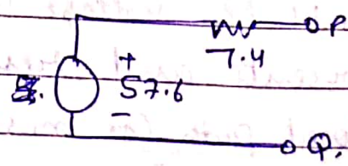
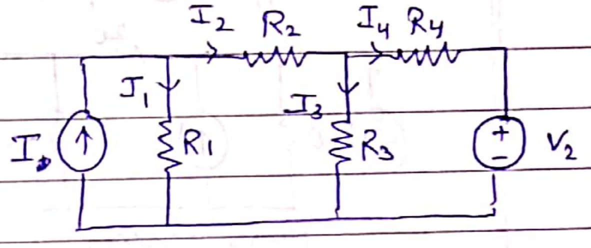


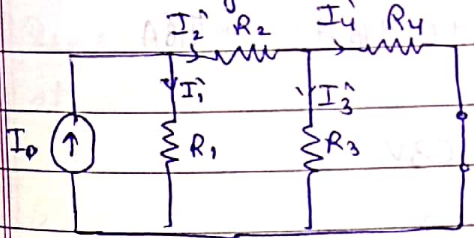
$E_{eq} = \left[\frac{E_1}{r_1} + \frac{E_2}{r_2}\right] r_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$

2.17 **Superposition Theorem** – It is applied to a multisource network. It states that the response in any branch of a linear, active bilateral network containing multisource is the algebric sum of the responses ~~of sum~~ obtained by considering each source acting separately during which all other sources are made zero.

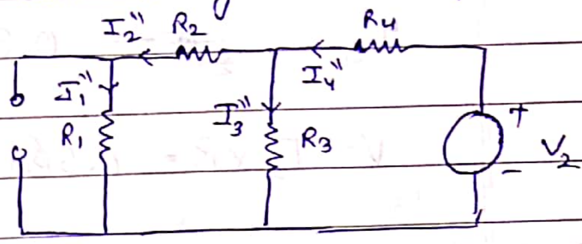
Since the given circuit is a multisource, linear, active and bilateral, we can apply superposition theorem.



Considering $V_2 = 0$.

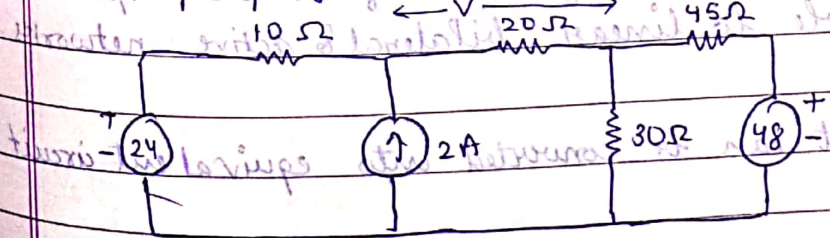


Considering I to be open

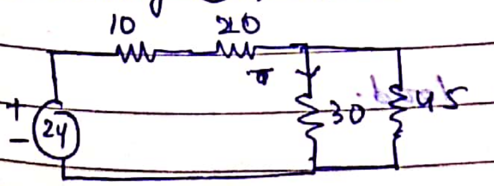


Thus $I_3 = I_3' + I_3''$, $I_2 = I_2' - I_2''$

Q. Use superposition theorem to find voltage V.



Considering ⓘ, (48) to be 0.



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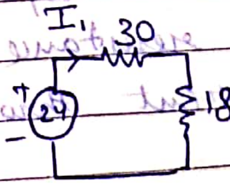
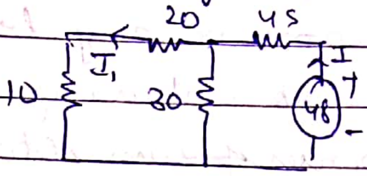


$\Rightarrow I_1 = \frac{24}{48} = \frac{1}{2} A$.

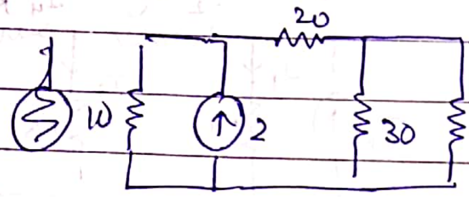
Considering ①, ㉔ to be 0.



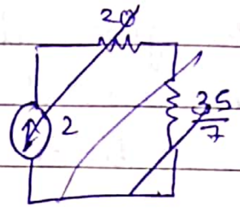
$\equiv I = \frac{V}{R} = \frac{48}{60} = \frac{4}{5} = 0.8\,A$

$\Rightarrow I_1 = 0.4A$ & current divided by symmetry.

Considering ㉔, ㊽ to be zero

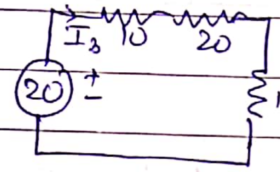


$\equiv$



$\frac{\cancel{18}^{9} \times \cancel{10}^{5}}{\cancel{28}_{7}} = \frac{35}{7}$

$\equiv$



$\equiv \quad I_3 = \frac{20}{48} = \frac{5}{12} = 0.413$

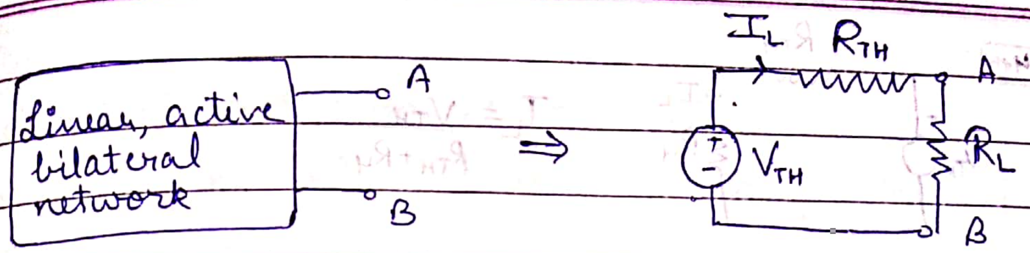
$I_{20} = \cancel{\frac{1}{2}A} - 0.5A - 0.8A + 0.416A = 0.516A$

$V = I_{20} \times R = 0.516A \times 20 \doteq 10.3V$

2.18 Thevenin Theorem – This theorem is applicable to determine current and voltage applied in element of network without going through complex procedures for ~~going through~~ solving a set of network equations. It is applicable to linear, bilateral & active networks.

Complete circuit can be converted into equivalent circuit consisting :

$V_{th} \rightarrow$ Thevenin equivalent voltage source
$R_{th} \rightarrow$ Thevenin equivalent resistance
$R_L \rightarrow$ Load resistance
$I_L \rightarrow$ Current through load.



We get $I_L = \frac{V_{TH}}{R_{TH} + R_L}$

2.19 Steps to follow for converting a network to Thevenin's circuit

1. Remove load resistor R_L and calculate open circuit voltage across load terminal.

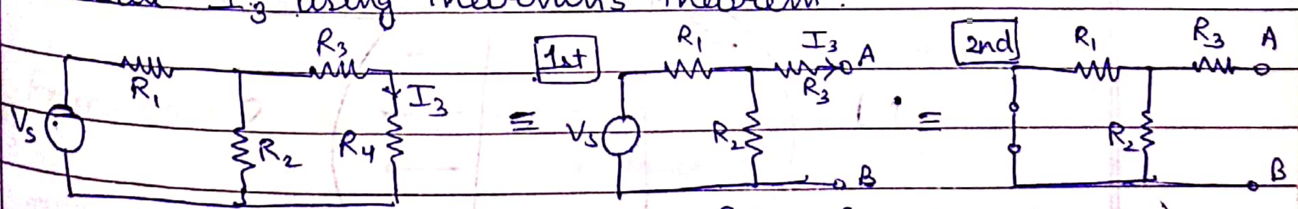
2. Determine Thevenin eq. Resistance R_{TH} by looking through open circuit terminal.

3. Replace voltage and current sources with no source at all

4. Obtain Thevenin eq. circuit by connecting R_{TH}, R_L in series with open circuit voltage / V_{TH}

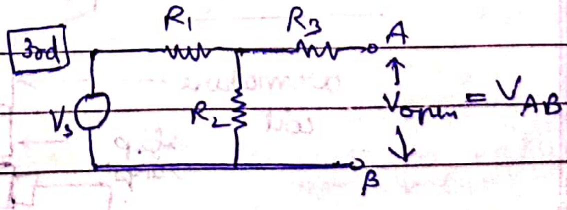
5. Find /calculate the value of I_L

Q. Calculate I_3 using Thevenin's theorem.

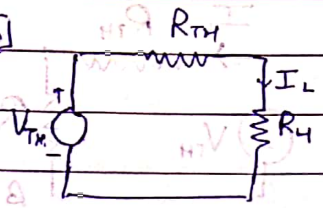


We get $R_{TH} = R_1 \| R_2 + R_3$

$V_{TH} = \frac{R_2 \times V_s}{R_2 + R_1}$

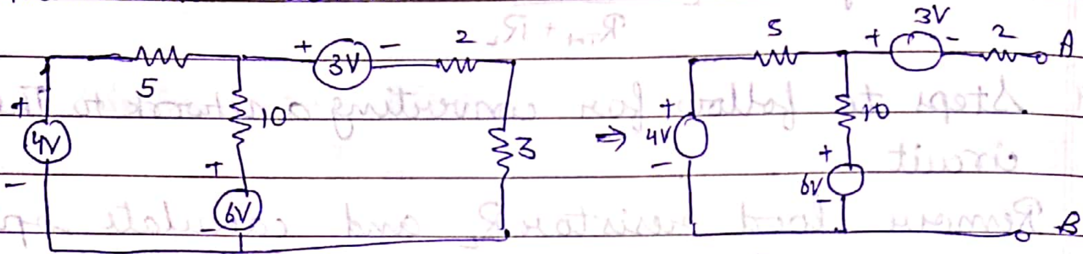


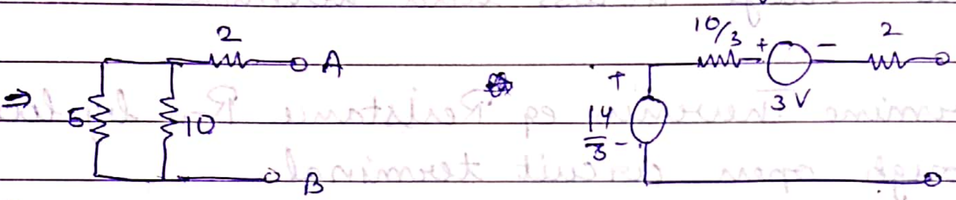
4th



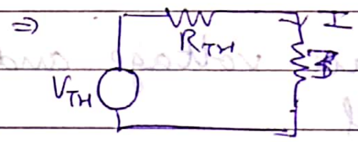
$$I_L = \frac{V_{TH}}{R_{TH}+R_4}$$

Q. Find the current in 3Ω resistor by using Thevenin's theorem.





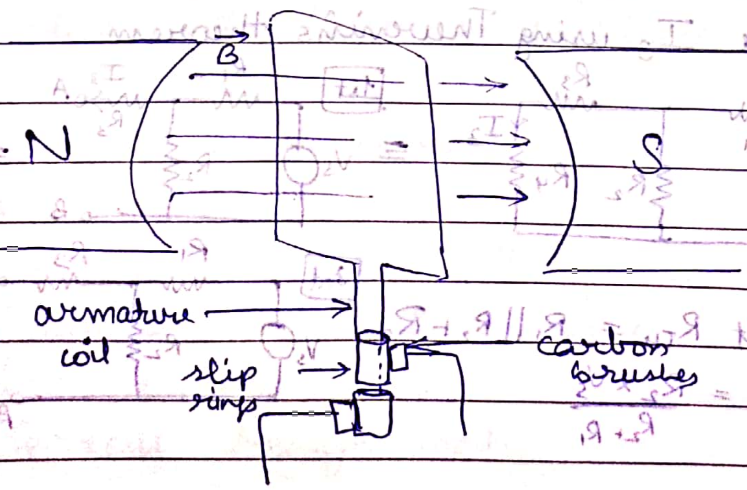
$$R_{TH} = \frac{5\times10}{5+10} + 2 = \frac{10}{3} + 2 = \frac{16}{3}\,\Omega$$



$$V_{TH} = \frac{14}{3} - 3 = \frac{5}{3}\,V.$$

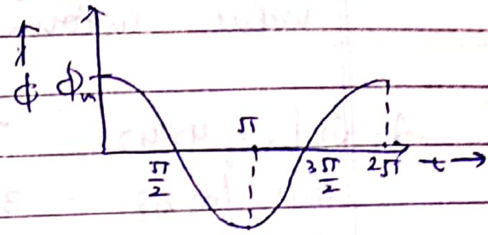
$$\Rightarrow I = \frac{V_{TH}}{R_{TH}+3} = \frac{5/3}{16/3+3} = \frac{5}{16+9} = \frac{5}{25} = \boxed{0.2A}$$

11.1 Generation of AC.



Ch-11 A.C. Fundamentals

1. Mechanical rotation of the coil
2. Change in the flux passing through the coil.
   $\phi = \phi_m \cos \omega t$
3. Induced emf $e = -N\frac{d\phi}{dt}$



where N = no. of turns of coil

$e = N\omega \sin \omega t \cdot \phi_m$

$\Rightarrow E_{max} = \omega N \phi_m$

$e = E_m \sin \omega t$ If Z is the impedance.

$I = \frac{e}{R} = \frac{E_m}{R} \sin \omega t = I_m \sin \omega t$, $I_m = \frac{E_m}{Z}$

$\Rightarrow i = i_m \sin \omega t$

Cycle: A complete cycle is from 0 to 2π

Time period (T): It is the time required for a quantity to complete one cycle.

Amplitude : Maximum value of the quantity in a cycle is the amplitude.

frequency : The no. of complete cycles per second.

RMS value (Root mean square value) $V_{rms}^2 = \frac{1}{T}\int_0^T v^2 dt$

$I_{rms} = \frac{I_m}{\sqrt{2}} \sin \omega t$

Mean or average value, $I_{avg} = \frac{2}{\pi} I_m = 0.636 I_m$

$V_{avg} = \frac{1}{T}\int_0^T V dt$

Form factor K_f — $K_f = \frac{\text{RMS value}}{\text{Average value}} = \frac{\pi}{2\sqrt{2}} = 1.11$

It is different for different wave forms.

Peak or crest or amplitude factor $K_a = \frac{\text{maximum value}}{\text{rms. value}}$

$K_a = 1.414 = \sqrt{2}$ for standard AC.

Q. The equation of alternating current is $i = 42.42 \sin 628t$
Determine (i) Its maximum value
(ii) its frequency (iii) its rms value (iv) its average value (v) form factor

A. (i) $i_m = 42.42$ (ii) $\omega = \overset{100}{\cancel{628}} = \cancel{2\pi} f$ $f = 100\ Hz$

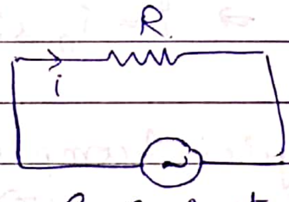
(iii) $i_m/\sqrt{2} = 30 = i_{rms}$

(iv) $i_{avg} = \frac{2}{\pi} i = 26.97 = 27$

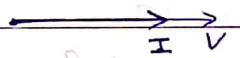
(v) form factor $= \frac{i_{rms}}{i_{avg}} = \frac{30}{27} = 1.11$

11.28 AC series circuit

(i) Circuit with pure resistance



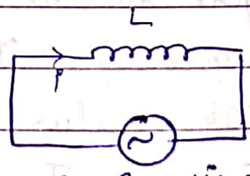
$e = e_m \sin \omega t$



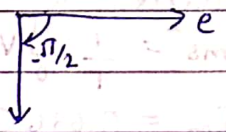
$e = e_m \sin \omega t$

$I = \frac{e}{R} = \frac{e_m \sin \omega t}{R} = i_m \sin \omega t$

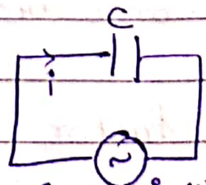
(ii) Circuit with inductor



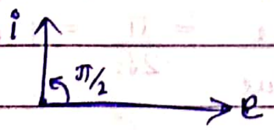
$e = e_m \sin \omega t$



11.32 (iii) circuit with capacitor



$e = e_m \sin \omega t$



(iv) R-L AC series circuit

Q. A coil of resistance 12Ω and inductive reactance of 25Ω is connected in series with a capacitive reactance of 41Ω. The combination is connected with supply of 230V, 50 Hz. Find (i) Z, (ii) I

A. $Z = \sqrt{(X_L - X_C)^2 + R^2} = \sqrt{(41-25)^2 + 12^2} = \sqrt{16^2 + 12^2} = 20\Omega$

$I = \frac{V}{Z} = \frac{230}{20} = 11.5 A$

Waveforms → The shape of the curve obtained by plotting the instantaneous values of voltage or current as the ordinate against time as a abscissa is called its waveform or wave shape.

The rms value of alternating current is given by that steady (d.c.) current which when flowing through a given circuit for a given time produces the same heat as produced by the A.C. when flowing through the same circuit for the same time.

In electrical engineering work, unless indicated otherwise, the values of the given current & voltage are always the r.m.s. values.

The average value of an A.C. is expressed by that steady current (D.C.) which transfers across any circuit the same charge as is transferred by that A.C. during the same time.

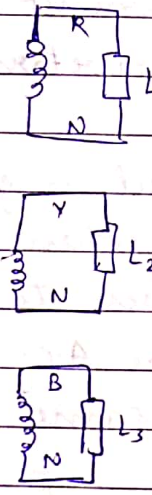
* A.C. instruments measure r.m.s. value.
* r.m.s. value > avg. value always except for rectangular wave where $I_{rms} = I_{avg}$
* The knowledge of form factor will enable the r.m.s

value to be found from the arithmetic mean value and vice versa 6

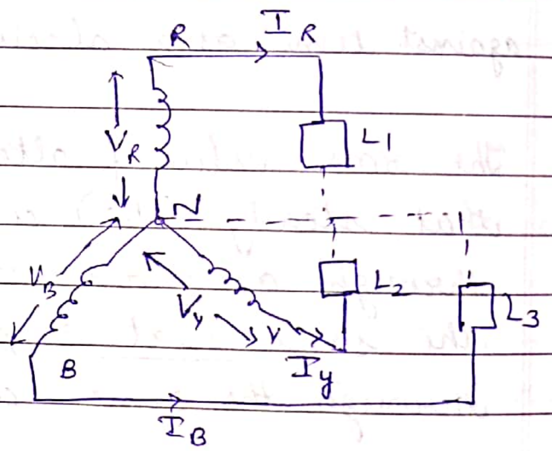
* Knowledge of crest factor is of importance in dielectric insulation testing, because the dielectric stress to which the insulation is subjected, is proportional to the max. or peak value of the applied voltage.

P-631

19.5 Three-phase a.c. circuit



1-ϕ a.c.



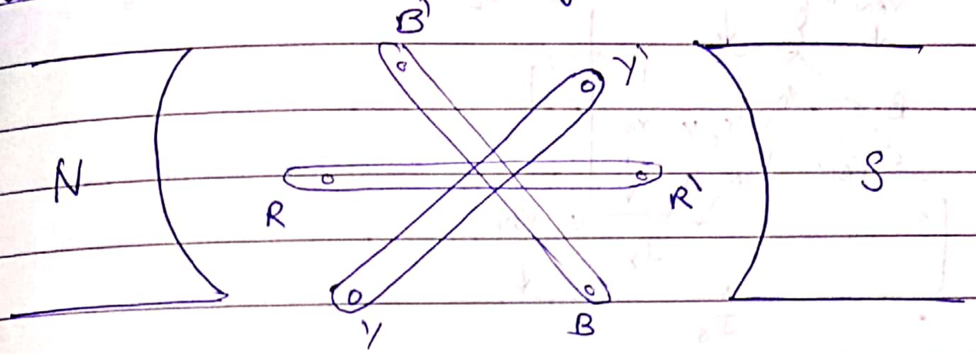
Star or Wye (Y) connection
3-ϕ a.c.

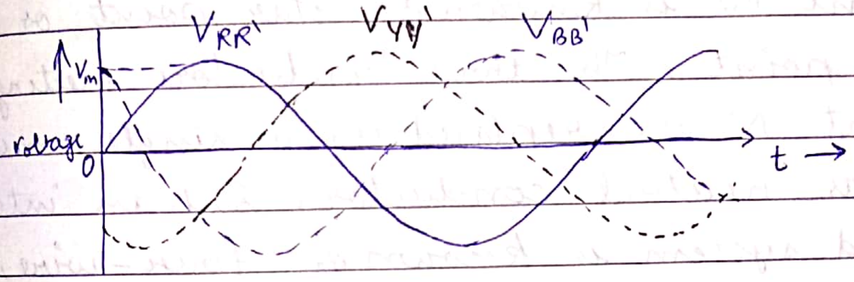
Advantages of 3-ϕ a.c.

1. Less requirement of wire
2. Regular, stable, balanced a.c. supply
3. No disturbances
4. Current rating of 1-ϕ & 3-ϕ is same. 7.
5. More power can be delivered. It is applicable only in case of power transmission & distribution. For higher power application 1-ϕ supply is not sufficient. eg. industrial & commercial requirement of power 8
6.

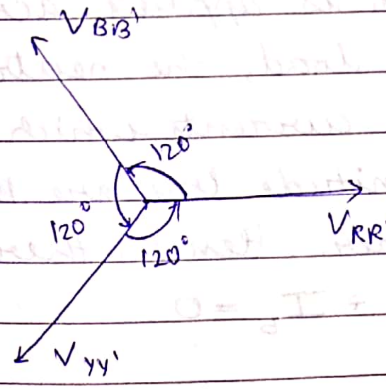
6. It contains 3 voltages, 3 currents, 3 conductors.

Generation of 3-ϕ supply





waveform of 3-ϕ AC.



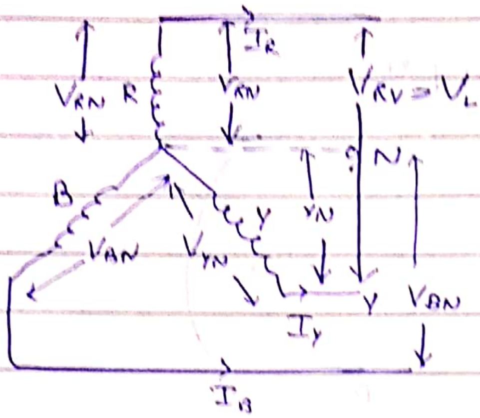
If the phase difference is variable or amplitude is variable then the ~~the~~ 3-ϕ a.c. is unbalanced.
The 3-ϕ a.c. is balanced if $\Delta\phi$ & amplitude are constant.

$V_{RR'} = V_m \sin \omega t$
$V_{BB'} = V_m \sin (\omega t - 2\pi/3)$
$V_{YY'} = V_m \sin (\omega t - 4\pi/3) = V_m \sin (\omega t + 2\pi/3)$

7. 3-ϕ a.c. is almost constant always.
3-ϕ power is more constant compared to single phase
3-ϕ system has uniform torque & machines run more smoothly.

8. Power transmission by 3-ϕ is very economical.

3-ϕ Star Connection (or) Wye connection (Y)



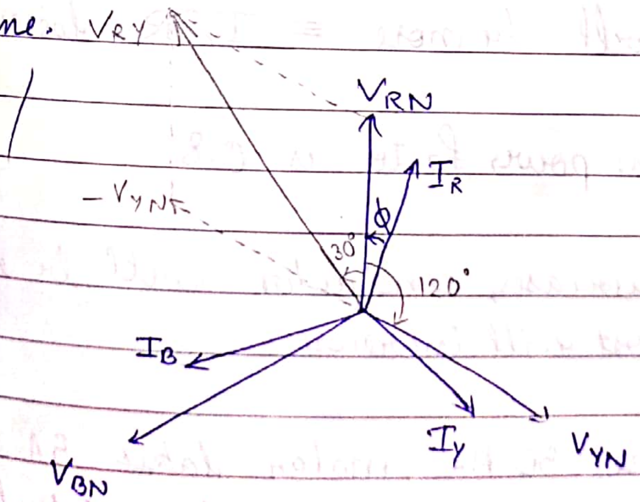
The point N is known as star point or neutral point. The three conductors meeting at point N are replaced by a single conductor known as neutral conductor. Such an inter-connected system is known as four-wire, 3-phase system. If it is applied across a balanced symmetrical load, the neutral wire will be carrying three currents which are exactly equal in magnitude but are 120° out of phase with each other. Hence, there vector sum is zero $I_R + I_Y + I_B = 0$.

(i) the arrow placed alongside I_R, I_Y & I_B flowing in the three phases indicate the directions of currents when they are assumed to be positive and not the directions at a particular instant.

At no instant will all the three currents flow in the same direction either outwards or inwards. The three arrows indicate that first the current flows outwards in phase R, then after a phase-time of 120°, it will flow outwards from phase Y and after a further 120°, outwards from phase B.

(ii) the current flowing outwards in one or two conductors is always equal to that flowing inwards in the remaining conductor(s).

In star connection, line current and phase current is same.



Considering the default case i.e. inductive circuit

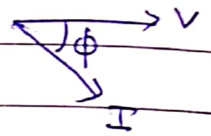
Applying KVL in RYL loop $V_{RY} = V_{RN} - V_{YN}$

$$V_{line} = V_{RY} = \sqrt{|V_{RN}|^2 + |V_{YN}|^2 + 2|V_{RN}||V_{YN}|\cos 60°}$$

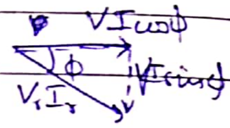
$$V_L = \sqrt{3}\, V_{PH}$$

* Line voltages are 120° apart
* Line voltages are 30° ahead of phase voltages
* Line voltage = $\sqrt{3}$ times phase voltage
* Line current = phase current
* In balanced condition, potential at neutral is 0.

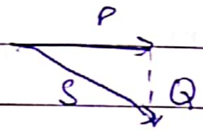
Power Factor $\Rightarrow$ $\cos\phi = \frac{R}{Z}$



conversion of normal Δ to power Δ



~~⇒ actual pow~~ P = active power = $VI\cos\phi$
Q = reactive power = $VI\sin\phi$
S = Apparent power = $V_r I_r$



$\cos\phi = \frac{P}{S} = \frac{P}{V_r I_r}$ $\Rightarrow$ $I_r = \frac{P}{V\cos\phi}$

If power factor is low, machines will start taking more current which is dangerous
Heat loss will be more = $I_r^2 R$ losses

normally, the power factor is 0.8

If current increases, conductor will be required thick and cost will increase

Q. A single phase 50 Hz motor takes 5A at 0.6 P.f lagging from 230 V power supply. Calculate
(a) active and reactive component of current
(b) active power
(c) The output of motor if the efficiency of motor at this load is 0.85.

A. $I_r = 5A$, $f = 50Hz$, $\cos\phi = 0.6$, $V_r = 230V$.

(A) active current component $= I_r \cos\phi = 5A \times 0.6 = 3A$

(B) reactive component $= I_r \sin\phi = 5A\sqrt{1-(0.6)^2} = 5\times 0.8 = 4A$

(b) active power $= I_r V_r \cos\phi = 5A \times 230V \times 0.6 = 690\ W$

(c) Output $= \eta \times$ input $= \eta \times$ active power
$= 0.85 \times 690\ W = 586.5\ W$

<u>3-ϕ power</u> : Y-star connection

$V_L = \sqrt{3} V_{ph}$, $I_L = I_{ph}$.

$P = V_R I_R \cos\phi + V_Y I_Y \cos\phi + V_B I_B \cos\phi$

For a balanced connection, phase difference is equal

$\Rightarrow P = (V_R I_R + V_Y I_Y + V_B I_B)\cos\phi$

Also $V_R = V_Y = V_B = V_{PH}$ and $I_R = I_Y = I_B = I_{Ph}$

$\Rightarrow$ Total 3-ϕ power $= 3 V_{Ph} I_{Ph} \cos\phi$ (phase values)

$= \sqrt{3} V_L I_L \cos\phi$ (line values)

Δ- Delta connection

Total 3-ϕ power $= \sqrt{3} V_L I_L \cos\phi$

Q. A balanced star connected load of $(8+j6)\,\Omega$ per phase is connected to a balanced 3-ϕ, 400V supply. Find the line current, power factor, and total power, total volt-ampere.

A. $Z = (8+j6)\,\Omega$, $\quad V_{rms} = 400V = V_L$

~~Line current~~ $\cancel{I = \frac{V_L}{Z} = \frac{\sqrt{3}V_{PH}}{R} = \frac{400\sqrt{3}}{8+j6\ 10} = 40A}$

Power factor $\cos\phi = R/Z$

$Z_{Ph} = (R + X_j) = (8 + 6j) \Rightarrow R = 8. \quad X = 6 = |X_L - X_C|$

~~cos~~ when it is not given that is it line or phase voltage then voltage is given V_{Line}

$Z = \sqrt{8^2 + 6^2} = 10$

$\cos\phi = \frac{R}{Z} = \frac{8}{10} = 0.8$ lagging (inductive is dominant) as j is positive

$P = \text{power} = \sqrt{3}V_{L}I_{L}\cos\phi = \sqrt{3}\,400 \times 23.1 \times 0.8 = \cancel{7392\ Watt}$ 12800 12803.32 watt

$V_{Ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 231V \quad I_{Ph} = \frac{V_{Ph}}{Z_{Ph}} = \frac{400}{\sqrt{3} \times 10} = \frac{40}{\sqrt{3}} = 23.094 = 23.1A$

Total volt-ampere, apparent power $S = V_L I_L$

$S = \sqrt{3} \times 400 \times 23.1 = 16000$ Watt $\quad 16$ kW

~~$Q = P\tan\phi$~~ $Q = \sqrt{3}V_L I_L \sin\phi = 16000 \times 0.6 = 9.6$ kVAR

$\Rightarrow P = 12.8$ kW

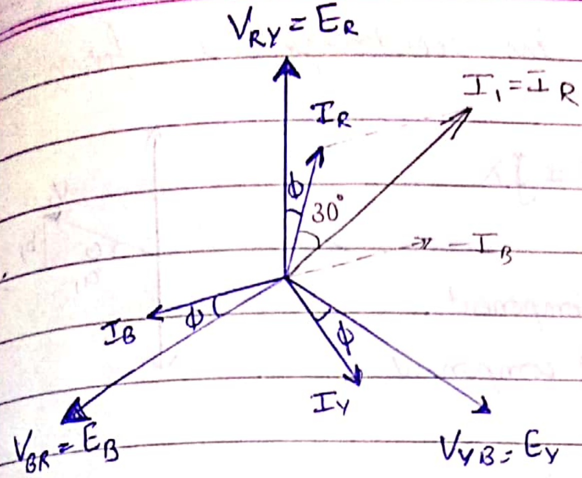
$Q = 9.6$ kVAR

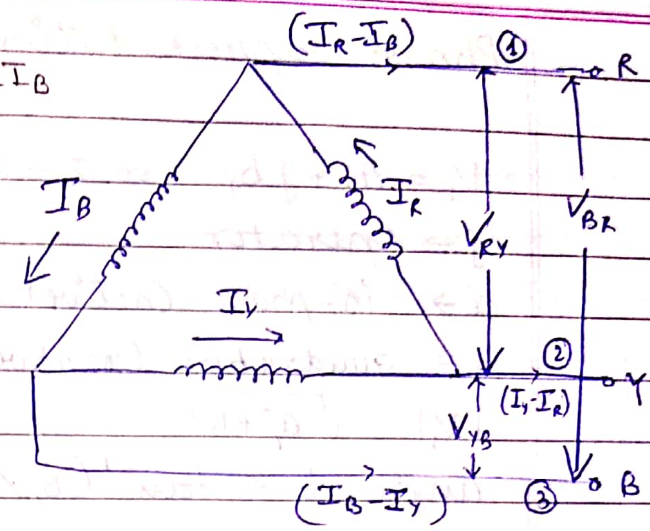
$S = 16$ kVA

~~Domestic Wiring~~ Delta or Mesh Connection -

In this form of interconnection, the dissimilar ends of the three phase windings are joined together. In the system (balanced), then sum of three voltages round the closed mesh is zero.

In it Line voltage = Phase voltage $V_L = V_{Ph}$





Current in line 1 is $I_1 = I_R - I_B$
" " line 2 is $I_2 = I_Y - I_R$
" " line 3 is $I_3 = I_B - I_Y$
} vector difference

If $I_B = I_R = I_Y$ = Phase current then
current in line No. 1 is $I_1 = 2 \times I_{Ph} \cos(60°/2)$

$I_1 = 2 \times I_{Ph} \times \sqrt{3}/2 = \sqrt{3} I_{Ph}$

Similarly $I_2 = \sqrt{3} I_{Ph}$, $I_3 = \sqrt{3} I_{Ph}$.

Since all line currents are equal in magnitude,

$I_1 = I_2 = I_3 = I_L = \sqrt{3} I_{Ph}$

* Line currents are 120° apart
* line currents are 30° behind the respective phase currents
* the angle between the line current and the corresponding line voltage is $(30+\phi)$ with the current lagging.

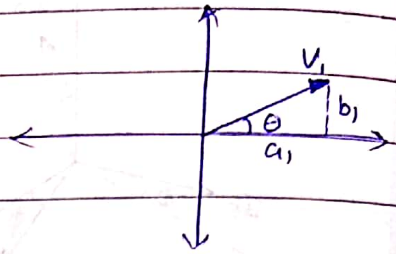
$\text{Power}_{Ph} = V_{Ph} I_{Ph} \cos\phi$

Total power $= 3 \times V_{Ph} I_{Ph} \cos\phi$
$= \sqrt{3} \times V_L I_L \cos\phi$

Phasor representation :- (i) polar
(ii) rectangular (iii) exponential

Ch-12 Complex Numbers

Phasor representation in rectangular form.



$V_1 = a_1 + j b_1$ or $Z = R \pm jX$

$j \rightarrow$ operator

$a_1 \rightarrow$ in-phase (active) component

$b_1 \rightarrow$ quadrature (reactive) component

$|V_1| = \sqrt{a_1^2 + b_1^2}$

angle $\phi = \tan^{-1}(b_1/a_1)$

j is used to indicate the counter-clockwise rotation of a vector through 90°. $j = \sqrt{-1}$

Phasor representation in Exponential form

Euler's equation: $e^{\pm j\theta} = \cos\theta \pm j\sin\theta$

$\Rightarrow V = Ve^{\pm j\theta}$

It represents a vector $\vec{V}$ of a numerical value V and having a phase angle of $\pm\theta$ with the reference axis.

Phasor representation in polar form

$V\angle \pm\theta$. $(\equiv Ve^{\pm j\theta})$ is polar form of Phasor.

Multiplication:

$\vec{A} = a_1 + jb_1 = A\angle\alpha = Ae^{j\alpha}$, $\alpha = \tan^{-1}(b_1/a_1)$

$\vec{B} = a_2 + jb_2 = A\angle\beta = Ae^{j\beta}$, $\beta = \tan^{-1}(b_2/a_2)$

$\vec{A}\vec{B} = A\angle\alpha \times B\angle\beta = AB(\alpha+\beta)$

$\vec{A}\vec{B} = Ae^{j\alpha} \times Be^{j\beta} = ABe^{j(\alpha+\beta)}$

Division: $\dfrac{A}{B} = \dfrac{A\angle\alpha}{B\angle\beta} = \dfrac{A}{B}\angle(\alpha-\beta)$

$$\frac{A}{B} = \frac{Ae^{j\alpha}}{Be^{j\beta}} = \frac{A}{B}e^{j(\alpha-\beta)}$$

Designing aspect of domestic Wiring

I Type of supply
II Expected load
III Probable modification
IV Electrical and mechanical Protection required
V Cost

Sub Circuits:

(i) Light and fan sub-circuit (low power consumption appliances) [5A]
(ii) Power sub circuit [15A]

Important points about light-fan sub-circuit.

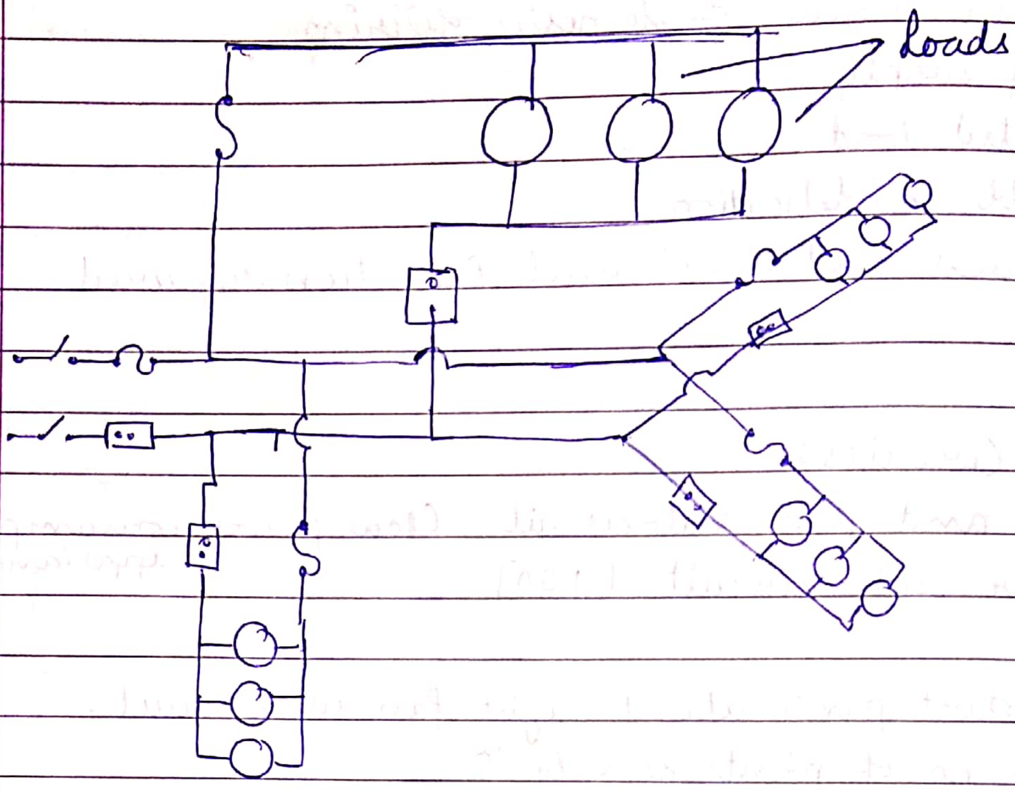
(i) Max. no. of point can be 10
(ii) The total load connected in sub circuit should not be more than 800 W
(iii) Control of light and fan points in any sub circuit should be carried out by 5A switches fitted on a switch board
(iv) 1-ϕ supply should be fed to these circuits

Important points about power sub circuit

(i) Hot plate, electric iron, refrigerator etc.
(ii) No. of power point connected in one sub circuit should not exceed than two.
(iii) The load connected to a sub circuit should not be greater than 3kW
(iv) Control of these circuits should be done by 15A switches
(v) Socket outlets provided in these circuits should be of 15A ratings.
(vi) These sub circuits must be used on single phase supply.

Domestic Connections

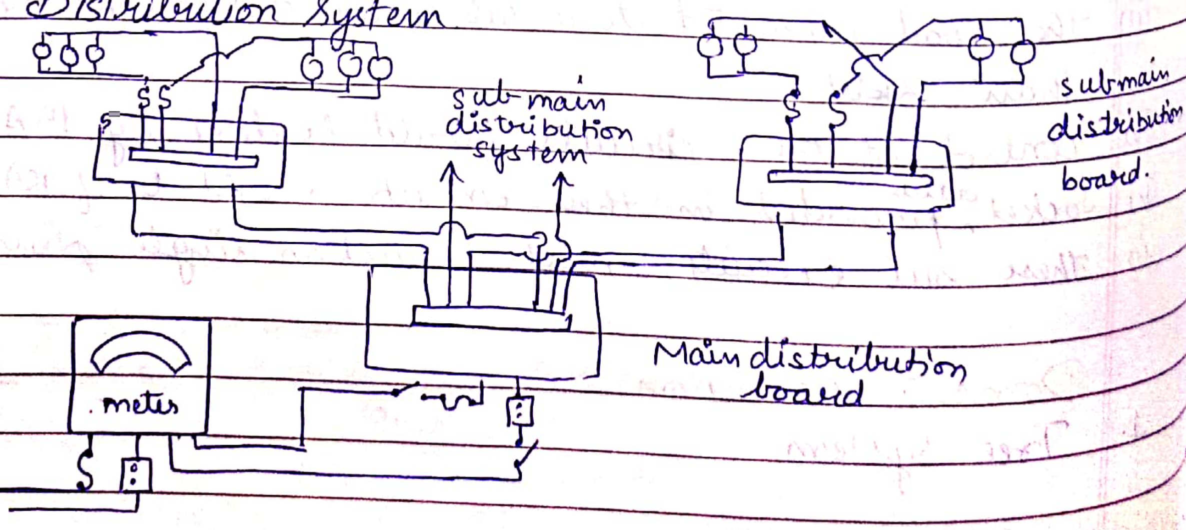
1. Tree System



1) There are many joints for sub circuits
2) Difficult to find fault
3) Voltage may vary
4) Appearance is not good.

1) Easy to build, modify
2) Less requirement of wire. Hence cost effective.
But it is not used in permanent connection requirement.

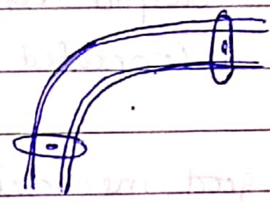
II Distribution System



1) Less complexity , identification is easy
2) More wire required , ~~fuses~~, board increased ⇒ costly
3) Voltage will be constant . Voltage division is equivalent in each circuit
4) No joints required .
5) Fault finding is easy .
6) Extension of circuit is easy .

Wiring Type

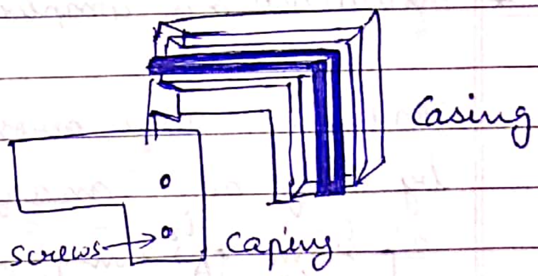
I Cleat Wiring – e.g inverter connection
simple PVC wire, easy, cheapest



not good in appearance, mechanical damage may increase , less life = 5 yrs. Not applicable for some places where mechanical protection is required .

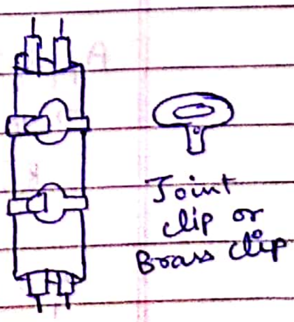
II Wooden casing and Capping Wiring –

* Suitable for low voltage .
* ~~Less~~ Suitable mechanical protection .
* Not suitable for damp places, it absorbs moisture
* It is a bit complex to find any fault occured .
* More skill needed . Its erection is not very simple



III CTS [Cable Tyre Sheathed Wiring] & TRS wiring System.
Tough Rubber Sheath

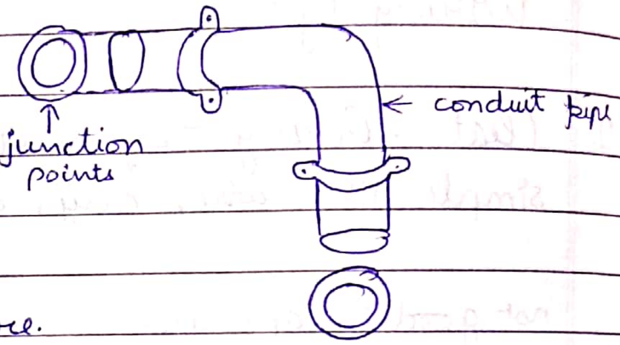
* Easy installation and is durable . long life
* Suitable for damp places , outer wiring
* Cheaper . Give a good appearance
* Lower risk of short circuit .
* Suitable for medium voltage installation .



* May be installed under exposed condition of the rain or dampness.
* Provide good mechanical protection
* Skilled workmen are required.
* Should not be exposed to direct sunlight

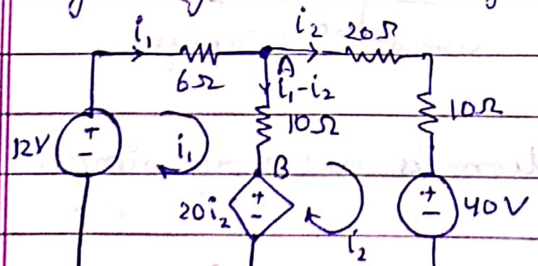
IV Conduit Wiring

(i) Surface conduit
(ii) Concealed conduit



* good mechanical protection
* protection against moisture.
* Surface conduit, damage is easily repairable
* Fitting arrangement is costly. Initial cost is very high.
* Very neat and attractive appearance in concealed conduit
* Require skilled workmen.
* Installation is complex and time consuming.

Q. Find the voltage across 10Ω resistor across terminal AB by using mesh analysis.



Applying KVL in mesh 1

$\Rightarrow 12V = 6i_1 + 10(i_1 - i_2) + 20i_2$

$16i_1 + 10i_2 = 12$

$8i_1 + 5i_2 = 6$

Applying KVL in mesh 2 $\Rightarrow 40 = -10i_2 + 10(i_1 - i_2) + 20i_2 - 20i_2$

$\Rightarrow 40 = \cancel{30}\ 10i_1 \cancel{20i_2} - 20i_2 \Rightarrow i_1 - 2i_2 = 4 \Rightarrow i_1 = 4 + 2i_2$

$8(4 + 2i_2) + 5i_2 = 6 \Rightarrow 32 + 21i_2 = 6 \Rightarrow i_2 = -\frac{26}{21} = -1.23\ A$

$i_1 = 4 + 2(-1.23) = 1.52\ A$

$V_{AB} = 10(1.52 + 1.23)$
$= 10(2.75) = 27.6V$

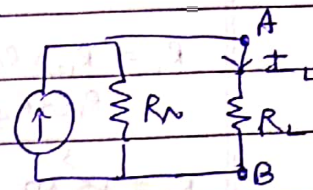
Norton's Theorem

Step 1 – Short the circuit at the load resistance R_L

Step 2 – Determine the current $I_{sc} = I_N$ in that shorted branch

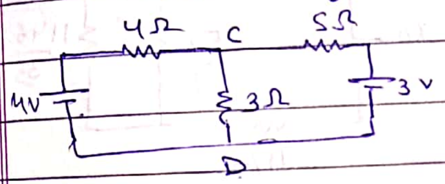
Step 3 – Calculate $R_{sc} = R_N$ in the closed network

Step 4 – Make the norton circuit as



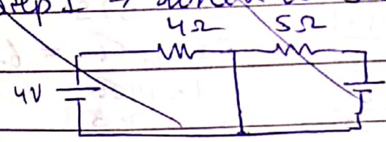
Thus, $I_L = \dfrac{R_N \times I_N}{R_N + R_L}$

Q. Using Norton's theorem find the current in the branch CD containing 3Ω resistor of the network.

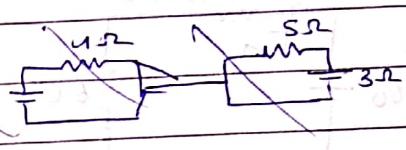


$\equiv$ $E_{eq} = \dfrac{E_1 r_2 + E_2 r_1}{r_1 + r_2} = \dfrac{20+12}{5+4} = \dfrac{32}{9}$ $\quad R_{eq} = \dfrac{r_1 r_2}{r_1 + r_2} = \dfrac{5\times4}{5+4} = \dfrac{20}{9}$

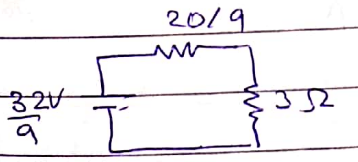
Step I ⇒ when we short the ckt



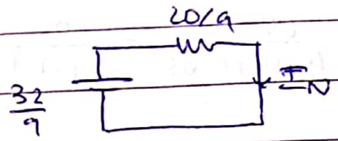
$\equiv$



$\equiv$



Step II ⟹

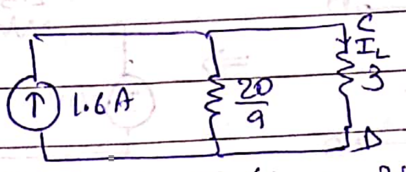


$I_N = \dfrac{V}{R} = \dfrac{32/9}{20/9} = \dfrac{8}{5}$

$= 1.6A$

$R_N = 20/9\,\Omega$

Step 4 ⇒

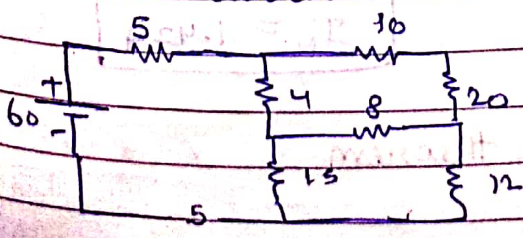


⇒ $I_L = \dfrac{R_N \times I_N}{R_N + R_L}$

$I_L = \dfrac{20/9 \times 1.6}{20/9 + 3} = \dfrac{32/9}{47/9} = \dfrac{32}{47} = 0.68A$

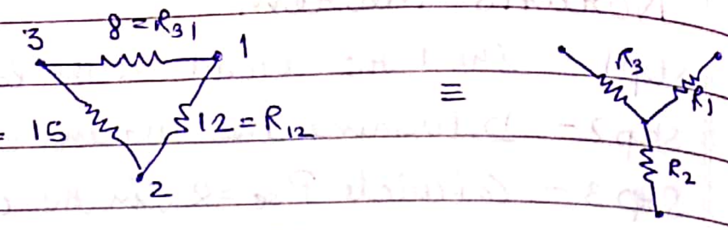
$V_L = I_L R_L = \dfrac{32}{47} \times 3\Omega = 2.042V$

Q. Find the current delivered by the battery.



$\equiv$

Consider the delta

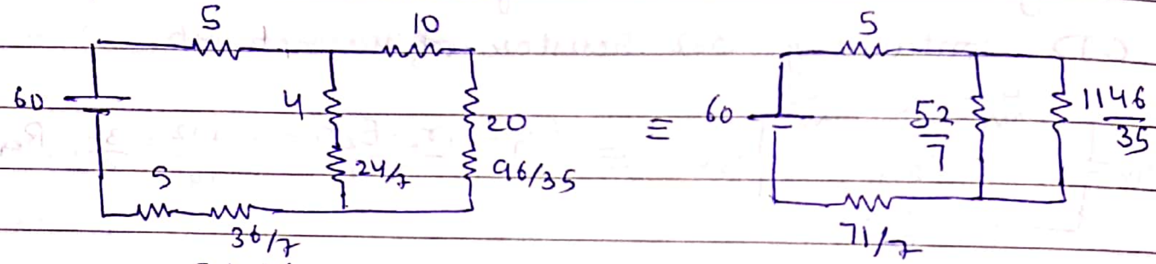


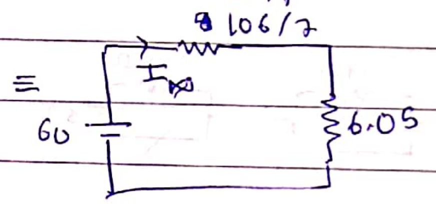
$R_1 = \frac{R_{12} \times R_{31}}{R_{12}+R_{23}+R_{31}} = \frac{12 \times 8}{12+8+15} = \frac{12 \times 8}{35} = \frac{96}{35} = 2.74$

$R_2 = \frac{\cancel{15}^{3} \times 12}{\cancel{35}_{7}} = \frac{36}{7} = 5.14$ $\qquad R_3 = \frac{8 \times \cancel{15}^{3}}{\cancel{35}_{7}} = \frac{24}{7} = 3.42$

I=2.86A

Thus, the circuit becomes

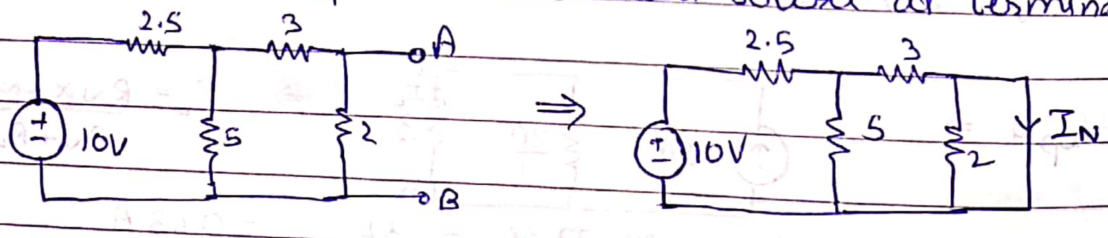




$\frac{\frac{52}{7} \times \frac{1146}{35}}{\frac{1406}{35}} = \frac{52 \times \cancel{1146}^{573}}{7 \times \cancel{1406}_{703}} = 6.05$

$I_1 = \frac{60}{15.14+6.05} = \frac{60}{21.19} = 2.83\ A$

Q. Find norton's equivalent current source at terminal AB.

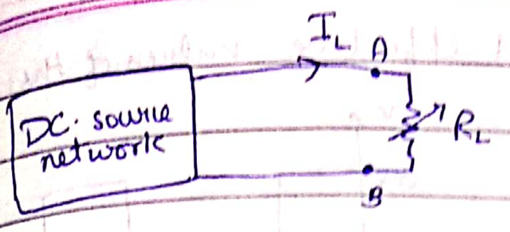


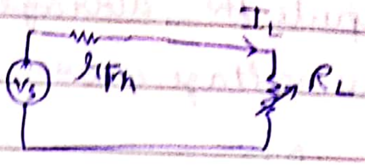
⇒ ~~Req~~ $R_N = 2.5 + \frac{3 \times 5}{3+5} = 2.5 + \frac{15}{8} = \frac{35}{8} = 4.37\Omega$

$I_{sc} = \frac{V}{R} = \frac{10}{35/8} = \frac{80}{35} = 2.285$ $\qquad I_N = \frac{5 \times 2.285}{8}$

$\boxed{I_N = 1.42A}$

Maximum Power Transfer theorem





$$I_L = \frac{V_{TH}}{R_{TH} + R_L} \qquad P_L = I_L^2 R_L = \left(\frac{V_{TH}}{R_{TH}+R_L}\right)^2 \times R_L$$

$$P_L = \frac{(V_{TH})^2}{\left(\frac{R_{TH}^2}{R_L}\right) + 2R_{TH} + R_L} \qquad \text{Let } A = \frac{R_{TH}^2}{R_L} + 2R_{TH} + R_L$$

For power to be maximum, A should be minimum

If $\frac{dA}{dR_L} = 0$ and $\frac{d^2A}{d^2R_L}$ is positive at a point then A is min.

$$A = \frac{(R_{TH})^2}{R_L} + 2R_{TH} + R_L \Rightarrow \frac{dA}{dR_L} = \frac{-(R_{TH})^2}{(R_L)^2} + 0 + 1 = 0$$

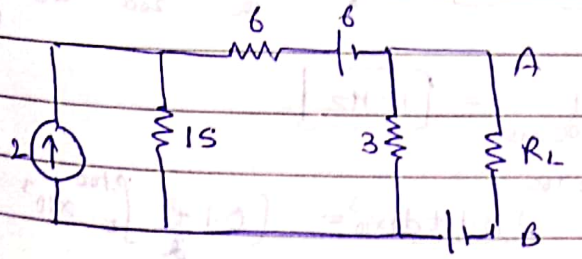
$$\Rightarrow \frac{(R_{TH})^2}{R_L^2} = 1 \Rightarrow (R_{TH})^2 = R_L^2 \Rightarrow R_{TH} = R_L$$

$$\frac{d^2A}{dR_L^2} = \frac{2(R_{TH})^2}{(R_L)^3} = \frac{2(R_{TH})^2}{(R_{TH})^3} = \frac{2}{R_{TH}} > 0 .$$

Thus A is minimum at $\boxed{R_L = R_{TH}.}$

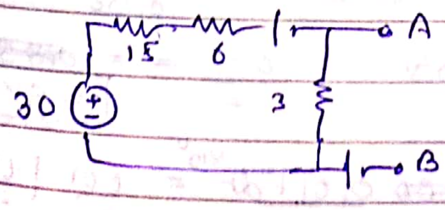
$$\Rightarrow \boxed{P_{max} = \frac{(V_{TH})^2}{4R_{TH}}}$$

Q.



Find R_L to have maximum power transfer in the circuit

A.



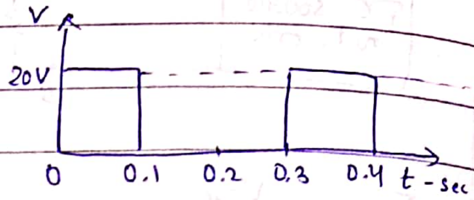
$30 - 6 = (15+6+3)I \Rightarrow I = \frac{24}{24} = 1A$

~~$V_{TH} = 1A \times 3 = 3V$~~.

$$R_{TH} = \cancel{3+}\ \frac{21 \times 3}{21+3} = \frac{21 \times \cancel{3}}{\cancel{24}\,8} = 2.625$$

For max. power $R_L = R_{TH} = 2.625 = \frac{21}{8}$

Q. Compute the average and effective values of the square voltage wave.



A. $V_{avg} = \dfrac{\int_0^{0.1} 20\,dt}{\int_0^{0.3} dt}$

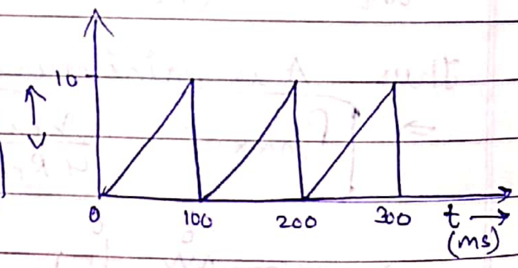
$= \dfrac{20[t]_0^{0.1}}{[t]_0^{0.3}} = \dfrac{20 \times 0.1}{0.3} = \dfrac{20}{3}\,V = 6.6\,V$

$V_{rms} = \sqrt{\dfrac{\int V^2 dt}{\int dt}} = \sqrt{\dfrac{\int_0^{0.1} (20)^2 dt}{\int_0^{0.3} dt}} = \sqrt{\dfrac{400[t]_0^{0.1}}{[t]_0^{0.3}}}$

$= 20\sqrt{\dfrac{0.1}{0.3}} = \dfrac{20}{\sqrt{3}} = 11.547\,V$

Q. Determine (a) freq. of waveform
(b) waveform eq. for $0 < t < 100$ ms
(c) average value (d) rms value ~~of for~~ & form factor

~~m~~ = slope $m = \dfrac{10}{100} = 0.1$, $T = 100ms$



(b) $\Rightarrow$ ~~V=~~ $\underset{m}{0.1}\,t = V(t) \Rightarrow \boxed{V(t) = 100t}$

$V(t+100) = V(t)$.

(a) frequency $\nu = \dfrac{1}{T} = \dfrac{1}{100\,ms} = \boxed{10\,Hz}$

(c) $V_{avg} = \dfrac{\int_0^{0,100} V dt}{T} = \dfrac{\int_0^{0,100} 0.1\,t\,dt \times 10^3}{100\,ms} = \dfrac{\left[0.1\frac{t^2}{2}\right]_0^{0,100} \times 10^3}{0.100}$

~~$\dfrac{0.1}{2}\left[\dfrac{100 \times 100}{100}\right] = 5V$~~ $= \dfrac{0.01}{2} =$ = ~~0.5×10^{-3} V~~ $\boxed{= 5V}$

(d) $V_{rms}^2 = \dfrac{\int_0^{100ms} V^2 dt}{T} = \dfrac{\int_0^{0,100} 0.01\,t^2 dt \times 10^6}{100\,m} = \dfrac{0.01}{0.1}\left[\dfrac{t^3}{3}\right]_0^{0.1} \times 10^6$

$V_{rms}^2 = 0.1\,\dfrac{0.001}{3} = \dfrac{1}{3} \times 10^{-4}\,V \times 10^6$ $\quad V_{rms} = 0.577 \times 10^{-2}\,V$

$\boxed{V_{rms} = 5.77\,V}$

~~form factor = $\dfrac{V_{rms}}{V_{avg}} = \dfrac{0.577 \times 10^{-2}}{0.5 \times 10^{-2}} = 1.15$~~

form factor $= \frac{V_{rms}}{V_{avg}} = \frac{5.77}{5} = 1.154$

Q. calculate $(5 \angle 30^\circ + 8 \angle -30^\circ)$ V = V when they are in series

$\Rightarrow V = 5(\cos 30 + j\sin 30) + 8[\cos(-30^\circ) + j\sin(-30)]$

$= 5\cos 30 + 5j\sin 30 + 8\cos 30 - 8j\sin 30$

$= 13\cos 30 - 3j\sin 30$

$= 13 \times \frac{\sqrt{3}}{2} - 3j\frac{1}{2} = 11.25 - j\,1.5$

$|\vec{V}| = \sqrt{(11.25)^2 + (-1.5)^2} = 11.35$

$\phi = \tan^{-1}\left(\frac{-1.5}{11.25}\right) = \tan^{-1}(-0.13) = -7.58$

$\Rightarrow V = 11.35 \angle -7.58$

Ch-6 Magnetism and Electromagnetism

6.21 Magnetic circuit concept – It may be defined as the route or path followed by magnetic flux. The law of magnetic circuit is quite similar to electric circuit

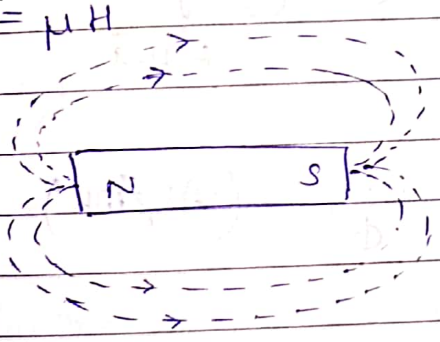
$T^{-2}A^{-1}$ Magnetic flux (ϕ) – The total magnetic field passing prependicularly through an area Unit – Wb

$T^{-2}A^{-1}$ Magnetic flux density ($\vec{B}$) – It is given by the flux passing per unit area through a plane at right angles to the flux

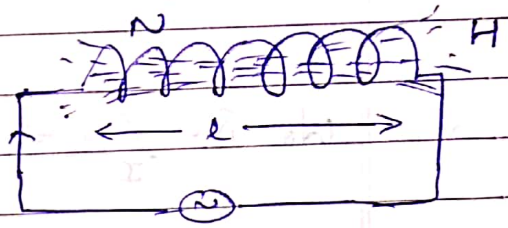
$$\vec{B} = \phi / A \quad (\text{Wbm}^{-2}) \div (T)$$

Magnetic field strength or Magnetic field intensity (H)

$B = \mu H$

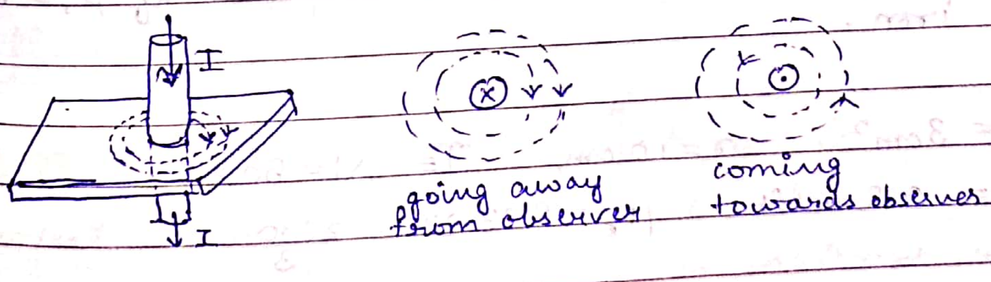


(a)



(b)

$$H = \frac{nI}{l} \quad (\text{TA m}^{-1})$$



$T^{-2}A^{-2}$ Permeability (μ) –

absolute $\mu_0 = \frac{B}{H}$ absolute permeability of free space $\mu_0 = 4\pi \times 10^{-7}$ H/m

relative permeability, $\mu_r = \frac{\mu}{\mu_0}$

6.22 magneto motive force (mmf) – Flow of electron is basically due to emf. Similarly the force behind the flow of flux or the production of flux in magnetic circuit is called magneto motive force or mmf.

$m.m.f = N.I = H \times l$ unit → AT (Ampere-Turns)

N → number of turns

I → current

$M^{-1}L^{-1}T^{2}A^{2}$ Reluctance (S) or (R) - It is the opposition offered to the flow of flux.

$$S \propto \frac{l}{a} \Rightarrow S = \frac{l}{\mu a} \Rightarrow S = \frac{l}{\mu_r \mu_0 a} \quad \left(K = \frac{1}{\mu}\right)$$

$$As\ R = \frac{V}{I} \Rightarrow S = \frac{mmf}{\phi} = \frac{NI}{\phi} \quad (AT/Wb)$$

Q. An iron ring of circular cross section area $3\,cm^2$ and mean diameter of 20 cm is wound with 500 turns of wire. The flux required is 0.5 mWb in the ring. Find the current required if $\mu_r = 8.3333$ for iron.

A. $A = 3\,cm^2$, $r = 10\,cm$, $N = 500\,T$

$\phi = 0.5\,mWb$ $\mu_r = 833.33 = \frac{2500}{3}$

$$S = \frac{l}{\mu_r \mu_0 A} \Rightarrow \frac{l}{\mu_r \mu_0 A} = \frac{NI}{\phi}$$

$$\Rightarrow I = \frac{l\phi}{N\mu_r\mu_0 A} = \frac{0.5\cancel{00} \times 2 \times \pi\,(10\,cm)\,m}{\cancel{500} \times \frac{2500}{\cancel{3}\,100} \times \cancel{3}\,cm^2 \times \cancel{4}\pi \times 10^{-7}\,2}$$

$$= \frac{10^{-3}}{5 \times 10^{-2-2}} = \frac{10}{5} = \cancel{0.02\,A}\ 2\,A$$

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2.5 Comparison between Magnetic and Electric Circuits.

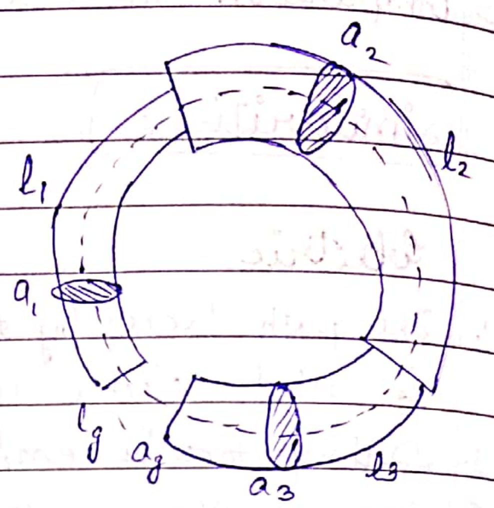
Similarities :-

	Electric	Magnetic
1.	The path traced by the current is called electric circuit	The path traced by flux is called magnetic circuit
2.	Driving force is emf	Driving force is mmf
3.	Current flows in the circuit I	Flux flows in the circuit ϕ
4.	R resistance	$\mathcal{R}$ or S reluctance
5.	$R = \rho \frac{l}{a}$	$\mathcal{R}$ or $S = \frac{l}{\mu a}$
6.	$I = \frac{emf}{R}$	$\phi = \frac{mmf}{\mathcal{R}}$
7.	Current density $J = \frac{I}{A}$ (Am^{-2})	Flux density $B = \frac{\phi}{A}$ (Wbm^{-2})
8.	Conductance $G = \frac{1}{R} = \sigma$ (Siemen)	Permeance $' = \frac{1}{S} = \frac{1}{\mathcal{R}}$ (Henry)
9.	KCL and KVL are applicable	Kirchoff's mmf and flux law is applicable

Differences :-

	Electric	Magnetic
1.	Current actually flows.	Flux does not actually flow
2.	Many materials are electric insulator	No material is magnetic insulator.
3.	Energy needed to be supplied to maintain current flow	Energy required only to create not to maintain
4.	At constant temperature, R and σ are free from current density.	$\mathcal{R}$ and permeance are dependent on ϕ.
5.	Continuous consumption of power	No continuous consumption of power

6.23 Series magnetic circuit



$$\mathcal{R} = \frac{l_1}{a_1 \mu_0 \mu_{r_1}} + \frac{l_2}{a_2 \mu_0 \mu_{r_2}} + \frac{l_3}{a_3 \mu_0 \mu_{r_3}} + \frac{l_g}{a_g \mu_0}$$

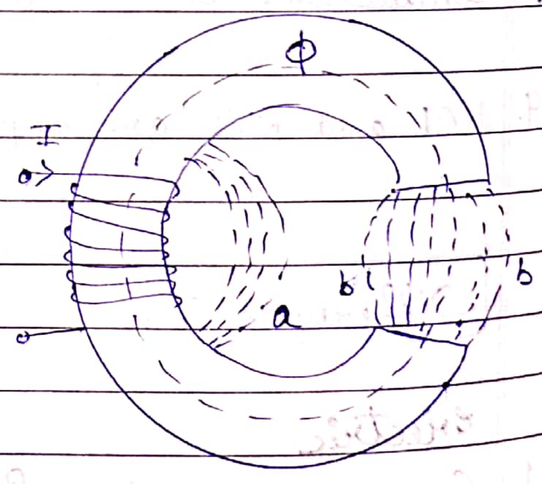
$$\text{Total mmf} = \phi \times \mathcal{R}$$

$$= \phi \left[\frac{l_1}{a_1 \mu_0 \mu_{r_1}} + \frac{l_2}{a_2 \mu_0 \mu_{r_2}} + \frac{l_3}{a_3 \mu_0 \mu_{r_3}} + \frac{l_g}{a_g \mu_0} \right]$$

$$= \frac{B_1 l_1}{\mu_0 \mu_{r_1}} + \frac{B_2 l_2}{\mu_0 \mu_{r_2}} + \frac{B_3 l_3}{\mu_0 \mu_{r_3}} + \frac{B_g l_g}{\mu_0} \qquad \left\{ B = \frac{\phi}{a} \right\}$$

$$= \left(H_1 l_1 + H_2 l_2 + H_3 l_3 + H_g l_g \right) \text{ A-T} \qquad \left\{ H = \frac{B}{\mu} \right\}$$

6.26 Parallel magnetic circuit -



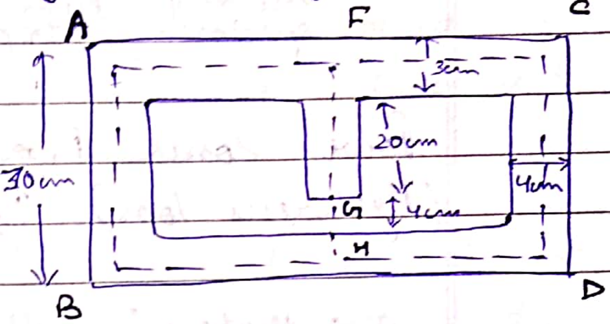
Leakage flux - The flux that does not follow the desired path in a magnetic circuit is called leakage flux

$$\phi_{leakage} = \phi_i - \phi_g$$

$\phi_i \rightarrow$ Total flux produced
$\phi_g \rightarrow$ Useful flux across the air gap

a → leakage (leaked flux)
b → fringing

Q. A 350 turn coil is wound on FG branch of the cast steel frame a shown in fig. A total flux of 1.2×10^{-3} Wb is required in the gap. Find what current is required. Assume that the gap. density is uniform & that all flux lines pass straight across gap.

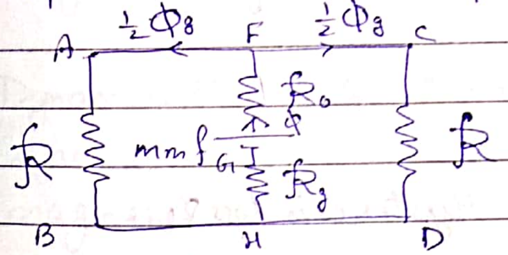


A. $N = 350$ turns

$\phi = 1.2 \times 10^{-3}$ Wb

$I = ?$

The given frame can be represented as the equivalent magnetic circuit.



In loop HGFABH

$$mmf = F = F_g + F_o + F_{ABH}$$

$$= \phi_g R_g + \phi_g R_o + \left(\frac{\phi_g}{2}\right) R$$

$$= \phi_g \left[\frac{l_g}{\mu a_g} + \frac{l_o}{\mu a_o} + \frac{l}{2\mu a}\right]$$

$$= \frac{\phi_g}{\mu_o}\left[\frac{4}{16} + \frac{20}{\mu_r 80} + \frac{30}{\mu_r 2 \times 120}\right] cm^{-1}$$

For Iron (99.8%)

$\mu_r = 5000$

flux in air gap $\phi_g = 1.2 \times 10^{-3}$ Wb

length of air gap $= 4 \times 10^{-2}$ m

Area of air gap $= 16 \times 10^{-4} m^2$

$F = 24306$

$I = 69.45 A$

$$= \frac{\phi_g}{4\pi \times 10^{-7}}\left[\frac{1}{4} + \frac{1}{4\mu_r} + \frac{1}{8\mu_r}\right] cm^{-1}$$

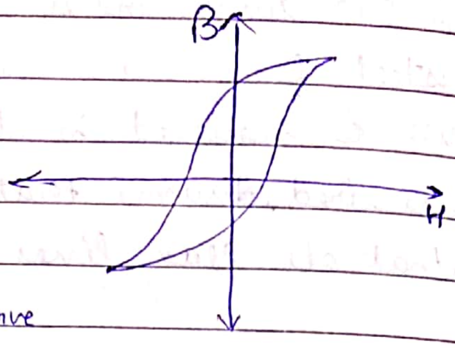
$$= \frac{\phi_g}{4\pi \times 10^{-7}}\left[\frac{3}{4\mu_r} + \frac{1}{4}\right] cm^{-1}$$

$$= \frac{\overset{0.3}{\cancel{1.2}} \times 10^{-3}}{\cancel{4} \times 4\pi \times 10^{-7}}\left[\frac{3}{\mu_r} + 1\right] \times 100 \; m^{-1} = \frac{3 \times 10^5}{4\pi}\left[\frac{3}{\mu_r} + 1\right] AT$$

Ans =

Ch-7 Electromagnetic Induction

B-H Curve.



Energy consumed,

$W = \underbrace{a.l}_{\substack{\downarrow \\ \text{volume of specimen}}} \cdot \underbrace{H.dB}_{\text{area of elementary strip in B-H curve}}$

Power losses $P_h \propto B_{max}^{1.6} f V$

(Hysteresis loss) $P_h = \eta B_{max}^{1.6} f V$

$\eta \rightarrow$ Hysteresis coefficient

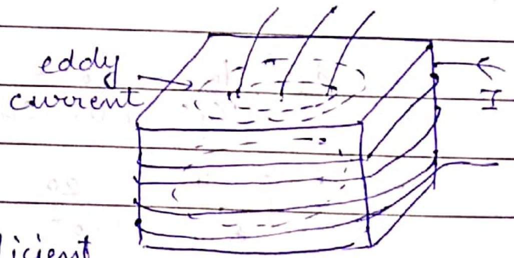
$B_{max} \rightarrow$ peak value of flux density

$f \rightarrow$ frequency

$V \rightarrow$ volume of specimen

Eddy Current loss and Hysteresis loss flux.

Eddy Current loses $= K_e (B_m)^2 f^2 t^2 V$



$K_e \rightarrow$ Eddy current coefficient

$B_m \rightarrow$ Magnetic flux ~~f~~ density peak

$f \rightarrow$ frequency

$t \rightarrow$ thickness of material

$V \rightarrow$ potential applied

To reduce it, we can use laminated material

Eddy current loses arise from the fact that the core itself is composed of conducting material, so that the voltage induced in it by the varying flux produces circulating currents in the material.

These are called eddy currents and are accompanied by 'i^2R' loss in the core called eddy current loses

While Hysteresis loss is associated with the phenomena of hysteresis and is an expression of the fact when ferromagnetic materials. Involved, not all the energy of the magnetic field is returned to the circuit when mmf is reduced

7.8 Static induced emf - The induced emf which is not dependent on the motion of the conductor or the magnetic flux is called static induced emf

7.7 Dynamically induced emf - The induced emf which is dependent on the motion of the conductor or the magnetic flux is called dynamic induced emf
e.g. Dynamo.

7.9 Self Inductance - $L_1 = \frac{N_1 \phi_1}{I_1}$ $\phi = \frac{mmf}{R} = \frac{NI}{R}$

$$\Rightarrow L = \frac{N}{I} \frac{NI}{R} = \frac{N^2}{R} \; (H) = \frac{\mu A N^2}{l} \Rightarrow \boxed{L_1 = \frac{N_1^2 \mu_0 \mu_r a_1}{l_1}}$$

7.11 Mutual Inductance - when the magnetic field generated by a coil of wire induces voltage in an adjacent coil of wire, it is called mutual inductance

$$M = \frac{N_1 \phi_2}{I_2} = \boxed{\frac{N_1 N_2 a_1 \mu_0 \mu_r}{l_1}}$$

$1 \text{ Henry} = 1 \frac{\text{Weber-Turns}}{\text{Ampere}}$ $L(H) = \frac{N\phi}{I} \left(\frac{Wb\text{-}T}{A}\right)$

Mutually induced emf

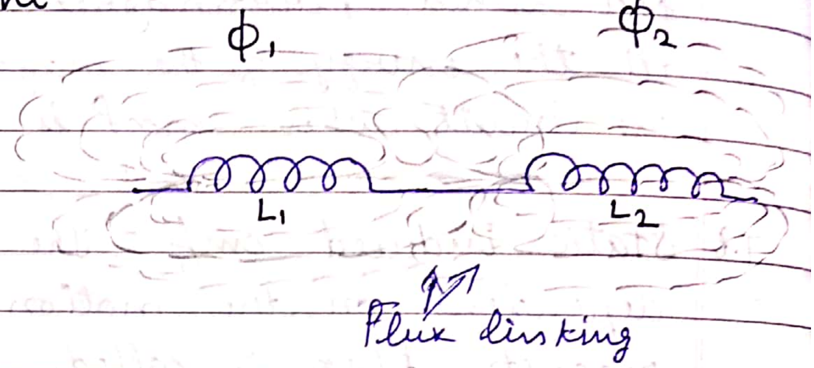
$$e_m = -N_1 \frac{d\phi_2}{dt} = -N_2 \frac{d\phi_1}{dt}$$

7.13 Coupling Coefficient

$0 < K < 1$

$\phi_{12} = K\phi_1$

flux



$\phi_{21} = k\phi_2$

$$\phi_1 = \frac{N_1 i_1}{R} \qquad \phi_2 = \frac{N_2 i_2}{R}$$

$$M_{12} = \frac{N_2 \phi_{12}}{i_1} = \frac{N_2 k\phi_1}{i_1} = \frac{kN_1N_2}{R}$$

$$M_{21} = \frac{N_1 \phi_{21}}{i_2} = \frac{N_1 k\phi_2}{i_2} = \frac{N_1N_2k}{R} = M_{12}$$

Self Inductance $L = \frac{N\phi}{i} = \frac{N^2\phi}{Ni} = \frac{N^2 BA}{Hl} = \frac{N^2}{R}$

$$L_1 = \frac{N_1^2}{R}, \quad L_2 = \frac{N_2^2}{R}$$

then $L_1 L_2 = \frac{N_1^2 N_2^2}{R^2} \Rightarrow \frac{N_1 N_2}{R} = \sqrt{L_1 L_2}$

$$\Rightarrow \boxed{M = k\sqrt{L_1 L_2}}$$

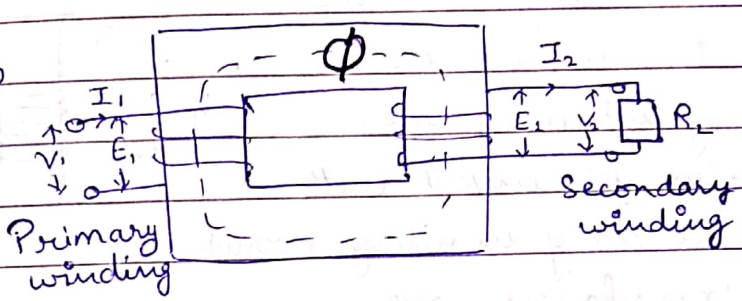
Q. Two inductance of 15mH and 33 mH are connected in series such that their flux oppose each other. The value of coefficient of coupling is 0.7. Calculate the mutual inductance between two coils.

Chapter -32 Transformer

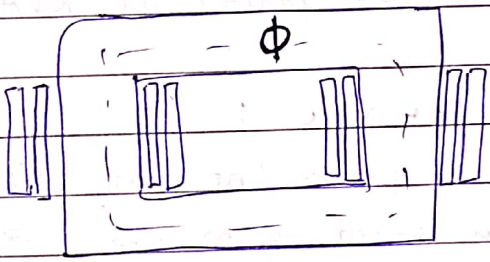
A: $M = K\sqrt{L_1 L_2} = 0.7\sqrt{15m \times 35m} = 0.7m\sqrt{3\times7}\times5$
$= 16.039\,mH = 16.04\,mH$

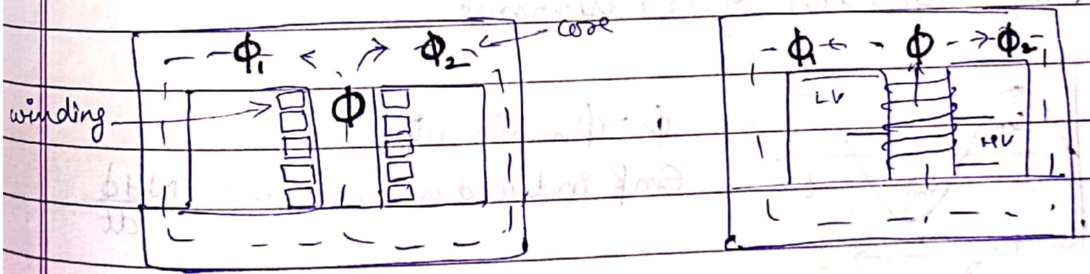
Transformer - It is a static device which converts one form of the energy to the other form.

Construction Type :



1-ϕ core type transformer





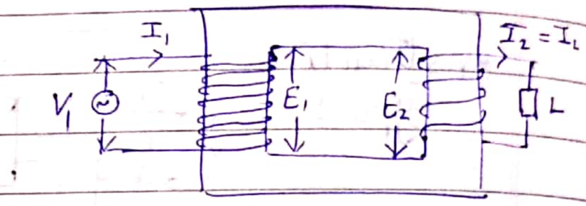
1-ϕ Shell type transformer

Shell type transformer is more protected than the core type transformer. But it has a large heating effect and thus ~~so~~ must be cooled by external agent.

Supply type: (i) 1-ϕ transformer
(ii) 3-ϕ transformer

Rating type : (i) Power transformer – larger
(ii) ~~Simple~~ Distribution transformer

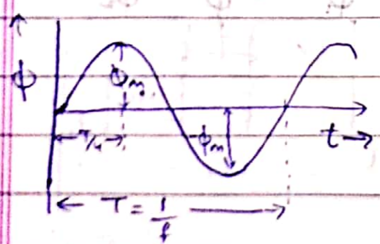
Working of core type transformer – When supply is provided (V_1), current I_1 starts flowing. The alternating current generates flux in the primary winding core. This flux gets linked with the secondary winding through the transformer core



It represents its power as kVA [rating]

Ideal transformer :
(i) $R_1 = 0$ (ii) $\mu = \infty$ (no magnetic flux leakage)
(iii) No losses in winding or core. $\Rightarrow \eta = 100\%$

32.6 Emf equation of transformer



$\phi = \phi_m \sin \omega t$

Emf induced in coil $e = -N \frac{d\phi}{dt}$

$$e = -N \frac{d}{dt}(\phi_m \sin \omega t) = -N\phi_m \omega \cos \omega t$$

$$e = N\omega\phi_m \sin(\omega t - \frac{\pi}{2})$$

$$\therefore e = E_m \sin(\omega t - \frac{\pi}{2}) \qquad E_m = N\omega\phi_m = \text{max. emf}$$

$$E_{rms} = \frac{E_m}{\sqrt{2}} = \frac{N}{\sqrt{2}}\omega\phi_m = \frac{N(2\pi f)\phi_m}{\sqrt{2}}$$

$$E_{rms} = \sqrt{2} N \pi f \phi_m \Rightarrow \boxed{E_{rms} = 4.44 f \phi_m N}$$

This is called emf equation of transformer

$\Rightarrow E_1 = 4.44 f \phi N_1$

$E_2 = 4.44 f \phi N_2$

Transformation ratio (K)

Voltage transformation ratio $K = \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$

$\cancel{\frac{E_1}{E_2} = \frac{N_1}{N_2} = K = \frac{I_2}{I_1}}$

Q. A 50 kVA, single phase transformer has 600 turns in primary and 40 turns in secondary. The primary winding is connected to 2.2 kV, 50 Hz supply. Determine (i) E_2, (ii) I_1 & I_2 at full load.

(i) $\frac{E_1}{E_2} = \frac{N_1}{N_2} \Rightarrow E_2 = \frac{E_1 N_2}{N_1} = \frac{2.2kV\,(40)}{15(600)} = \frac{2200}{15} V = 146.67 V$

(ii) $P = V_1 I_1 \Rightarrow I_1 = \frac{P}{V_1} = \frac{50 kVA}{\cancel{220}\; 2.2kV} = \frac{500}{22} A = 22.72 A$

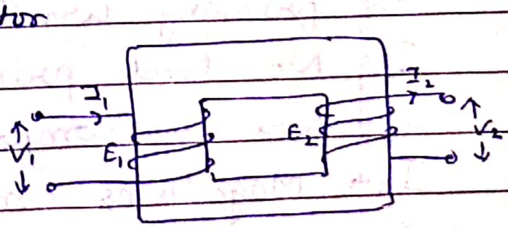
$I_2 = \frac{P_{full\ load}}{V_2} = \frac{50kVA}{2.2kV} \times 15 = \frac{500 \times 15}{22} A = 340.9 A = 341 A$

Phasor diagram of Ideal transformer

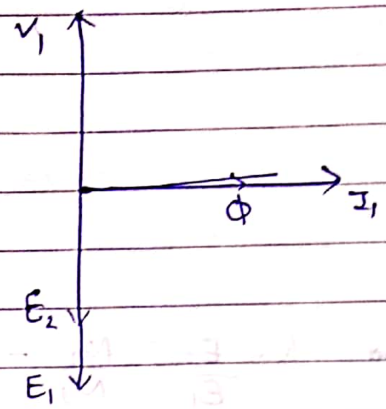
Ideal → $R=0$, $X=0$ → pure inductor

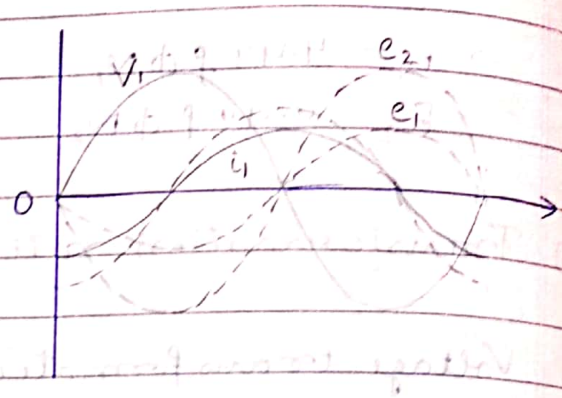
$V_1 \Rightarrow L_1$, $R_1 = 0$

$\phi = \frac{N_1 I_1}{R_1}$

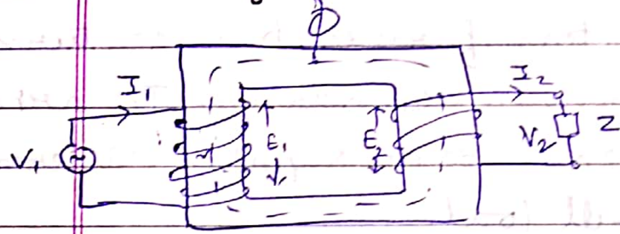


$E_1 = -N_1 \frac{d\phi}{dt}$ $\quad E_2 = -N_2 \frac{d\phi}{dt}$



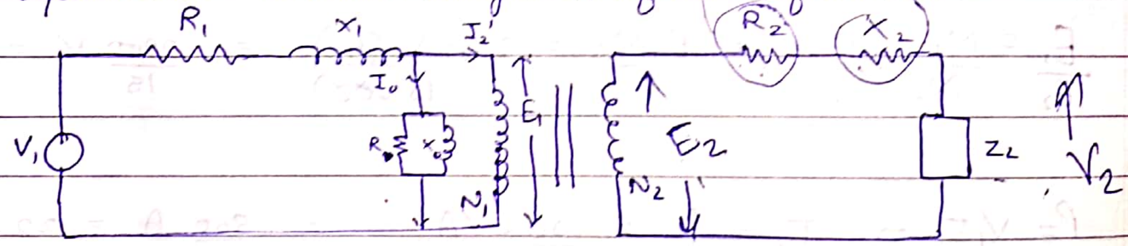


32.10 Transformer On Load



$R + jX_L$

Equivalent circuit diagram of transformer

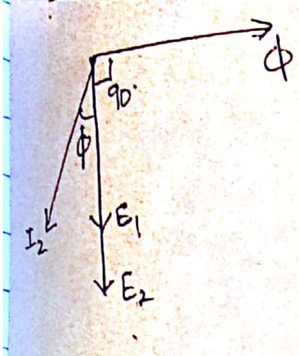


At load, $I_1 = I_0 + I_2'$

$R_1 \rightarrow$ primary winding resistance
$N_1 \rightarrow$ primary turns $\quad$ $N_2 \rightarrow$ secondary turns
$V_1 \rightarrow$ primary / supplied voltage.
$I_1 \rightarrow$ current in primary winding
$X_1 \rightarrow$ primary winding leakage reactance
$I_0 \rightarrow$ No load primary current
$I_c \rightarrow$ Core loss component of no load primary current
$I_\mu \rightarrow$ Magnetising component of I_1
$R_2 \rightarrow$ secondary winding resistance
$V_2 \rightarrow$ secondary voltage
$R_c \rightarrow$ Resistance

$E_1 \rightarrow$ primary induced emf
$E_2 \rightarrow$ secondary induced emf
$X_2 \rightarrow$ secondary leakage reactance / magnetizing reactance
$I_2' \rightarrow$ component of I_1 to nullify effect of ϕ_2

Phasor diagram of 1-ϕ transformer on load

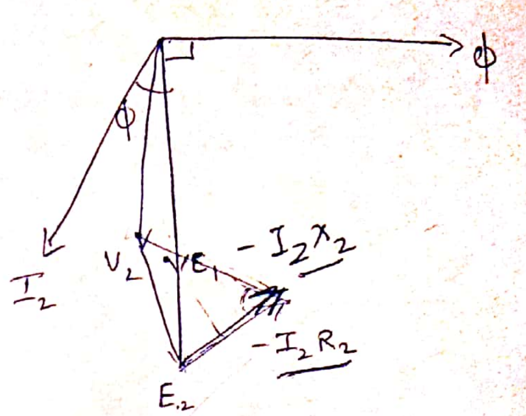


$$\vec{I_1} = \vec{I_0} + \vec{I_2'}$$

$$\vec{I_0} = \vec{I_c} + \vec{I_\mu}$$

$$V_2 = E_2 - I_2R_2 - I_2X_2$$

$$V_1 = -E_1 + I_1R_1 + I_1X_1$$



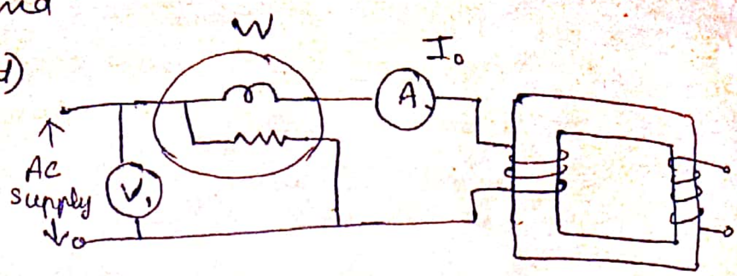
~~los~~

losses in transformer

1. Cu loss $\rightarrow$ These losses occur in primary winding and secondary winding.
2. Core loss $\rightarrow$ flux leakage

32.20
Open circuit test – If one winding is open, it becomes open circuit test and

$I_1 = I_0$ (5% of total ~~to~~ current)

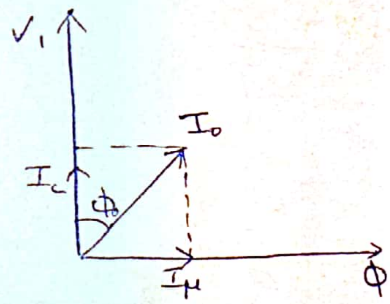


Total loss = Iron + Cu loss

Value of I_0 is very small.
So Cu loss will be small.

Primary winding Cu loss = $I_1^2 R_1 + I_2^2 R_2$ ~~and~~ which will be very small. So the total losses in open circuit test will be equal to iron core losses.

(a) To know iron losses
(b) H.V. winding kept open.
(c) L.V. is connected with supply voltmeter, ammeter and wattmeter. $W = V_1 I_0 \cos\phi$



Iron losses = $W - I_0^2 R_0$

W → wattmeter reading (active power)

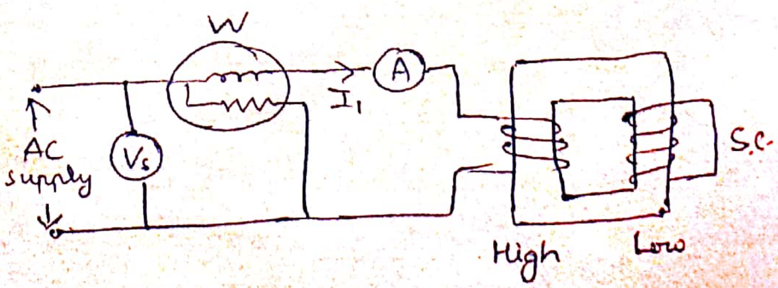
$\cos\phi_0 = \frac{W}{V_1 I_0}$ $\quad R_0 = \frac{V_1}{I_w} = \frac{V_1}{I_0 \cos\phi_0}$

Resistive component $I_c = I_0 \cos\phi$

Magnetising component $I_\mu = I_0 \sin\phi$

32.22
Short circuit test – To know Cu losses [Impedance test]

(a) Secondary winding is short circuited
(b) H.V. is connected with supply, voltmeter, ammeter at wattmeter



(c) L.V. is short circuited. It is never reversed.

$Z_{01} = \frac{V_{sc}}{I_1}$ $\quad W = I_1^2 R_{01}$

Z_{01} → combined impedance of primary & secondary winding over short circuit.

$R_{01} = \frac{W}{I_1^2}$

$X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$

Q. A 330/660, 8kVA, 50 Hz 1-ϕ transformer has full load ~~open~~ copper loss of 90 W. If it has an efficiency of 98% at full load unity power factor. Determine the core losses. What would be the efficiency of transformer at half load. 0.85 pf lagging?

A. ~~$K = \frac{330}{660} = 0.5$ $S = 8kVA$ Active power = $8kVA \times \cos\phi = 8kW$~~

~~Cu loss $W = 90W$ $\eta = 98\%$ $\cos\phi = 1$.~~

~~core losses = $W - I_0^2 R_0$~~

~~$= 2\%$ of $8kVA - 90W = \frac{160}{\cancel{98}} \times \cancel{8000} - 90 = 70W$~~

~~At half load, Power = 4kVA~~

~~$\cos\phi_0 = \frac{W}{V_1 I_0} = 0.85 = \frac{W}{4kVA}$~~

~~$\Rightarrow W = 0.85 \times 4000 = 3400$~~

~~$\eta = 1 - \frac{W}{4kV} = 1 - \frac{3.4}{4} = 15\%$~~

When the load value is changed only current value gets affected

$\Rightarrow$ At half load, $I' = \frac{I}{2}$

A. (a) $\eta = \frac{O/P}{I/P} \Rightarrow I/P = \frac{O/P}{\eta} = \frac{8kVA \times \cos\phi}{98\%}$

$I/P = \frac{8kW \times 1}{0.98} = 8.16\ kW$.

Total losses = $I/P - O/P = 8.16\ kW - 8kW = 160W$

Iron losses = Total losses − Cu losses = 160 − 90 = 70W

(b) $O/P = 8kVA \times \cos\phi = 6.8kW$

at half load, $O/P = \frac{1}{2}(6.8kW) = 3.4kW$

Iron losses are not affected by current change. So

Iron losses = 70 W at half load

Copper losses in half load = $\left(\frac{I}{2}\right)^2 \times$ Cu loss at full load

$= \frac{90}{4} =$

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$$\eta = \frac{\text{output}}{\text{output} + \text{losses}} = \frac{3.4\,kW}{3.4\,kW + 92.5\,W} = \frac{3400}{3492.5} = 0.9735$$

$= 97.35\%$

Chapter-10 Electrical Instruments and measurements

Measurement – It is a process to know unknown quantity in terms of known standards.

Measuring Instrument - voltmeter, ammeter, wattmeter etc.

Instrumentation – The process which we undergo to take the measurement

Classification of Measuring Instrument

- Function
  - indicating
  - integrating
  - Recording
- Type of Impact
  - Digital
  - Analog
- Type
  - moving coil
  - moving iron
- Deflection based design
  - Absolute
  - Secondary

indicating – ammeter, wattmeter, multimeter
integrating – summation –, energy meter, odometer
Recording – CRO , ECG

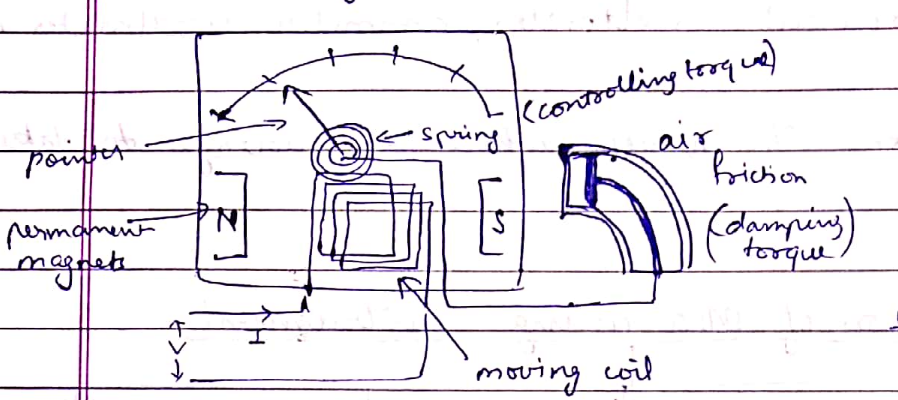
Effect	Instrument utilize the effect
Magnetic	Voltmeter, Ammeter and Wattmeter
Heating	AC and DC ammeters & voltmeter
EMI	I, V, W
Electrostatic	Voltmeter, indirect application in ammeter and wattmeter.

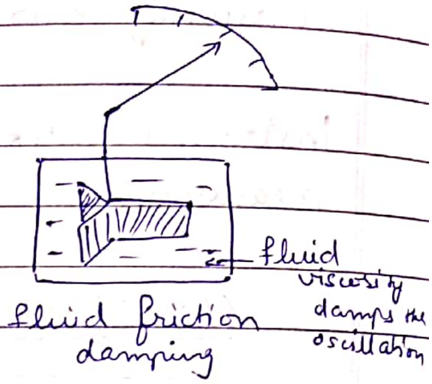
10.3 Analog instruments
10.4 Different torque
T_d) Deflection Torque $\propto$ unknown quantity (V, I or other)

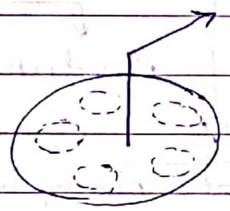
10.5 T_c 2) Controlling torque – spring, weight (gravity)

10.6 3) Damping torque – stability to pointer fluctuation / oscillation

At the right point $T_d = T_c$

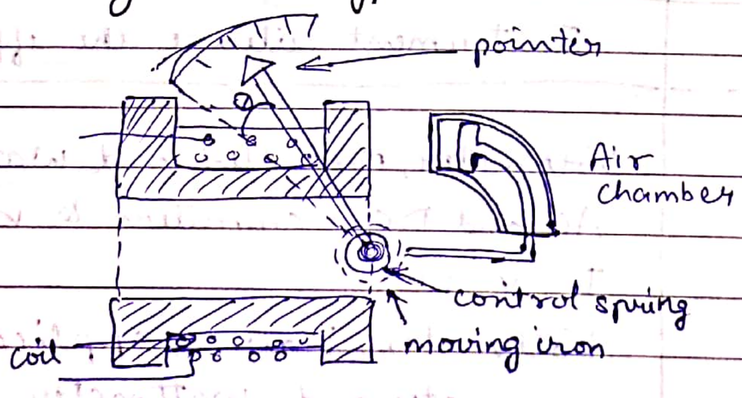






eddy current damping
(mechanical damping)

10.7 Moving iron type



Attraction type moving iron.

$F \alpha mH$ $m \rightarrow$ developed pole strength.

Now $m \alpha i$ $H \rightarrow$ field produced

$m = ia$ $F \rightarrow$ force pulling soft iron piece

$H \alpha i$.

$\Rightarrow F \alpha i^2$

$\Rightarrow$ Deflection torque $T_d = i^2$

Controlling torque $t_c = \theta$ [spring control.]

At equilibrium, $T_d = t_c \Rightarrow \theta = i^2$

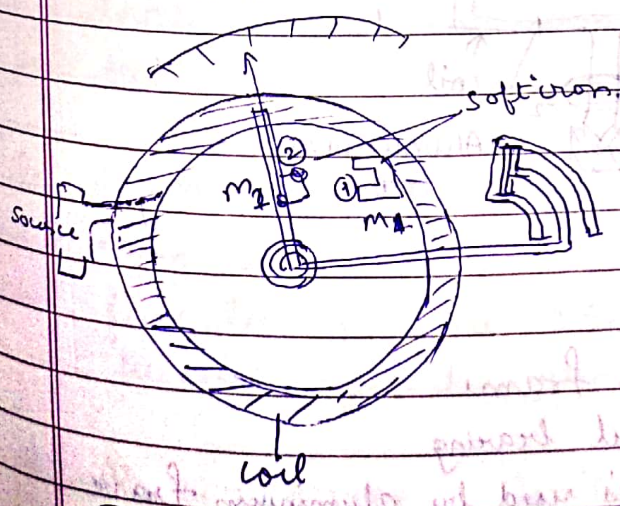
Since $i = \sqrt{\theta} \Rightarrow$ The scale is not linear

Advantages -

1. It is less expensive, robust, easy maintainance and simple in construction
2. It can be used to measure AC and DC both
3. It gives torque/weight ratio

Disadvantage -

1. Non-uniform scale
2. Not sensitive as PMMC instrument.
3. Affected by stray magnetic field
4. Degree of precision of calibration is not high.



Repulsion type moving iron instrument

$t_d \propto m_1 m_2 \propto i^2$

$t_d = i^2$, $t_c = \theta$

$\Rightarrow$ At equilibrium $\theta = i^2$

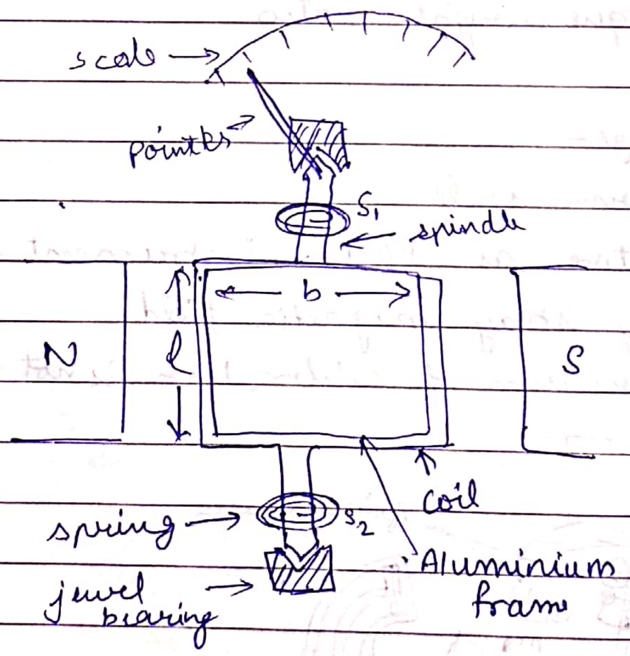
Advantages-

1. It is less expensive, simple construction
2. Can be used for AC and DC both
3.

Disadvantage

1. Non uniform scale
2. Less sensitive than PMMC type

10.15 Moving Coil type.



1. Coil has no. of Turns
2. Rectangular aluminium frame
3. Coil is pivoted upon jewel bearing
4. Eddy current damping is used by aluminium frame

B → flux density in air gap (T)

$N \rightarrow$ no. of turns in the coil
$i \rightarrow$ current in the coil
$l \rightarrow$ length of the coil
$b \rightarrow$ breadth of the coil
$A \rightarrow$ Area $(= l \times b)$
$k_s \rightarrow$ spring constant
$\theta \rightarrow$ deflection

$F = NBil$

$T_d \propto F \propto$ prependicular distance (Nm)

$T_d = N i B l \times b = N i B A = \cancel{B} k_b i$ $\quad k_b = NBA$

$T_c = k_s \theta$

At equilibrium $\quad T_d = T_c \Rightarrow k_b i = k_s \theta \Rightarrow \theta = k i$

Advantages
(i) reduced size
(ii) linear scale
(iii) more sensitivity
(iv) electrical damping is advantageous
(iv) less power consumtion
(v) lesser losses
(vi) very accurate & reliable.

Disadvantage
(i) can not measure AC

Application – DC Ammeter, voltmeter, galvanometer, ballistic galvanometer, multimeter

Q. A PMMC instrument has 40 turn coil with Al frame 18mm wide & 25mm effective length. It moves in 0.6T flux density. $K_s = 2.5 \times 10^{-6}$ Nm/degree. Calculate the current required to produce a deflection of 110° degrees

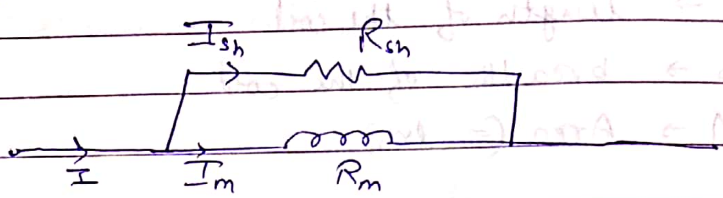
A. At equilibrium $\quad T_d = T_c \Rightarrow K_s \theta = BiNA$

$$i = \frac{K_s \theta}{BNlb} = \frac{2.5 \times 10^{-6} \text{ Nm/degree} \times 110^\circ \text{ degree}}{0.6\,T \times 40 \times 18 \times 25 \times 10^{-6} \text{ m}^2}$$

$= 0.02$ A

10.17 Range extension :

Shunt – Range extension of ammeter



$R_m \rightarrow$ resistance of meter $R_{sh} \rightarrow$ Resistance of shunt
$I_m \rightarrow$ Current through meter $I_{sh} \rightarrow$ Current through shunt
$I \rightarrow$ Current to be measured.

A Low shunt resistance connected in parallel with the ammeter to extend the range of current. Large current can be measured using low current rated ammeter by using a shunt.

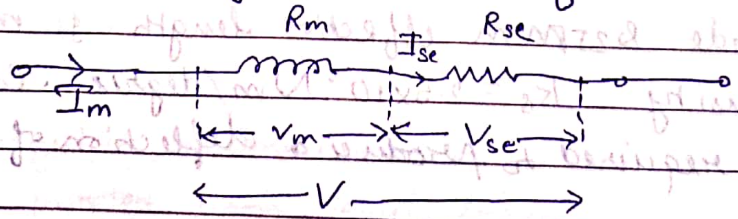
Now $V_m = V_{sh} \Rightarrow I_m R_m = I_{sh} R_{sh}$

$$\frac{I_m}{I_{sH}} = \frac{R_{sH}}{R_m}$$

$$I = I_m + I_{sh} \Rightarrow \frac{I}{I_m} = 1 + \frac{I_{sh}}{I_m}$$

$$\frac{I}{I_m} = 1 + \frac{R_m}{R_{sh}} \Rightarrow I = I_m \underbrace{\left(1 + \frac{R_m}{R_{sh}}\right)}_{\text{multiplication factor}}$$

Multiplier – Range extension of voltmeter



$$I_m = I_{se} \Rightarrow \frac{V_m}{R_m} = \frac{V_{se}}{R_{se}}$$

$$V = V_m + V_{se} \Rightarrow \frac{V}{V_m} = 1 + \frac{V_{se}}{V_m} = 1 + \frac{R_{se}}{R_m}$$

$$\Rightarrow \quad V = V_m \left(1 + \frac{R_{se}}{R_m}\right)$$

Q. A moving coil instrument has a resistance of 75 Ω and gives full scale deflection when carrying a current of 35mA. Show how it can be adopted to measure
(i) current upto 80 A
(ii) voltage upto 550 V.

A. (i) To extend the range of current, we will use a shunt in parallel to the instrument. For, this

$$I = I_m \left(1 + \frac{R_m}{R_{sh}}\right)$$

$$\Rightarrow \cancel{35m}\ 80 = 35m\left(1 + \frac{75}{R_{sh}}\right)$$

$$\Rightarrow \frac{80000}{35} = 1 + \frac{75}{R_{sh}} \qquad \Rightarrow \frac{75}{R_{sh}} = \frac{80000}{35} - 1 = 2284.714$$

$$\Rightarrow R_{sh} = \frac{75}{2284.714} = \cancel{0.3287\,\Omega} \quad = \cancel{328.7\,m\Omega}$$

$$= 0.0328\,\Omega$$

(ii) To extend the range of voltage, we will use a multiplier in series with the instrument.

$$V = V_m \left(1 + \frac{R_{se}}{R_m}\right)$$

$$\overset{22}{\cancel{550}} = (35m)(\overset{3}{\cancel{75}})\left[1 + \frac{R_{se}}{75}\right]$$

$$\left(1 + \frac{R_{se}}{75}\right) = \frac{22000}{35 \times 3} = \cancel{0.2093}\ 209.523$$

$$\frac{R_{se}}{75} = 208.523$$

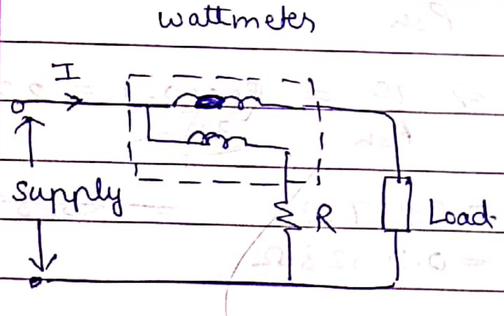
$$R_{se} = 15639.22\,\Omega$$

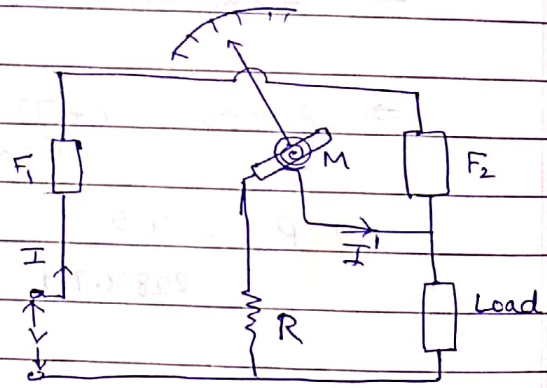
Measurement of power

DC power $P_{DC} = V_L I_L$
AC power $P_{LAC} = V_L I_L \cos\phi$

Two types of wattmeter –
(i) Dynamometer wattmeter → a.c. & d.c power measure
(ii) Induction type wattmeter → AC power.

10.37 Dynamometer wattmeter
Moving coil dynamometer and voltmeter
⇒ mechanical force exists between two current carrying conductor or coil





EMMC → electro magnetic moving coil.
F_1, F_2 → Air core fixed coils
M → moving coil
F_1, F_2 produce field & M moves & provides deflection Torque. Spring provides controlling ~~frict~~ Torque. Air friction provides damping torque

DC measurement –
I → Current coil or fixed coil → B (Wb/m²)
I' → current through pressure coil
$V \propto I'$

$T_d \propto BI \Rightarrow T_d \propto IV \Rightarrow T_d = kVI$

AC measurement-

$T_d = kVi$, $\quad V = V \sin\theta$, $\quad i = I_m \sin(\theta - \phi)$

$$\Rightarrow T_{d(mean)} = \frac{kV_m i_m}{2\pi} \int_0^{2\pi} \sin\theta \sin(\theta-\phi)\, d\theta$$

$$= \frac{kV_m I_m}{4\pi} \int_0^{2\pi} [\cos\phi - \cos(2\theta-\phi)]\, d\theta$$

$$= \frac{kV_m i_m}{4\pi} [(2\pi - 0)\cos\phi + 0] = \frac{kV_m i_m}{2} \cos\phi$$

$T_d = k V_{rms} I_{rms} \cos\phi$

$T_c = k\theta$ $\quad$ [Spring control]

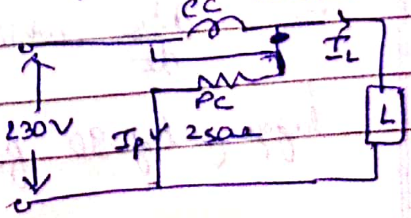
At equilibrium, $T_d = T_c \Rightarrow \theta \propto \underbrace{V_{rms} I_{rms} \cos\phi = P}_{\text{load power}}$

Wattmeter will always measure active power $\theta \propto P$
Thus, it has a uniform scale.

Advantages- 1. Uniform scale
2. higher accuracy
3. Can be used for both ac & dc measurement
4. It can be used for calibration and standard.

Disadvantages- 1. Expensive

Q. The pressure coil of wattmeter has a resistance of 250Ω. The wattmeter is connected across a load. Determine the actual load if wattmeter reading is 350W. Assume load voltage equal to 230V.

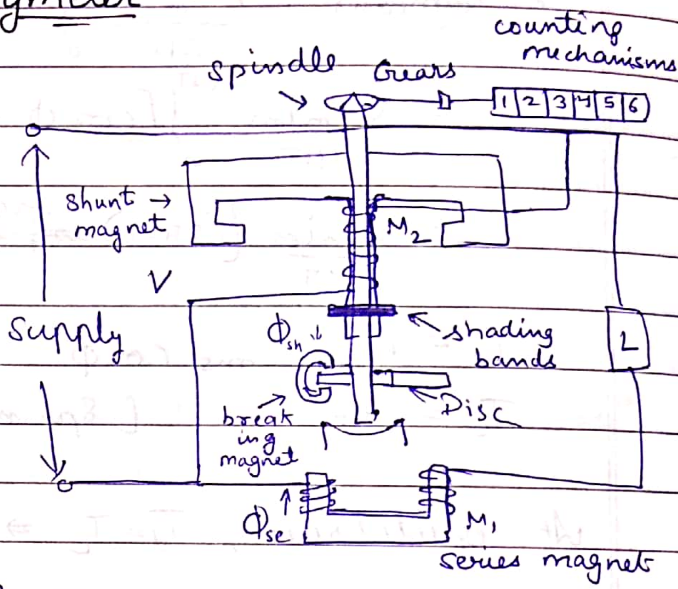


A. $I_p = \frac{V}{R_p} = \frac{230}{250} = 0.92\,A$

$W_p = VI = 230 \times 0.92 = 211.6\ W$

load power $= 350W - W_p = \boxed{138.4\ W}$

Induction type Energymeter



Deflection torque is produced by eddy currents and mutual induction.

Breaking ~~Controlling~~ torque is produced by the braking magnet. But it does not bring the pointer to zero.

Shading band is a Cu band to produce phase difference in flux. It is used to adjust flux in M_2 magnet lag by V at 90°.

~~Bo~~ M_1 and M_2 are silicon-steel laminated electromagnet. Disc is of Al. Torque is proportional to eddy current induced in disc.

V is connected with pressure coil

∴ I is connected with current coil.

$V \rightarrow \phi_{sh} - M_2 \rightarrow 90°$ (Due to shading bands)

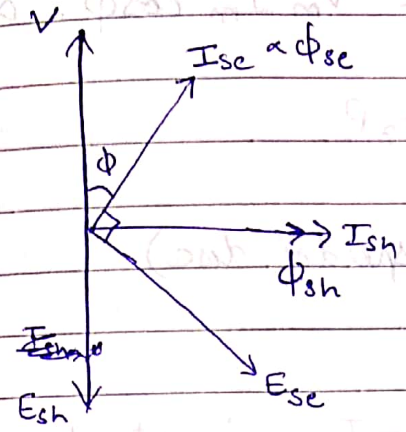
$E_{sh} = -\frac{d\phi_{sh}}{dt}$ which will produce current. (eddy current)

↓

lagging by 90° from ϕ_{sh}

In series magnet, current and flux will be in phase but

$e = -\frac{d\phi_{se}}{dt}$ ⇒ E is 90° apart from ϕ_{se}.



$V = V_m \sin\omega t$

$i = I_m \sin(\omega t - \phi)$

$\phi_{se} \propto i \propto I_m \sin(\omega t - \phi)$

$E_{se} \propto -\frac{d\phi_{se}}{dt} \propto -I_m \omega \cos(\omega t - \phi)$

Considering series eddy current $\boxed{i_{se} \propto -I_m \omega \cos(\omega t - \phi)}$

Now, $\phi_{sh} \propto -\int V dt \propto -\int V_m \sin\omega t \, dt$

$\propto \frac{V_m}{\omega} \cos\omega t$.

$E_{sh} \propto -\frac{d\phi_{sh}}{dt} \propto -V_m \sin\omega t$

$\boxed{i_{sh} \propto -V_m \sin\omega t}$

If we assume eddy current path is purely resistive having a value R.

$i_{se} \propto \frac{E_{se}}{R}$, $I_{se} = k_1 \frac{E_{se}}{R}$

$i_{se} = -\frac{k_1}{R} I_m \omega \cos(\omega t - \phi)$

$i_{sh} = k_2 \frac{E_{sh}}{R}$ ⇒ $i_{sh} = -\frac{k_2 V_m}{R} \sin\omega t$

$\tau \propto \phi_{sh} i_{se} - \phi_{se} i_{sh}$

⇒ $\tau \propto \frac{k_2 V_m}{\omega} \times \frac{k_1 I_m \omega}{R} \cos\omega t \cos(\omega t - \phi)$

$+ \frac{k_1 I_m k_2 V_m}{R} \sin\omega t \sin(\omega t - \phi)$

$\Rightarrow \tau_d \propto \frac{k_1 k_2}{R} V_m I_m \cos\phi$

Thus, we get $T_d \propto V_m I_m \cos\phi, \propto \underset{\text{Power consumed}}{P}$

$\Rightarrow T_D \propto P \Rightarrow T_D = k_3 P$

$T_{Breaking} = T_B \propto n$ (speed of disc)

$T_B = k_4 n.$

At equilibrium $T_D = T_B$ i.e. at steady state of rotation.

$\Rightarrow k_4 n = k_3 P$

$k_4 n dt = k_3 P dt.$

$$\int_0^t n\,dt = \frac{k_3}{k_4} \int_0^t P\,dt$$

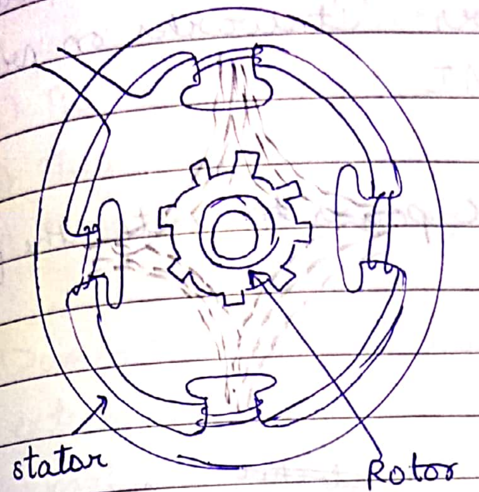
No. of revolution made by disc in time t $= k \times$ energy consumed in time t.

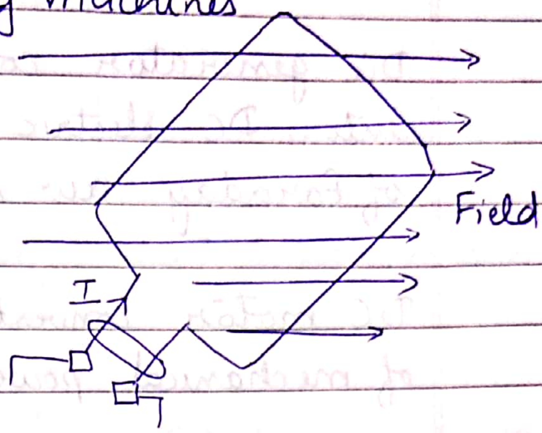
Electrical Machines

Rotating Machines -

General parts of rotating machines

I





Silicon steel

Stator and rotor are made of same material.
Rotor rotates in the field (flux pressure) of the ~~stat~~ stator coil.

II Air gap. - It separates stator and rotor (to avoid friction b/w the two). It needs to be small as it reduces power factor

III Two windings - Armature winding & Field winding.
Field winding produces flux/field (which can also be created by permanent magnet)
Armature winding rotates in the field

IV AC current in armature winding.

V Ventilating Ducts.

Rotating Machines

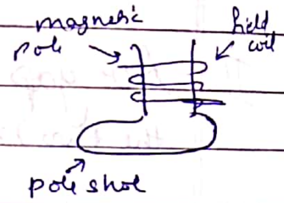
- DC Machines
  - DC generator
  - DC motor
- AC machines
  - Synchronous
    - generator
    - motor
  - Asynchronous (Induction)
    - motor
      - squirrel cage
      - slip ring type
    - generator

D.C Machines - These work on DC

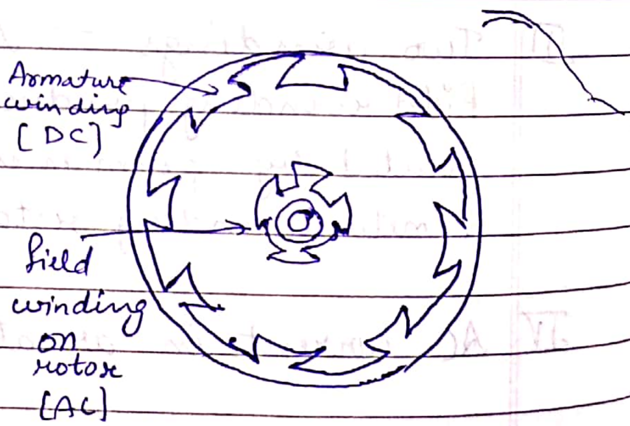
DC generator converts the mechanical power into DC electric power. It works on principle of Faraday law of EMI.

DC motor converts DC power ~~to~~ into the form of mechanical power.

Parts of DC machine -
1. Yoke - the body
2. Magnetic pole or field coils ~~pole shoe~~ Cu (field coil) - on which wire is wound
3. Armature core and armature winding
4. Commutator - terminal changer (converter)
5. Brushes (carbon)
6. Shaft bearing, pulley, fan.
7. pole shoe → uniform flux distribution



Synchronous machine



Doubly excited → stator
→ rotor

synchronous speed N_s

$$N_s = \frac{120 f}{P}$$

f → supply freq. in Hz
P → no. of poles

Generator - Power house 500 MVA
Motor (large size) - In industry as phase advancers
a) lagging current b) leading current

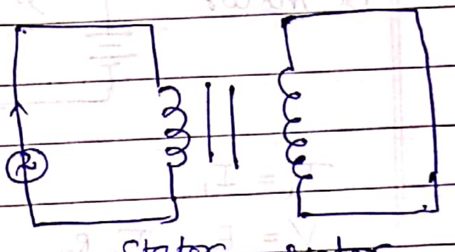
It is normally not used in industrial sector. But it has an advantage of power factor.

Merits - 1) It is used for power factor improvement
2) The speed is constant & independent of load.
3) They are better mechanically than induction motor.
4) They operate at high efficiency

Demerits - 1) DC excitation for rotor requires a separate external source.
2) Variable speed control is not possible.
3) Cost /kW output is higher
4) Motor is not self starting.

Induction ~~machine~~ motor

conductor winding is shorted. Current is induced in it which is high. Torque is applied on the rotor winding.



DC Motor - When DC electric power is fetched to this machine, then it convert into the form of mechanical power.

Emf equation -
$\phi \to$ flux linked with each pole.
$Z \to$ total no. of armature conductors.
$P \to$ no. of poles
$A \to$ no. of parallel path in which conductor are distributed
$N \to$ speed of armature in ~~sp~~ rpm.

$E_g \rightarrow$ generator emf

Then, total flux = flux produced by each pole × no. of poles

$\Rightarrow d\phi = P\phi$

Time taken to complete one revolution by a conductor in sec

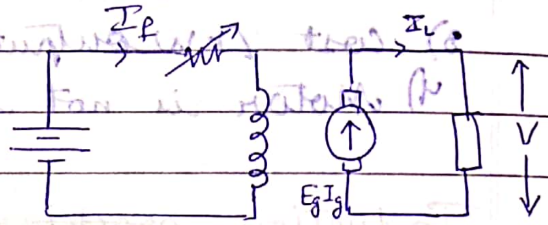
$dt = 60/N$

$e = \frac{d\phi}{dt} = \cancel{P\phi}$ emf/conductor × $\frac{\text{Total no. of armature}}{\text{no. of }\parallel\text{ path}}$

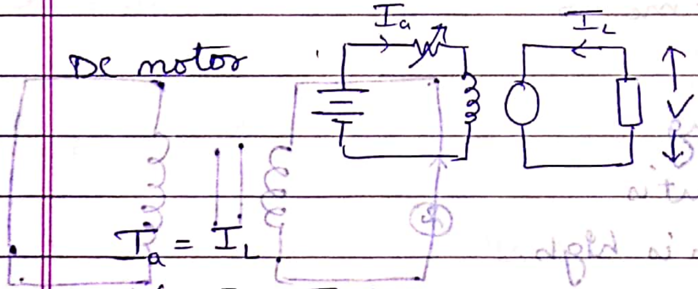
$= \frac{P\phi}{60/N} \times \frac{Z}{A} \Rightarrow \boxed{e = \frac{P\phi N Z}{60 \cdot A}}$

Types of DC Generator

Self excited → series type,
shunt type.



DC motor



current direction changes. Field winding & armature winding are separated from each other

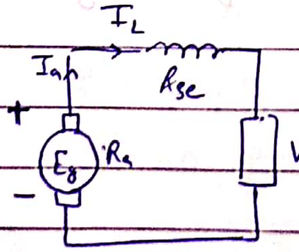
$I_a = I_L$

$V = E_g - I_a R_a$

electric power output $= V I_a$

Power generated $= E_g I_a$

Power at load $= E_g I_a - \underbrace{I_a^2 R_a}_{\text{lost power}}$



Series type

It is self excited machine. Field winding is connected in series with armature winding

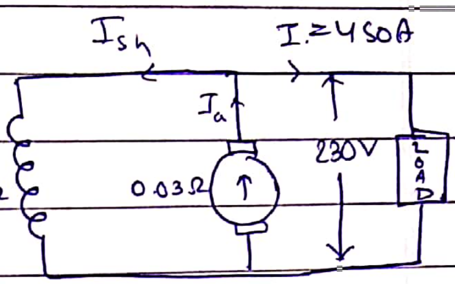
Power developed $= E_g I_a$

Output power $= E_g - I_a (R_a + R_{se})$

$I_a = I_{se} = I_L = I$

$\Rightarrow V = E_g - I_a R_a - I_a R_{se}$

Q. A shunt generator ~~develops~~ delivers 450A at 230V and ~~armature are 50Ω are~~ the resistance of shunt field and armature are 50Ω and 0.03Ω respectively. Calculate the generated emf.



A. $I_{sh} = \frac{230V}{50\Omega} = 4.6A$

Load current $I = 450A$

$\Rightarrow I_a = I + I_{sh} = 454.6A$

$E_g = V + I_aR_a = 230V + (454.6)(0.03) = 230 + 13.6$

$\boxed{E_g = 243.6V}$

MEASURING INSTRUMENTS

TERMINOLOGY

1. **Measurement**: is a process to know unknown quantities in terms of known standards.

2. **Measuring Instrument**: Tools which are used for the purpose of measurement.

3. **Instrumentation**: Technology used for measurement

Classification of Measuring Instruments

- Function
  - Indicating
  - Integrating
  - Recording
- Type of Input
  - Digital
  - Analog
- Deflection
  - Absolute
  - Secondary

Effect	Instrument utilizing the effect
Magnetic	Voltmeter, Ammeter & wattmeter
Heating	AC & DC ammeter & voltmeter
E.M.I.	Voltmeter, Ammeter & wattmeter
Electrostatics	voltmeter, indirect application in Ammeter & wattmeter.

Page No.:

I On the basis of Function:

1. Indicating Instruments
The value of electrical quantity is indicated at the time when it is being measured.
Pointers moving over the scale give indication.
Eg: ammeters, voltmeters & wattmeters.

2. Recording Instruments
A continuous record of variations of the electrical qty. over a long period of time is given by these instrument
It has a moving system which carries an inked pen which rests tightly on a graph chart.
Eg: Graphic recorders, galvanometers, etc.

3. Integrating Instruments
The total amount of electricity or electrical energy supplied over a period of time is measured.
Eg: Ampere-hour meters, energy meters.

II On the basis of Deflection:

1. Absolute Instruments
Gives the value of the quantity to be measured in terms of the constants of the instrument and their deflection only.
Eg: tangent galvanometer
↓
gives value of I in terms of tangent of deflection produced, no. of turns + radius of wire used & horizontal component of earth's mag. field.

NOTE: No previous calibration is required in this case.

Page No.:

2. Secondary Instruments
The value of electrical qty. to be measured is determined from the deflection of these instruments
Eg: ammeter, voltmeter, etc.
Pre-calibrated with absolute instruments.

On the basis of Type of Input

1. Digital
2. Analog

Essentials of Indicating Instruments:

Indicating instruments consist of a pointer which moves over a calibrated scale and which is attached to a moving system pivoted in jewelled bearings.
The moving system is subjected to these 3 torques:

(a) Deflecting / Operating Torque (T_d): Produced by utilizing any of the effects in table 3·1. It causes movement of the pointer.

(b) Controlling / Restoring Torque (T_c): Opposes the deflection torque & increases the deflection of the moving system of instrument. The pointer is brought to rest at a position where the two opposing torques are equal
In the absence of restoring torque, the pointer once deflected will not return to its original position
It is obtained either by

(i) Spring control (ii) Gravity

Instrument Type

- Moving coil Type
- Moving Iron Type
  - Attraction Type
  - Repulsion Type

(i) Spring control:

A hair-spring, usually of phosphor-bronze, is attached to the moving system of the instrument.

with the deflection of the pointer, the spring is twisted in the opposite direction.

This twist in the spring produces restoring torque

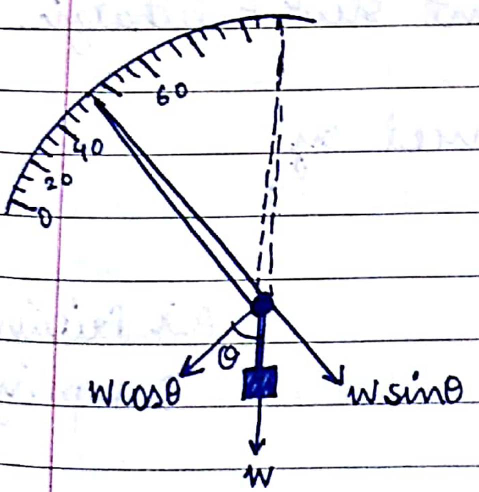
$T_c \propto \theta$.

(ii) Gravity Control

A small adjustable weight is attached to some part of the moving system such that the 2 exert torques in the opposite direction.

$T_D \propto I$

$T_c \propto \sin\theta$. $\Rightarrow I \propto \sin\theta$



The degree of control is adjusted by screwing the weight up or down the carrying system.

It gives a cramped scale at the lower ends

[$\because$ $I \propto \sin\theta$ and at low value of θ value of $\sin\theta$ is also less]

It is cheap, unaffected by temp. and is not subjected to fatigue or deterioration with time.
The instrument has to be kept vertical.

(c) Damping Torque (Stabilizing Torque)
↓
acts on the moving system of the instrument only when it is in motion
↓
opposes its motion

Such stabilizing force or damping force is necessary to bring the pointer to rest quickly, otherwise due to inertia of the moving system, the pointer will oscillate about its final deflected position for a long time.

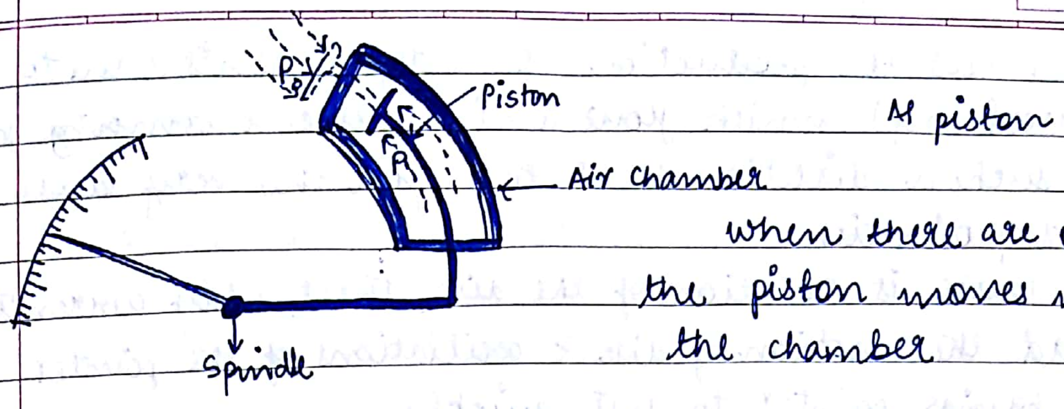
The degree of damping should be adjusted to a value which is sufficient to enable the pointer to rise quickly to its deflected position.

Overdamping makes the instrument slow & lethargic. and is said to be dead beat.
The damping force can be produced by

Liquid Friction Damping OR Fluid Damping

Eddy Current Damping

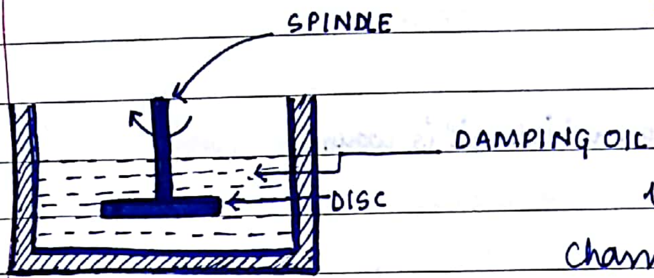
Air Friction Damping



when there are oscillations the piston moves in & out of the chamber

Fluid Friction damping

when piston moves inside the chamber, $P > P_0$; so air opposes the motion of piston & the moving system



when piston moves out of the chamber $P\downarrow$ and $P < P_0$, so again there is an opposition to the motion.

Advantages of fluid friction:

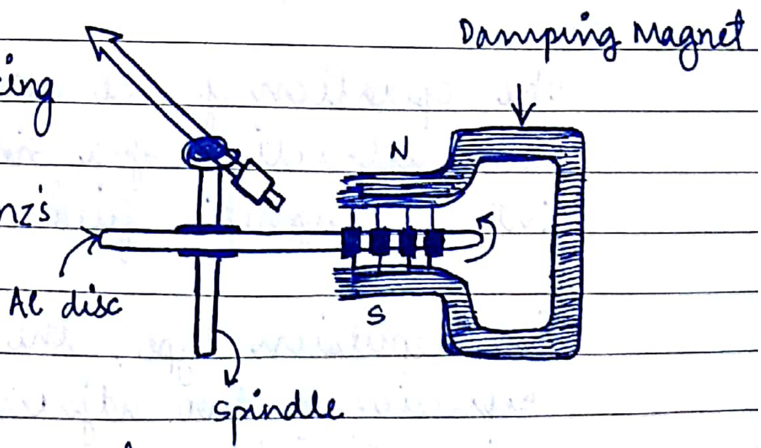
Due to more viscosity of fluid, more damping is provided.
Oil can also be used for insulation purposes.

Disadvantages:

Used only for instruments in vertical position.
Objectionable creeping of oil.

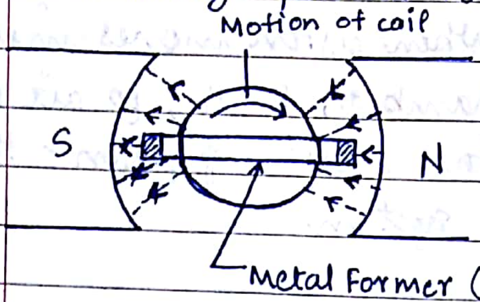
Eddy Current Damping

Most efficient way of producing damping.
Based on Faraday's law & Lenz's law.
When Al disc rotates, it cuts the magnetic flux b/w the poles of a permanent magnet.



This causes the production of eddy currents (due to induced emf) which flow and produce a damping force in such a direction so as to oppose the very cause of its production.

Since, The cause is rotation of the disc, these eddy currents retard the motion of disc & oscillations of the pointer. This brings pointer to rest quickly.



Moving Iron Type
- Attraction
- Repulsion

Hot-wire Type

Moving Coil Type
- Permanent Magnet
- Electrodynamic

Induction Type

Electrostatic
(Voltmeters only).

MOVING IRON INSTRUMENTS
↓
movable part is iron

The operation of the attraction type depends on the attraction of a single piece of soft iron into a magnetic field.

For repulsion type, the operation depends on the repulsion of two adjacent pieces of soft iron magnetised by the same magnetic field.

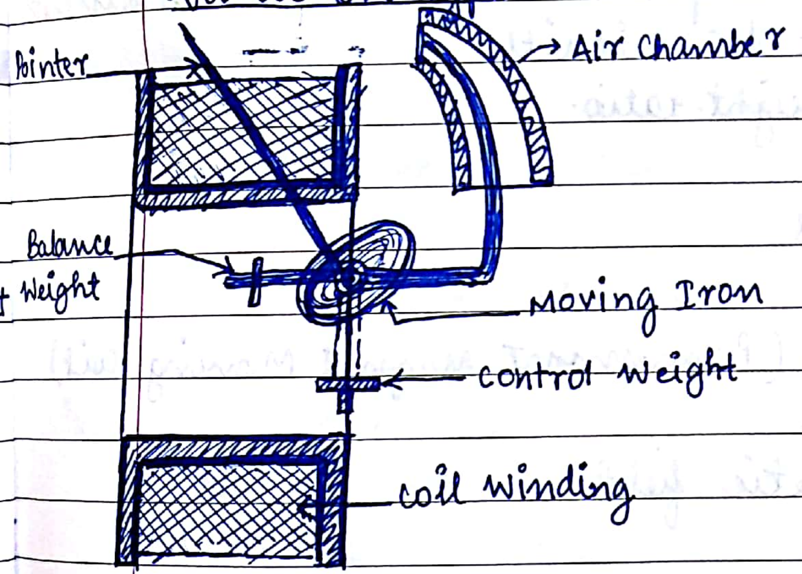
Scanned by CamScanner

The necessary magnetic field is produced by the ampere-turns of a current carrying coil.

For ammeter ⇒ coil has fewer turns of wire so that ammeter has lower resistance since it is connected in series with a circuit.

For voltmeter ⇒ coil has high impedance (large no. of turns) so as to draw as small a current possible since it is connected in ∥ with the circuit.

Attraction Type



Principle

If a piece of an unmagnetised soft iron is brought near a current carrying coil, it would be attracted into the coil.

* An oval-shaped disc of soft-iron is pivoted on a spindle between bearings near the coil, the iron disc will swing into the coil when the latter has an electric current passing through it.

* Whatever the direction of current through the coil be, the iron disc is always magnetised in such a way that it is pulled inwards.

* Therefore, these type of instruments can be used for both d.c. & a.c.

$F \propto mH$

force pulling iron disc

$H \Rightarrow$ field produced

$m \Rightarrow$ developed pole strength

If current i flows through the loop.

$m \propto i \qquad H \propto i$

$F \propto i^2$

$\boxed{T_d \propto i^2} \qquad T_c \propto \theta$

$T_D = T_C$

$\boxed{\theta \propto i^2} \Rightarrow$ Non-uniform scale

Advantages of M.I. instruments

⇒ less expensive, robust & simple in ~~concentration~~ construction

⇒ Can be used for a.c. & d.c. circuits

⇒ Gives high torque to weight ratio.

Disadvantages of M.I. instruments

⇒ Non-uniform scale

⇒ Not sensitive as PMMC (Permanent Magnet Moving coil) instruments

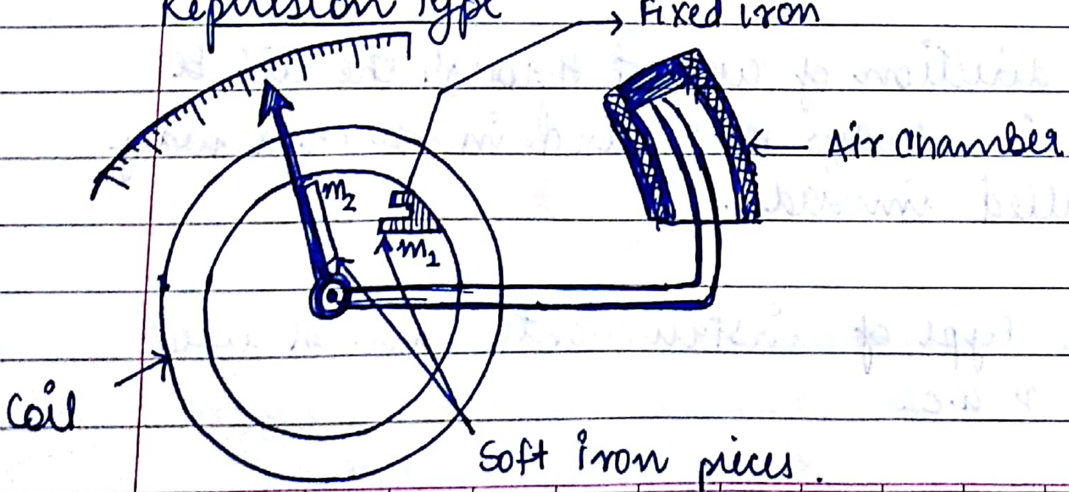
⇒ Affected by stray magnetic field.

⇓

* Due to which instruments in lab are enclosed in a wooden box.

⇒ Degree of precision of calibration is not high.

Repulsion Type



Scanned by CamScanner

It consises of a fixed coil inside which 2 soft iron bars are placed parallel to one another & along the axis of the coil.
when current passes through the coil, it generates its own magnetic field which magnetizes the rods similary and they start to repel.

$$T_D \propto m_1 m_2 \propto i^2$$

$$T_C = \theta$$

$$\boxed{\theta \propto i^2}.$$

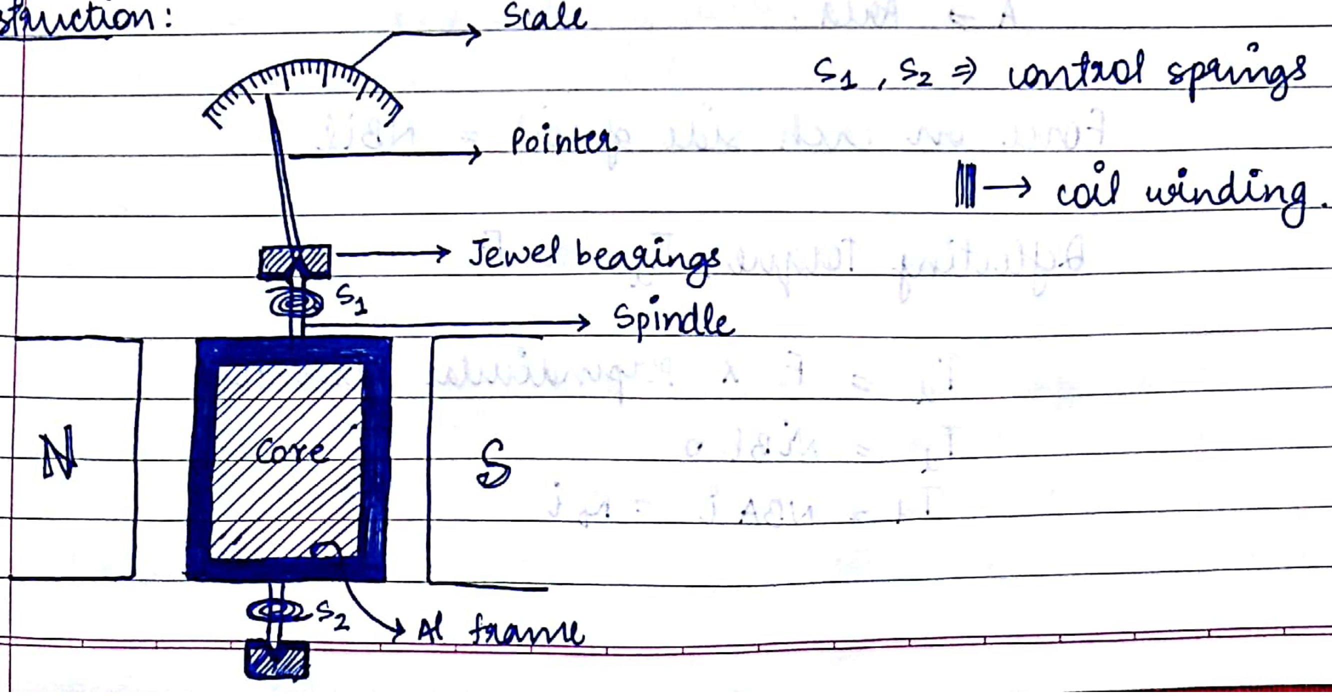
MOVING COIL INSTRUMENTS

→ Permanent-Magnet Moving coil (PMMC).
→ Dynamometer type

I. Permanent Magnet Type Instrument

Principle: when a current-carrying conductor is placed in a magnetic field, it is acted upon by a force which tends to move it to one side and out of the field.

Construction:



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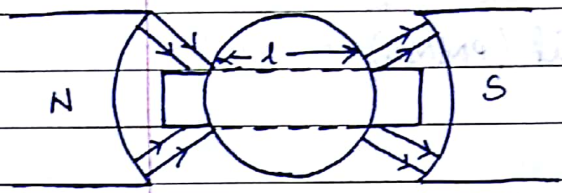
* A rectangular coil of many turns wound on a light Al or copper frame inside which is an iron core.

* Soft-iron cylinder is fixed b/w the poles
→ to make field radial & uniform
→ to decrease the reluctance of the air path b/w poles & hence increase the magnetic flux.

* The Al frame provides support to the coil and also provides damping by eddy current induced in it.



* when current is passed through the coil, force acts upon in both sides producing a deflecting torque.

Let, B → flux density in air gap
N → no. of turns in the coil
i → current in the coil
b, l → breadth & length of coil
A → Area.

Force on each side of coil = NBil

Deflecting Torque, $T_d \propto F$

$T_d = F \times$ perpendicular distance

$T_d = NiBl\,b$

$T_d = NBAi = K_o i$

Control Torque,

$$T_c = K_s \theta$$

↳ spring constant.

At final deflection position

$$T_d = T_c$$

$$K_d i = K_s \theta$$

$$\Rightarrow \boxed{\theta \propto i} \Rightarrow \text{uniform scale}$$

* Since the Al frame moves in an intense magnetic field, the induced eddy currents are large and damping is very effective.

Advantages:

→ Low power consumption
→ uniform scale
→ High (torque / weight) ratio
→ No hysterisis loss
→ Effective & efficient eddy current damping
→ Not much affected by stray magnetic fields.
⇓
due to strong operating fields
→ Accurate, reliable & sensitive.

Disadvantages:

→ Cannot be used to measure a.c.
⇓
direction of current will be reversed during -ve half cycle and hence direction of torque will also be reversed which gives average torque zero. The pointer will not deflect from its mean position showing zero reading.

→ quite expensive.

* PMMC instruments can be used as ammeters or as voltmeters.

Q: The coil of PMMC instrument has 40 turns on an Al frame whose dimensions are 18 mm wide & 25 mm effective length. It moves in a uniform field of flux density 0.6T. The control spring constant is 2.5×10^{-6} Nm/degree. Calculate the current required to produce a deflection of $110°$.

Sol:-
$N = 40$ $\quad l = 25$ mm $\quad b = 18$ mm

$B = 0.6T$ $\quad K_s = 2.5 \times 10^{-6}$ Nm/degree.

$\theta = 110°$

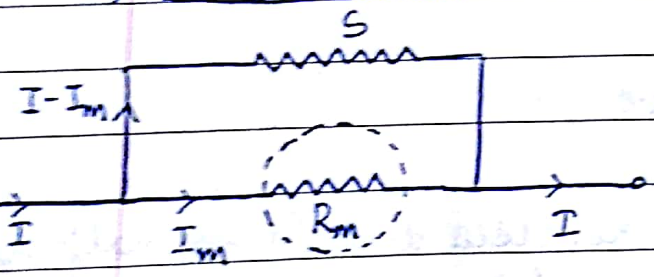
$$K_s \theta = NAB\,i$$

$$\frac{K_s \theta}{NAB} = i \Rightarrow i = \frac{\cancel{2.5} \times \cancel{10^{-6}} \times 11\cancel{0}}{40 \times 18 \times \cancel{25} \times \cancel{10^{-6}} \times 0.6}$$

$$\Rightarrow i = \frac{11}{24 \times 18} = 0.02A$$

Extension of Range

(1) As Ammeter



$R_m \Rightarrow$ instrument resistance

$S \Rightarrow$ shunt resistance

$I_m \Rightarrow$ full-scale deflection current of the instrument

$I \Rightarrow$ line current to be measured

→ A low resistance shunt is connected in parallel with ammeter to extent the range of current.

→ large current can be measured using low current rated ammeter using a shunt

$$V_m = V_s$$

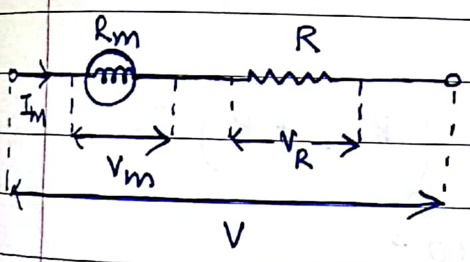
$$I_m R_m = (I - I_m) R_s$$

$$I_m (R_m + R_s) = I R_s$$

$$\boxed{I = \left(1 + \frac{R_m}{R_s}\right) I_m}$$

$\left(1 + \frac{R_m}{R_s}\right) \Rightarrow$ multiplying power

(2) As Voltmeter (multiplier)



$I_m \Rightarrow$ full scale deflection current

$V \Rightarrow$ voltage to be measured.

Since same current flows through R_m & R

$$V_m/R_m = V_R/R.$$

$$V_m/R_m = (V - V_m)/R$$

$$V_m (R_m^{-1} + R^{-1}) = V/R. \Rightarrow V_m \left(\frac{1}{R_m} + \frac{1}{R}\right) = \frac{V}{R}$$

$$\boxed{V = \left(1 + \frac{R}{R_m}\right) V_m}$$

Page No.:

Q: A moving coil instrument has a resistance of 75 Ω and given full scale deflection, when carrying a current of 35 mA. Show how it can be adapted to measure

i) current upto 80 A
ii) voltage upto 550 V.

(i)

$$I = \left(1 + \frac{R_m}{R_s}\right) I_m .$$

$$80 = \left(1 + \frac{75}{R_s}\right) 35 \times 10^{-3}$$

$$1 + \frac{75}{R_s} = \frac{80}{35} \times 10^{3} .$$

$$\frac{75}{R_s} = \frac{\cdot 8 \times 10^{4}}{35} - 1 .$$

$$R_s = 0.032\ \Omega$$

(ii)

$$V = \left(1 + \frac{R}{R_m}\right) V_m . = \left(R_m + R\right) I_m .$$

$$V = \left(75 + R\right) 35 \times 10^{-3} .$$

$$75 + R = \frac{550 \times 10^{3}}{35}$$

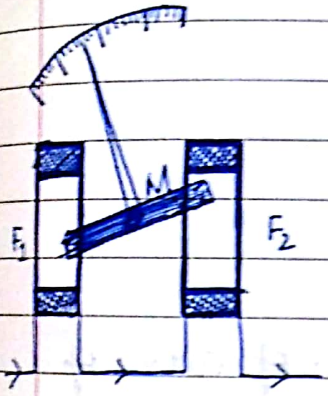
$$R = 15{,}639\ \Omega$$

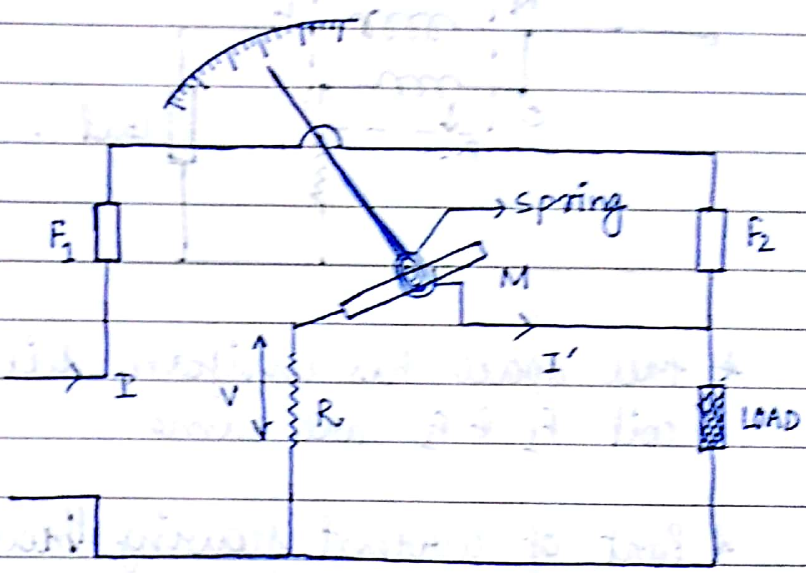
I. Dynamometer Type Instruments / Electrodynamic:
EMMC (Electromagnet moving coil)

Operating field produced in moving coil by another fixed coil.

Can be used either as an ammeter or voltmeter but generally used as a wattmeter.

Electrodynamic Wattmeter
↓
used to measure power taken from ac or dc sources





$F_1, F_2 \Rightarrow$ fixed coils.
$M \Rightarrow$ movable coil

* It consists of two coils, namely fixed coil and movable coil.

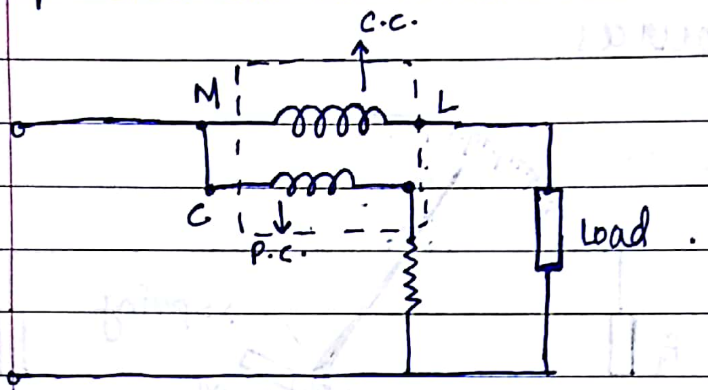
* The fixed coil is split into two equal parts which are placed close together and parallel to each other.

* Moving coil is pivoted between the fixed coils & is placed on the spindle.

* The fixed coils are connected in series with the load and carry circuit current.
  It is therefore called current coil.

* The moving coil is connected across the load & carries current proportional to the voltage & is hence called potential or pressure coil.

* A high resistance is connected in series with pressure coil to limit the current through it.



* Free space has uniform field if no. of turns of coil F_1 & F_2 are same

* Part of current flowing through fixed coil creates magnetic field & current flowing in moving coil creates deflection torque

* Spring control used for controlling torque.

* Air friction damping is used.

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DC measurement

Let $I_1 \Rightarrow$ current through fixed coil
$I_2 \Rightarrow$ current through moving coil

$$B \propto I_1 \Rightarrow B = K I_1.$$

Deflection torque,

$$T_d = NBAI_2$$
$$T_d = NAK I_1 I_2$$
$$\boxed{T_d \propto I_1 I_2}$$

Controlling torque,

$$\boxed{T_c \propto \theta} \Rightarrow T_c = K'\theta.$$

when

$$T_d = T_c. \Rightarrow NAK I_1 I_2 = K'\theta.$$

$$\Rightarrow \boxed{\theta \propto I_1 I_2}$$

AC measurement

$$T_d \propto vi \Rightarrow T_d = Kvi$$

$v = V_m \sin\theta \qquad i = i_m \sin(\theta - \phi)$

$$(T_d)_{mean} = \frac{KV_m i_m}{2\times 2\pi}\int_0^{2\pi} 2\sin\theta \sin(\theta-\phi)\, d\theta.$$

$$= \frac{KV_m i_m}{4\pi}\int_0^{2\pi}[\cos(\theta-\theta+\phi)+\cos(2\theta-\phi)]\,d\theta$$

$$= \frac{KV_m i_m}{4\pi}\left[\int_0^{2\pi}\cos\phi\, d\theta + \int_0^{2\pi}\cos(2\theta-\phi)\,d\theta\right]$$

$$= \frac{KV_m i_m}{4\pi}\left[2\pi\cos\phi - \frac{[\sin(2\theta-\phi)]_0^{2\pi}}{2}\right].$$

$$(T_d)_{mean} = \frac{K V_m i_m \times \cancel{2\pi} \cos\phi}{2\cancel{\pi}}$$

$$(T_d)_{mean} = \frac{K V_m i_m}{2} \cos\phi$$

$$(T_d)_{mean} = K V_{rms} i_{rms} \cos\phi$$

Controlling torque, $T_c \propto \theta$.

$$T_d = T_c$$

$$\theta \propto V_{rms} I_{rms} \cos\phi \propto P$$

↳ Active power.

Advantages:

→ uniform scale

→ High degree of accuracy.

→ Can be used for a.c. & d.c. measurement.

→ Can be used for standardization & calibration.

→ Free from hysterisis & eddy current losses.

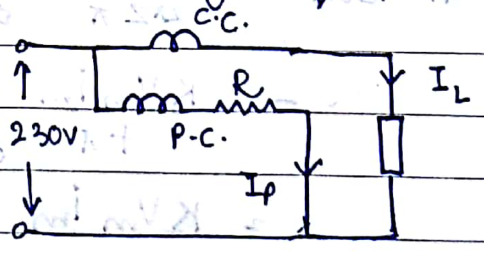
Disadvantages:

→ Quite expensive

→ Small (torque / weight) ratio ⇒ low sensitivity.

Q: The pressure coil of wattmeter has a resitance of 250Ω. The wattmeter is connected across a load. Determine the actual load if wattmeter is reading 350W. Assume the voltage equal to 230V.

$R = 250\Omega$.



$$I_p = \frac{230}{250} = 0.92\,A$$

$$W_p = VI = 230 \times 0.92 = 211.6\,W$$

$$W_L = W - W_p = 350 - 211.6 = 138.4\,W$$

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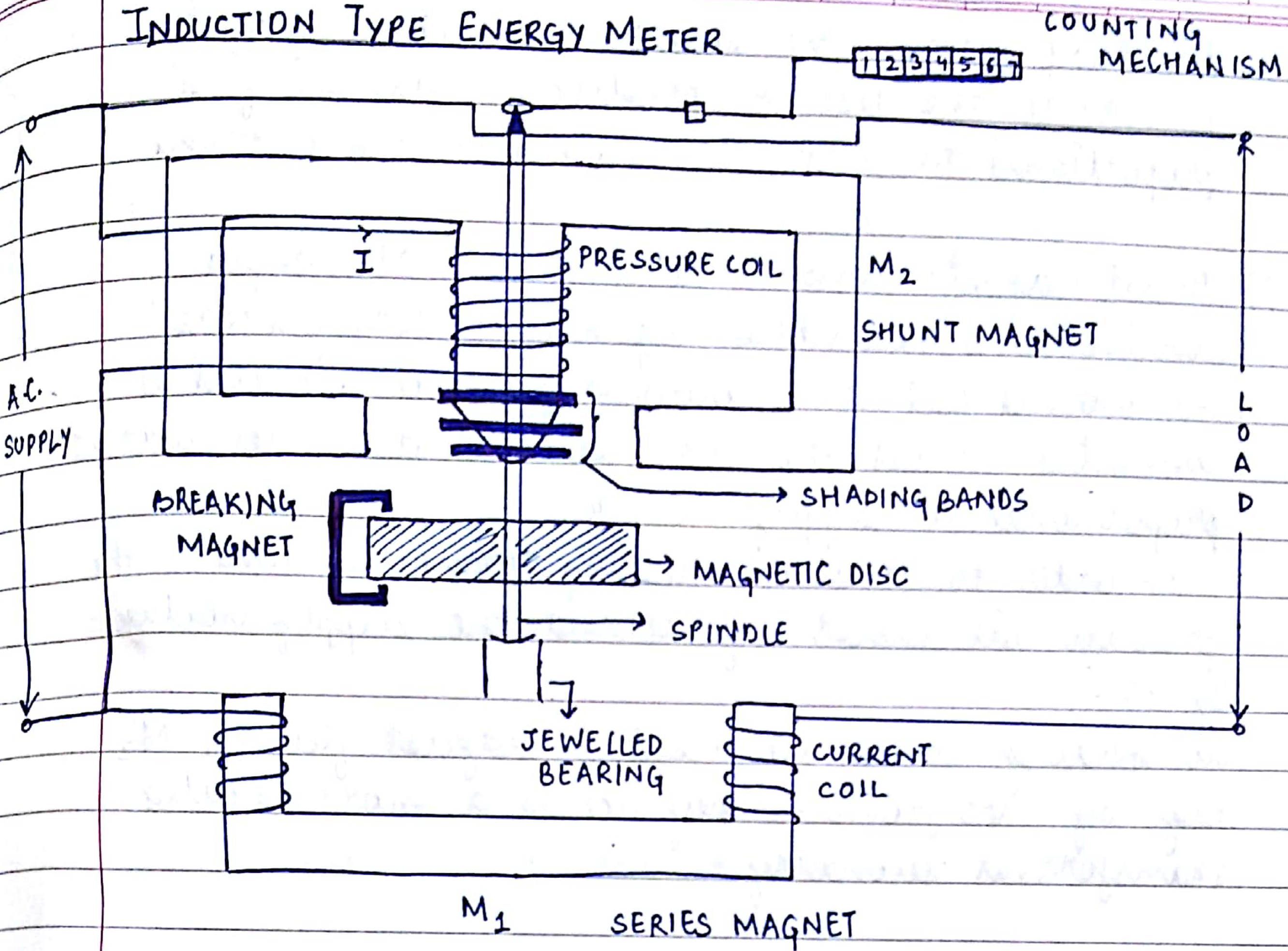
INDUCTION TYPE ENERGY METER



Construction

It generally has -

(1) Moving System

→ Consists of a light Al disc mounted on a vertical spindle.

→ No pointer & control spring ⇒ disc makes continuous rotations under the action of deflecting torque.

(2) Operating Mechanism

→ Consists of series magnet, shunt magnet & breaking magnet.

(a) Series magnet : A thick wire of few turns is wound on both legs of the U-shaped laminated core. The wound coil is known as current coil and is connected in series with the load so that it carries the load current. The series magnet is placed underside the disc & produces magnetic field proportional to and in phase with the current.

(b) Shunt magnet: consists of a no. of M-shaped laminations assembled together to form a core. The wound coil is known as pressure coil and is connected across the load so that it carries current proportional to supply voltage.

In order to obtain deflecting torque, current in the pressure coil must lag behind the supply voltage by 90°.

Cu shading bands are used to adjust flux in M_2 lag by 90° from V. They act as a short circuited transformer secondary.

(c) Breaking Magnet:

↓

control the speed of the Al disc.

→ The magnet is mounted so that the disc revolves in the air gap between its poles.

→ As the disc rotates, currents are induced in the disc because it cuts the flux produced by the breaking magnet.

→ The direction of current in the disc is such that it opposes the rotation of the disc.

$$I_{ind} \propto V_{disc} \propto \text{Breaking torque}$$

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~~(4)~~ (3) Recording mechanism

The no. of revolutions of the disc is a measure of the electrical energy passing through the meter & is recorded on dials which are geared to the shaft.

Working

$I_L \Rightarrow$ line current
$V_s \Rightarrow$ supply voltage

Energy meter connected to the circuit

↓

C.C. ⇒ carries load current ⇒ B in phase with I_L

P.C. ⇒ carries current proportional to V_s ⇒ B lags from I_L by $90°$

↓

C.C. field produces eddy currents in the disc which reacts with the field due to the pressure coil.

↓

Thus a driving force is created which causes the disc to rotate.

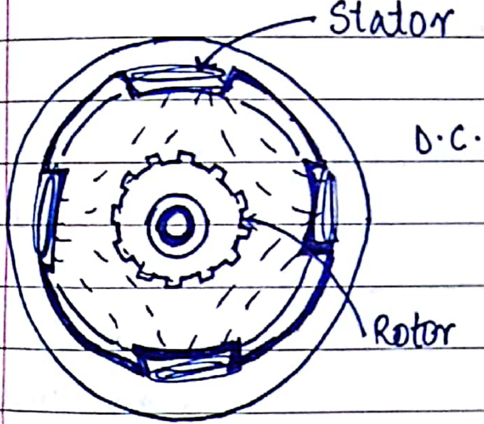
ROTATING MACHINES

Voltages are generated in windings or group of coils by rotating these windings mechanically through a magnetic

Components of Rotating Machines

(1) Stator & Rotor

Stator is the stationary component of an electrical machine that's going around the rotor.
It contains windings & provides mechanical support & protection for the motor



Rotor is general term for the main spinning part of machine.
It's the part of the machine where electronomechanical energy conversion occurs.
Laminated core type electrical steel used for construction of S&R

(2) Air Gap

→ Separates rotor and stator (to avoid friction b/w the two)
→ Needs to be as small as possible (As it reduces power factor)

(3) Windings

(i) Armature winding : set of windings on a rotating machine which carry ac currents.
In a.c. machines ⇒ armature windings is on the stator
In d.c. machines ⇒ armature winding is found on rotor

(ii) Field winding: carry dc current & are used to produce the main operating flux in the machine
a.c. machines : found on rotor
d.c. machines : found on stator

Only synchronous a.c. machines & d.c. machines have field winding

Permanent magnets also produce dc magnetic flux and are used in the place of field windings in some machines.

(4) Ventilating ducts provide cooling

ROTATING MACHINES

- D.C. Machines
  - D.C. Generator
  - D.C. Motor
- A.C. Machines
  - Synchronous
    - Motor
    - Generator
  - Asynchronous (Induction)
    - Motor
      - Squirrel Cage
      - Slipring type
    - Generator

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D.C. MACHINES

Works on the principle of Faraday's Law of EMI.

Armature winding is on rotor with current conducted from it by means of carbon brushes.
The field winding is on the stator & is excited by d.c.

DC. MOTOR
↓
converts electrical energy into mechanical energy.

Principle : When a current-carrying conductor is placed in a magnetic field, it faces or experiences a mechanical force given by

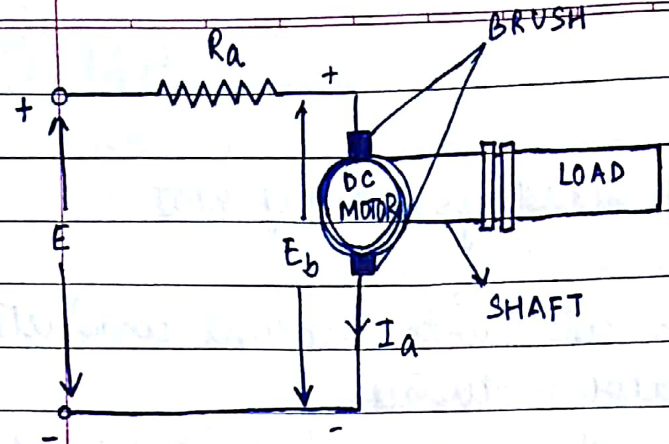
$$F = BIl$$

Direction of F ⇒ Fleming's Left-Hand Rule.

D.C. Motor
- Shunt Wound
- Series Wound
- Compound Wound

Parts of a D.C. motor

→ Stator & Rotor
→ Yoke (Magnetic Frame ⇒ made of cast iron or steel)
→ Poles & pole shoe or field coils
→ Armature core & armature winding
→ Commutator (to relay the supply current from mains to arm. winding)
→ Brushes
→ Shaft, bearing, pulley



$R_a \Rightarrow$ armature resistance
E $\Rightarrow$ input voltage

when voltage is applied across the motor, I_a produces torque in the presence of magnetic field

Due to this torque, armature rotates and it produces an induced emf E_b directed opposite to E & is known as back emf.

$$E_b = \frac{P \cdot \phi \cdot Z \cdot N}{60 \cdot A}$$

where
- $P \Rightarrow$ no. of poles
- $\phi \Rightarrow$ flux per pole
- $Z \Rightarrow$ no. of conductors
- $A \Rightarrow$ no. of parallel paths in which conductors are di
- $N \Rightarrow$ speed of dc motor in rpm

$$E_b = \frac{P \cdot \phi \cdot N}{60} \times \frac{Z}{A}$$

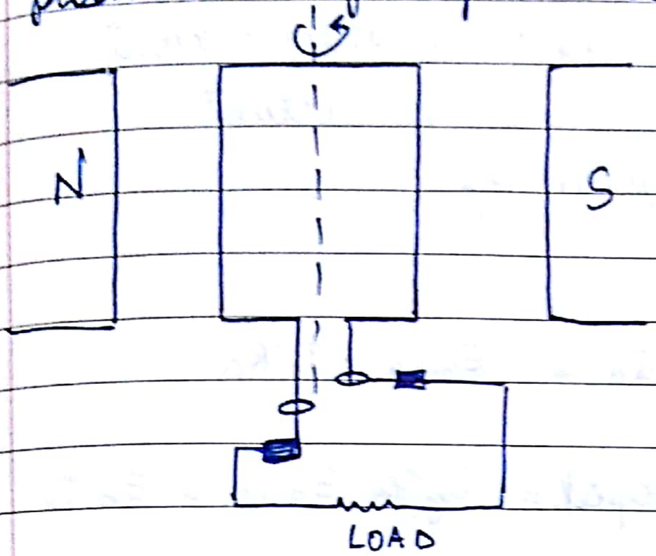
$$E_b = \text{emf per conductor} \times \frac{\text{Total no. of Armature conductors}}{\text{No. of parallel path}}$$

$$I_a = \frac{E - E_b}{R_a}$$

D.C. GENERATOR

converts mechanical energy into electrical energy

This energy conversion is based on the principle of production of dynamically induced emf.

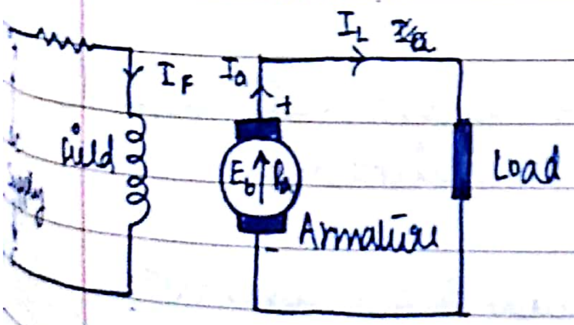


Need of a split ring commutator: to achieve single direction of current

D.C. Generator

Separately excited

Field coils are energized from an independent external DC source



Self excited

Field coils are energized from the current produced by the generator itself.

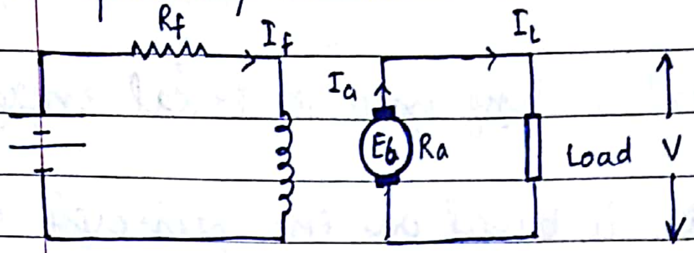
It is further classified into

i) series

ii) shunt

iii) compound.

(1) Separately Excited



$I_a = I_L$

$I_a \Rightarrow$ armature current

$I_L \Rightarrow$ line current

Terminal voltage V is given by

$V = E_b - I_a R_a$

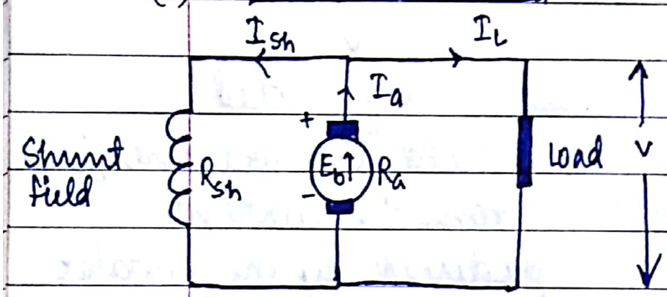
Power at load, $P_L = V I_a = E_b I_a - I_a^2 R_a$

Power supplied / developed $=$ ~~$E_g I_a$~~ $E_b I_a = E_b I_a$

$E_b \Rightarrow$ back emf.

(2) Self Excited

(i) Shunt wound



Field winding is connected across the armature winding forming a parallel / shunt circuit.

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

$R_{sh} \Rightarrow$ shunt field winding resistance

practically constant at all loads $\Rightarrow \phi_{sh} =$ constant

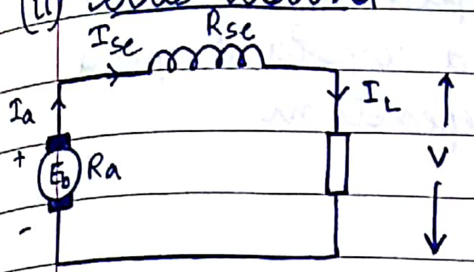
$I_a = I_{sh} + I_L$

$V = E_b - I_a R_a$.

Power developed $= E_b I_a$

Power output $= V I_L = (E_b - I_a R_a)\left(I_a - \frac{V}{R_{sh}}\right)$.

(ii) Series wound



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

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

Power developed $= E_b I_a$

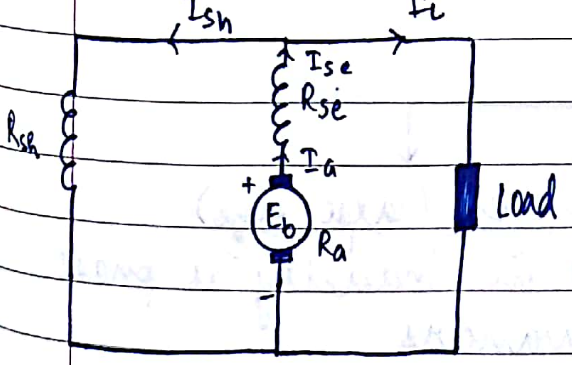
Power output $= V I_L = V I_a = E_b I_a - I_a^2 (R_a + R_{se})$.

$$\phi_{se} \propto I_{se}$$

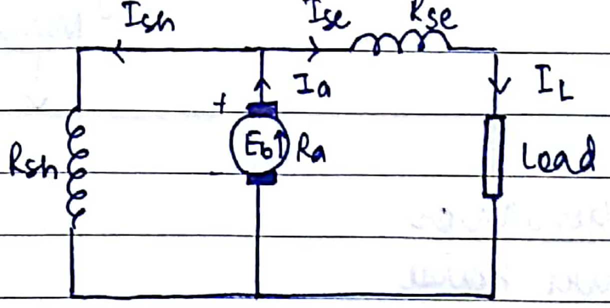
But flux becomes constant after magnetic saturation even if I_{se} is increased.

(iii) Compound wound

Long shunt compound Generator



Short shunt compound Generator



A compound wound generator, there are 2 sets of field winding on each pole. Has both shunt & series fields

A.C. MACHINES

1) SYNCHRONOUS MACHINE (S.M)

Electromechanical transducer (Principle: Faraday's law of EM)

* It runs either at synchronous speed or not at all, i.e. while running it maintains a constant speed.

It's satisfactory operation depends on the relation

$$N_s = \frac{120f}{P}$$

where,

$N_s \Rightarrow$ synchronous speed in rpm

$f \Rightarrow$ supply frequency

$P \Rightarrow$ no. of poles of the machine.

* As a motor, if S.M. fails to maintain N_s the machine will not develop sufficient torque to maintain its rotation & will stop.
The motor is said to be pulled out of step.

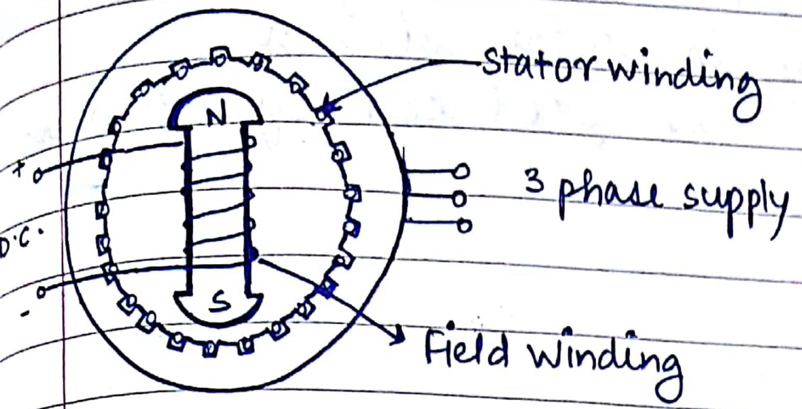
* As a generator, it has to run at a fixed N_s to generate the power at a particular f.

Synchronous Machine

Generator (Power House 500mVA)

Motor (large size) used in industry as phase advancers
a) Lagging current
b) leading current.

Merits



* used for power factor improvement
* speed is constt. & independent of load
* mechanically better than induction motor
*

2) ASYNCHRONOUS MOTOR / INDUCTION MOTOR

Merits

→ Rotor rotates at a speed less than the synchronous speed

→ Does not require any additional starting source

→ Less costly and reliable.

→ Requires min. maintenance & has high overloading property

Demerits

→ Speed cannot be varied without sacrificing some of its efficiency.

→ Speed ↓es with increase in load