BASIC ELECTRICAL AND ELECTRONICS ENGINEERING
LECTURE NOTES

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

MALLA REDDY ENGINEERING COLLEGE AUTONOMOUS

MAISAMMAGUDA, DULAPALLY– 500014, Hyderabad

SYLLABUS:

MODULE I : DC Circuits [09 Periods]

Electrical circuit elements (R, L and C), voltage and current sources, Kirchhoff's current and voltage laws - Series, parallel, series-parallel, star-to-delta and delta-to-star transformation-analysis of simple circuits with dc excitation. Superposition, Thevenin's and Maximum Power Transfer Theorems with DC excitation.

MODULE II: AC Circuits 09 Periods]

Representation of sinusoidal waveforms, peak and rms values, phasor representation,real power, reactive power, apparent power, power factor. Analysis of single-phase ac circuits consisting of R, L, C, RL, RC, RLC combinations (series and parallel).

MODULE III: Introduction to Electrical Machines [10 Periods]

A: DC Machines : Construction & Principle of Operation of DC Generators – E.M.F Equation. Principle of operation DC Motors – Back E.M.F. - Torque equation – Brake Test - Characteristics.

B: AC Machines: Construction and Principle of operation of Transformer- EMF Equation. Construction and Principle of Operation of 3 Phase Induction Motors - Brake test on 3-Phase Induction Motor – Applications

MODULE IV: P-N Junction Diode [10 Periods]

A: P-N Junction Diode: Diode equation, Energy Band diagram, Volt-Ampere characteristics, Temperature dependence, Ideal versus practical, Static and dynami resistances, Equivalent circuit, Diffusion and Transition Capacitances. Zener diode operation, Zener diode as voltage regulator.

B: Rectifiers : P-N junction as a rectifier - Half Wave Rectifier, Ripple Factor – Full Wave Rectifier, Bridge Rectifier.

C: Filters : Filters – Inductor Filters, Capacitor Filters, L- section Filters, π- section Filters.

MODULE V : BJT and Junction Field Effect Transistor (JFET) [10 Periods]

A:Bipolar Junction Transistor (BJT): Construction, Principle of Operation,Symbol, Amplifying Action, Common Emitter, Common Base and CommonCollector configurations and Input-Output Characteristics, Comparison of CE, CB and CC configurations

B: Junction Field Effect Transistor and MOSFET: Construction, Principle ofOperation, Symbol, Pinch-Off Voltage, Volt-Ampere Characteristic, Comparisonof BJT and FET.

TEXT BOOKS

1. M.Surya Kalavathi, Ramana Pilla, Ch. Srinivasa Rao, Gulinindala Suresh,"Basic Electrical and Electronics Engineering", S.Chand and CompanyLimited, New Delhi, 1st Edition, 2017.
2. R.L.Boylestad and Louis Nashlesky, "Electronic Devices & Circuit Theory",Pearson Education, 2007.

REFERENCES

1. V.K. Mehtha and Rohit Mehta, "Principles of Electrical Engineering andElectronics", S.Chand & Co., 2009.
2. Jacob Milliman, Christos C .Halkias, Satyabrata Jit (2011), "ElectronicDevices and Circuits", 3 rd edition, Tata McGraw Hill, New Delhi.
3. Thomas L. Floyd and R. P. Jain, "Digital Fundamentals", Pearson Education,2009.
4. David A. Bell, "Electronic Devices and Circuits", Oxford University Press,2008.

(10Q) State & explain Maximum power transfer theorem:-

Statement:- It states that maximum power is delivered from a source to a load when the load resistance is equal to the source resistance.

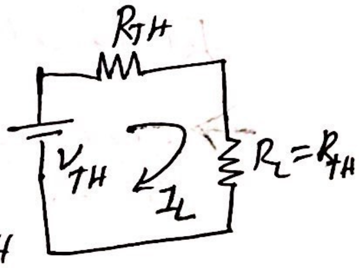
Steps to be followed in Maximum power Transfer theorem:-

(1) Remove the variable load resistance R_L
(2) Find the open circuit voltage V_{TH} across points A & B
(3) Find the resistance R_{TH} as seen from points A & B
(4) Find the resistance R_L for maximum power transfer.

$$R_L = R_{TH}$$

(5) Find the max. power.

$$I_L = \frac{V_{TH}}{R_{TH}+R_L} = \frac{V_{TH}}{2R_{TH}}$$



$$P_{max} = I_L^2 R_L = \frac{V_{TH}^2}{4R_{TH}^2} \times R_{TH}$$

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

(1Q) Define current, voltage & power

Current :- The flow of free electrons through the conductor is called Electrical current.

D1, D4, E4, E5.

→ **Formulas:-** (i) Constant current (I) :-

$$I = \frac{Q}{t} \text{ Amp}$$

(ii) Instantaneous current

$$i(t) = \frac{dq}{dt} \text{ Amp}$$

→ The unit of current is Ampere

→ It is denoted by I (or) $i(t)$.

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Electrical Voltage:-

→ Statement:- The potential difference (P.D) between two points is the energy required to move one coulomb of charge from one point to the other

→ Constant voltage; $V = \frac{W}{Q}$ (volts)

Instantaneous voltage $v(t)$:- $v(t) = \frac{dW}{dq}$

→ The unit of voltage is volt

→ It is denoted by V (or) $v(t)$.

Electrical power:-

→ Statement:- The rate at which work is done in an electric circuit is called Electric power.

$\therefore$ Electric power = $\frac{\text{Workdone in electric circuit}}{\text{Time}}$

C1, D3, F7, F8, G9, H4, H5.

→ Formulas:-

$$P = \frac{W}{t}$$

$$= \frac{VQ}{t} \quad (\because V = \frac{W}{Q})$$

$$= V \cdot \frac{Q}{t} \quad (\because I = \frac{Q}{t})$$

(a) $\boxed{P = V \cdot I}$ watt

(b) $\boxed{P = I^2 R}$ watt

(c) $\boxed{P = \frac{V^2}{R}}$ watt

→ The unit of power is watt

→ It is denoted by P (or) $P(t)$.

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(2a) Write Shortes on Resistance, Inductance & Capacitance:

1-3

Resistance :-

→ Statement:- Which opposes the flow of electrons through the conductor.

→ Its symbol is ⩘⩘

→ Its unit is Ohm (Ω)

→ It is Abbreviated as R (or) r.

Resistance of a conductor depends upon

(i) Resistance of a conductor depends upon the material

(ii) Resistance of a conductor is directly proportional to its length.

$$\boxed{R \propto L} \rightarrow (1)$$

(iii) Resistance of a conductor is inversely proportional to its area of cross-section

$$\boxed{R \propto \frac{1}{A}} - (2)$$

(iv) Resistance depends on the temperature of the conductor

From equ (1) & (2)

$$R \propto \frac{L}{A}$$

$$\boxed{R = \rho \frac{L}{A}} \Omega$$

Where ρ = specific resistance of the conductor.

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Inductance:-

→ Statement:- It is property of a coil that opposes any change in the current flowing through it.

→ Formula:- $\boxed{V = L\frac{dI}{dt}}$ volt

→ The unit of Inductance is Henry (H)

→ It symbol is

→ It is denoted by L or l.

Factors on which Inductance depends upon:-

(i) It depends on shape of the core

(ii) It is directly proportional to the square of the number of turns

(iii) It is inversely proportional to the reluctance of the magnetic path.

$$\boxed{L \propto \frac{N^2}{S}}$$

Capacitance:-

→ Statement:- The property of a material which opposes ~~redu~~ change in voltage across the material is known as capacitance.

→ 'Q' stored in a capacitor is directly proportional to the potential difference across the capacitor.

$$Q \propto V$$

$$Q = CV$$

$$\boxed{C = \frac{Q}{V}} \text{ farad.}$$

→ Its unit is Farad (F)

→ Its symbol is or

→ It is Abbreviated as 'C'

Factors on which capacitances depends upon

(i) It is directly proportional to the Area of plates.

$$\boxed{C \propto A} - ①$$

(ii) It is inversely proportional to the thickness of the dielectric.

$$\boxed{C \propto \frac{1}{D}} - ②$$

(iii) The greater the relative permittivity of the insulating material, the greater will be the capacitance. $\boxed{\therefore C = \frac{\epsilon A}{D}}$

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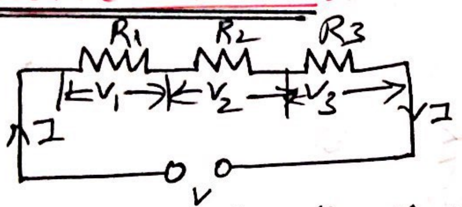
3Q Resistance in series:-



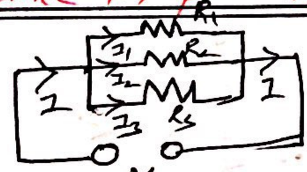
(i) Same currents flows through all parts of the circuit

(ii) Different resistors have their individual voltage drops

(iii) Applied voltage equals the sum of different voltage drops i.e $\boxed{V=V_1+V_2+V_3}$

(iv) Equivalent resistances is equal to the sum of the individual resistance i.e $\boxed{R_T=R_1+R_2+R_3}$

Resistance in parallel:-



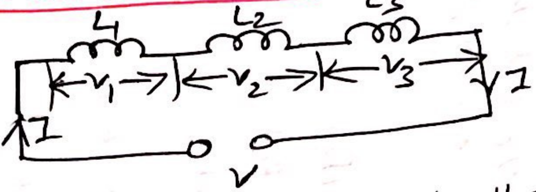
(i) Same voltage acts across all parts of the circuit.

(ii) Different resistors have their individual current

(iii) Total currents equals the sum of individual current i.e $\boxed{I=I_1+I_2+I_3}$

(iv) Reciprocal of their equivalent resistance is equal to the sum of the reciprocal of the individual resistance i.e. $\boxed{\frac{1}{R_T}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}}$

4Q Inductance in series:-



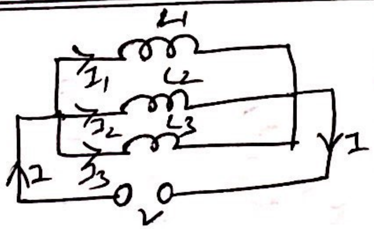
(i) Same current flows through all parts of the circuit

(ii) Different Inductances have their individual voltage drop.

(iii) Applied voltage equals the sum of different voltage drop i.e $\boxed{V=V_1+V_2+V_3}$

(iv) Equivalent Inductance is equal to the sum of the Individual Inductance ($L_T = L_1+L_2+L_3$)

Inductance in parallel



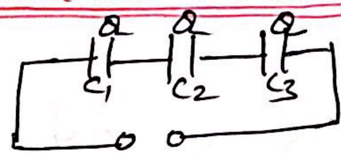
(i) Same voltage acts across all parts of the circuit

(ii) Different Inductance have their individual current.

(iii) Total current equals to the sum of different Individual current

(iv) Reciprocal of their equivalent Inductance is equal to the sum of the reciprocal of the Individual Inductances $\boxed{\frac{1}{L_T}=\frac{1}{L_1}+\frac{1}{L_2}+\frac{1}{L_3}}$

5Q Capacitance in series



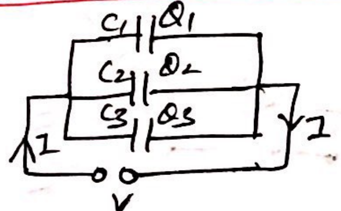
(i) Charge on each capacitor is same

(ii) Different capacitance have their individual voltage drop

(iii) Applied voltage equals the sum of the different voltage drop i.e. $\boxed{V=V_1+V_2+V_3}$

(iv) Reciprocal of the equivalent capacitance is equal to the sum of the reciprocal of individual capacitance i.e $\boxed{\frac{1}{C_T}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}}$

Capacitance in parallel



(i) Charge on each capacitors is different

(ii) Voltage across each capacitor is same

(iii) Total charge is equal to the sum of different individual charges on capacitor $\boxed{\text{i.e } Q=Q_1+Q_2+Q_3}$

(iv) Eq. capacitance is equal to the sum of the Individual capacitance i.e $\boxed{C=C_1+C_2+C_3}$

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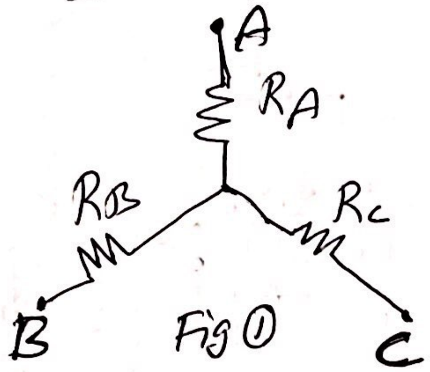
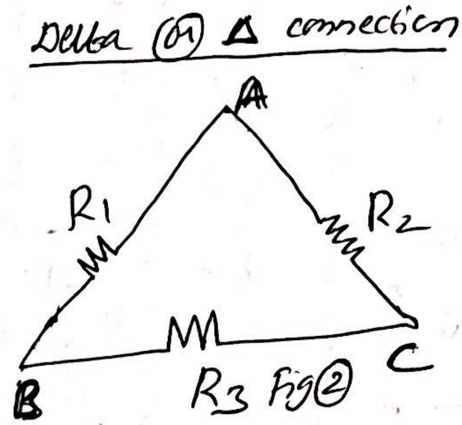
6Q) Derivation for Δ-Y and Y-Δ Transformation:





The above two circuits are equal if their respective resistances from the terminals AB, BC & CA are equal.

Consider the star-connected circuit in fig ①, the resistance from the terminals AB, BC & CA respectively are

$$R_{AB}(Y) = R_A + R_B$$

$$R_{BC}(Y) = R_B + R_C$$

$$R_{CA}(Y) = R_C + R_A$$

Similarly, in the Δ-connected network in fig ②, the resistance seen from the terminals AB, BC & CA resp. are

$$R_{AB(\Delta)} = R_1 \| (R_2+R_3) = \frac{R_1(R_2+R_3)}{R_1+R_2+R_3}$$

$$R_{BC(\Delta)} = R_3 \| (R_1+R_2) = \frac{R_3(R_1+R_2)}{R_1+R_2+R_3}$$

$$R_{CA(\Delta)} = R_2 \| (R_1+R_3) = \frac{R_2(R_1+R_3)}{R_1+R_2+R_3}$$

Delta-Star:-

Now, if we equate the resistances of star & Delta circuits, we get

$$R_A + R_B = \frac{R_1(R_2+R_3)}{R_1+R_2+R_3} \quad \text{—①}$$

$$R_B + R_C = \frac{R_3(R_1+R_2)}{R_1+R_2+R_3} \quad \text{—②}$$

$$R_C + R_A = R_2(R_1+R_3) \quad \text{—③}$$

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From equation 1, 2 & 3, we get

1 − 2 + 3

$$R_A + \cancel{R_B} - \cancel{R_B} - \cancel{R_C} + \cancel{R_C} + R_A = \frac{R_1+R_2+R_1R_3}{R_1+R_2+R_3} - \frac{R_3R_1 - R_3R_2}{R_1+R_2+R_3} + \frac{R_2R_1+R_2R_3}{R_1+R_2+R_3}$$

$$2R_A = \frac{R_1R_2 + \cancel{R_1R_3} - \cancel{R_3R_1} - \cancel{R_3R_2} + R_2R_1 + \cancel{R_2R_3}}{R_1+R_2+R_3}$$

$$2R_A = \frac{2R_1R_2}{R_1+R_2+R_3}$$

$$\boxed{\therefore R_A = \frac{R_1R_2}{R_1+R_2+R_3}} \rightarrow 4$$

Similarly :-

$$\boxed{R_B = \frac{R_1R_3}{R_1+R_2+R_3}} \rightarrow 5 \qquad \boxed{R_C = \frac{R_2+R_3}{R_1+R_2+R_3}} \rightarrow 6$$

STAR- Delta :-

From equation 4, 5 & 6 we can get

4 × 5 + 5 × 6 + 6 × 4

$$R_AR_B + R_BR_C + R_CR_A = \frac{R_1^2R_2R_3 + R_3^2R_1R_2 + R_2^2R_1R_3}{(R_1+R_2+R_3)^2}$$

$$R_AR_B + R_BR_C + R_CR_A = \frac{R_1R_2R_3(R_1+R_2+R_3)}{(R_1+R_2+R_3)^2}$$

$$R_AR_B + R_BR_C + R_CR_A = \frac{R_1R_2R_3}{(R_1+R_2+R_3)}$$

Divided throughout by R_A

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$$\frac{R_AR_B+R_BR_C+R_CR_A}{R_A} = \frac{\frac{R_1R_2R_3}{R_1+R_2+R_3}}{R_A}$$

$$\boxed{\therefore R_A = \frac{R_1R_2}{R_1+R_2+R_3}}$$

$$\frac{R_AR_B+R_BR_C+R_CR_A}{R_A} = \frac{\frac{\cancel{R_1}R_2R_3}{\cancel{R_1+R_2+R_3}}}{\frac{\cancel{R_1R_2}}{\cancel{(R_1+R_2+R_3)}}}$$

$$\boxed{\therefore \frac{R_AR_B+R_BR_C+R_CR_A}{R_A} = R_3}$$

Similarly we can prove that,

$$\boxed{R_2 = \frac{R_AR_B+R_BR_C+R_CR_A}{R_B}}$$

$$\boxed{R_1 = \frac{R_AR_B+R_BR_C+R_CR_A}{R_C}}$$

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(7Q) State & explain KCL & KVL

1-9

Ans:- <u>Kirchhoff's current Law:-</u>

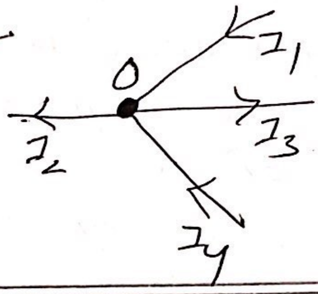
<u>Statement:-</u> The algebraic sum of the currents meeting at a junction in an electrical circuit is zero.

<u>Sign Convention:-</u> currents flowing towards a junction point are assumed to be +ve while currents flowing away from a junction point assumed to be negative.

<u>Explanation:-</u> Consider four conductors carrying currents I_1, I_2, I_3 & I_4 and meeting at a point 'O' as shown in fig (a). If we take the signs of currents flowing towards point 'O' as positive, then currents flowing away from point 'O' will be assigned -ve sign.

<u>Thus applying KCL to the junction 'O'</u>

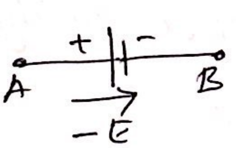
$$\boxed{I_1 + I_4 - I_2 - I_3 = 0}$$

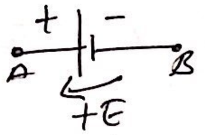


<u>Kirchoff's Voltage Law:-</u>

<u>Statement:-</u> In any closed circuit, the algebraic sum of all the electromotive (emfs) and voltage drops across circuit elements is equal to zero.

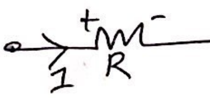
<u>Sign convention</u> (i)



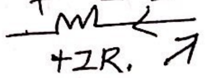


→ (Emf sign convention)

(ii)



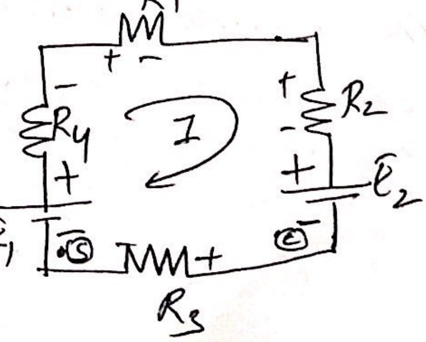
$= -IR$.



$+IR$. ↗ (voltage drop sign convention)

<u>explanation:-</u>
If the current direction has not given in the circuit, then follow this method.

$$\boxed{E_1 - IR_4 - IR_1 - IR_2 - E_2 - IR_3 = 0}$$



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(12) Write short notes on Mesh & Nodal Analysis

1-10

Sol **Mesh analysis:-**

→ Depending upon the sources, we have to select the mesh analysis & nodal analysis. If more no. of voltage sources, use mesh analysis (OR) if there are more no. of current sources used nodal analysis.

→ Mesh analysis is applicable only for planar network. For non-planar circuit mesh analysis is not applicable.

→ In general, if we have 'B' number of branches & N number of nodes including the reference node then, the number of linearly independent mesh equations

$$M = B - (N-1)$$

→ procedure to solve the problem for a given network:

(i) First step is to check whether the circuit is planar (or) not.

(ii) Second step, select closed loop of currents called mesh currents (or) loop current

(iii) Finally writing KVL equations in terms of unknown mesh currents & solving them leads to final solution.

→ KVL is used for Mesh analysis.

NODAL Analysis

→ In general in 'N' node circuit one of the nodes is choosen as reference node (or) datum node, then it is possible to write (N-1) Nodal equations, by assuming (N-1) node voltage.

→ The node voltage is the voltage of a given node with respect to one particular node called the reference node which we assume at zero potential.

→ KCL is applied to Nodal analysis.

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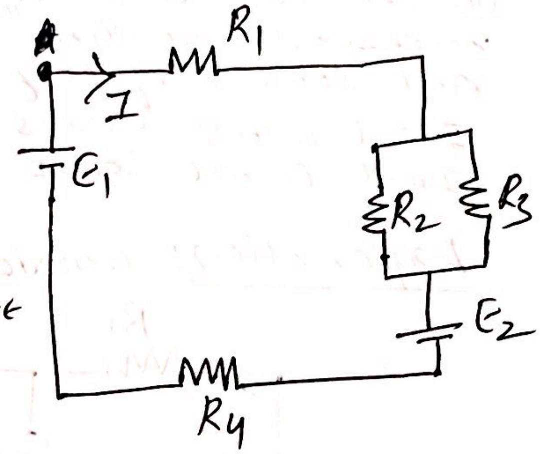
8Q) State and explain Superposition Theorem:- 1-11

Statement:- In a linear network containing more than one source of emf the resultant current in any branch is the algebraic sum of currents that would be produced by each emf acting alone, all other sources of emf being replaced meanwhile by their respective internal resistances.

Explanation:- To show that this statement is true, consider the circuit shown in fig. The total circuit resistance R_T is given by



$$R_T = R_1 + R_p + R_4$$
where $R_p = R_2R_3/R_2+R_3$

Step 1:-
Consider that emf E_1 is acting alone by replacing E_2 with a short circuit.

$\therefore$ current due to E_1 alone,
$$I_1 = \frac{E_1}{R_1+R_p+R_4}$$

Step 2:- Now consider that emf E_2 is acting alone by replacing E_1 with a short circuit

$\therefore$ current due to E_2 alone,
$$I_2 = \frac{E_2}{R_1+R_p+R_4}$$

Step 3:- When both sources are acting at a time, then the resultant current is

$$I = \text{Algebraic sum of } I_1 + I_2$$
$$= \left(\frac{E_1}{R_1+R_p+R_4}\right) + \left(-\frac{E_2}{R_1+R_p+R_4}\right)$$

$$\boxed{I = \frac{E_1}{R_1+R_p+R_4} - \frac{E_2}{R_1+R_p+R_4}}$$

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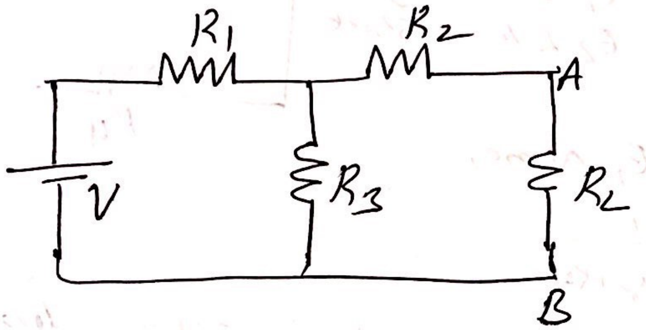
(92) State & explain Thevenin's Theorem:-

Statement:- Any network having terminals A and B can be replaced by a single source of emf V_{TH} in series with a single resistance R_{TH}.

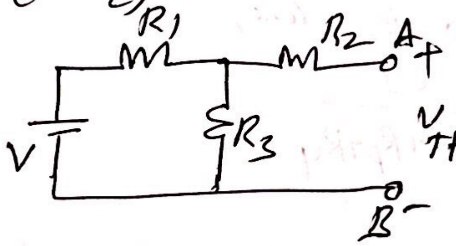
(i) The emf V_{TH} is the voltage obtained across terminals A and B with load, if any removed i.e. it is open-circuit voltage b/w terminals A & B.

(ii) The resistance R_{TH} is the resistance of the network measured between terminals A and B with load removed and sources of emf replaced by their internal resistances. Ideal voltage sources are replaced with short circuits. Ideal current source are replaced with open circuit.

Explanation:- Consider the circuit as shown in Fig.



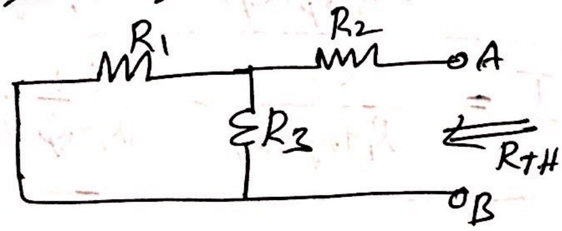
Finding V_{TH}:- The emf V_{TH} is the voltage across terminals AB with load (i.e. R_L) removed as shown in Fig.



V_{TH} = Voltage across R_3

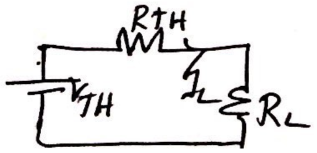
$$\boxed{V_{TH} = \frac{V}{R_1+R_3} \times R_3}$$

Finding R_{TH}:- To find R_{TH}, remove the load R_L & replace the battery by a short-circuit because its internal resistance is assumed zero. Then resistance b/w terminals A & B is equal to R_{TH}.



$$\boxed{R_{TH} = R_2 + \frac{R_1 R_3}{R_1+R_3}}$$

Thevenin's Eq. ckt :-



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

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12) Explain Types of Sources:-

There are basically two types of Energy Sources. They are

(1) Independent Sources
(2) Dependent Source.

(1) Independent sources :- Again Independent Sources are divided into two. They are.

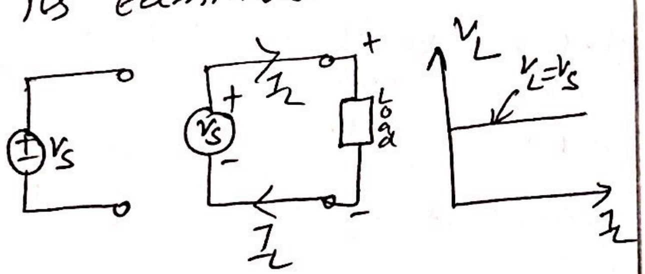
(a) Independent voltage source.
(b) Independent current source.

(a) Independent Voltage Source:- There are two types of Independent Voltage source. They are

(i) Ideal voltage source
(ii) practical voltage source.

(i) Ideal voltage source:-

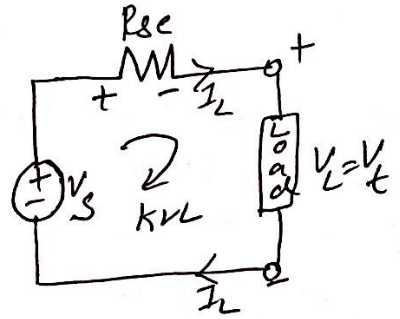
→ Ideal voltage source is defined as the energy source which gives constant voltage across its terminals irrespective of the current drawn through its terminals.

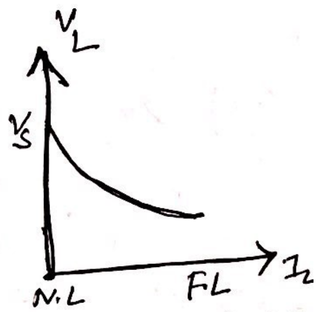


→ An Ideal voltage source is one whose internal resistance is zero. ($R_{se} = 0$).

(ii) practical voltage source.

→ A practical voltage source does not have a constant terminal voltage. As the output current (or) the Load current increases the terminal voltage will drop.





→ But practically every voltage source has small internal resistance is shown in series with the Ideal voltage source & is represented by R_{se}.

→ By Apply KVL to Loop

$$V_S - I_L R_{se} - V_L = 0$$

$$\boxed{V_L = V_S - I_L R_{se}}$$

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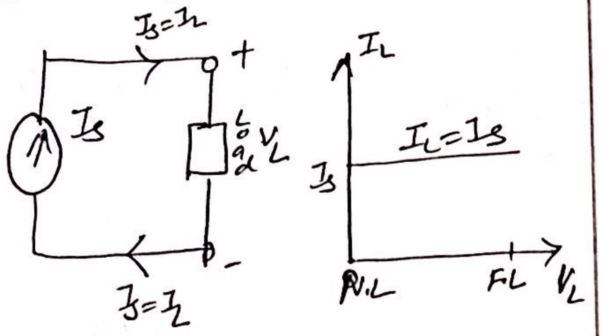
(b) **Independent current source**:- I.C.S are of two types.

(i) **Ideal current source**

→ Ideal current source is the source which gives constant at its terminals irrespective of the voltage appearing across its terminals.

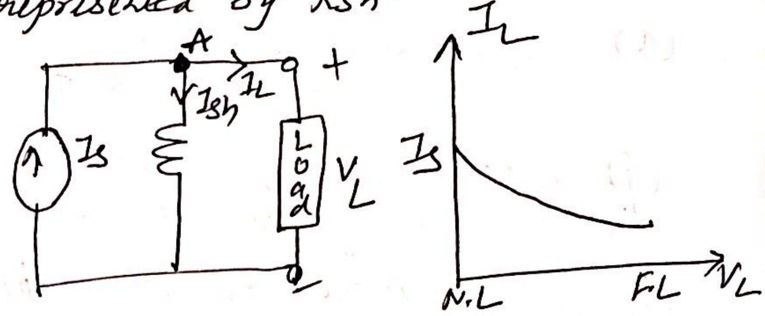


→ An Ideal current source is one whose internal resistance is infinity, $R_{sh} = \infty$

(ii) **practical current source**

→ A practical current source does not have a constant output current. As the voltage across its terminal voltage increases, the output current decreases.

→ But practically every current source has high internal resistance, shown in parallel with current source & it is represented by R_{sh}.



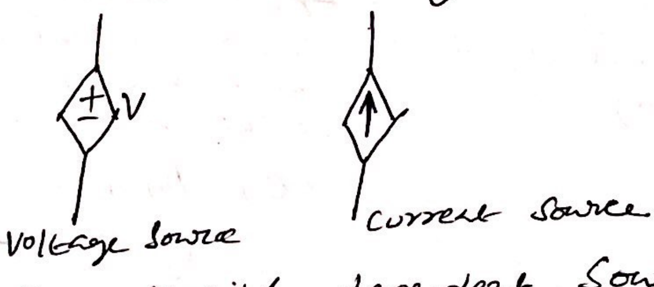
→ By apply KCL at node 'A'

$$I_s - I_{sh} - I_L = 0$$

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

(2) **Dependent Sources**:- A dependent voltage (or) current source is one which depends on some other quantity in the circuits which may be either a voltage (or) current.

→ A dependent source is represented by a diamond shape symbol as shown in fig.



→ There are four possible dependent sources.

(i) Voltage - dependent voltage sources

(ii) current - dependent voltage sources

(iii) Voltage - dependent current source

(iv) current - dependent current source.

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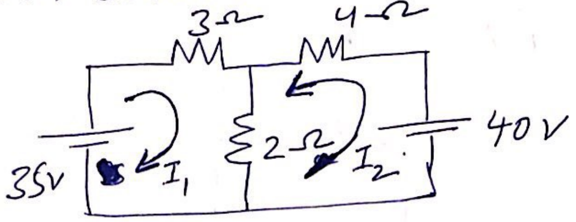
MESH Analysis

(1) calculate the current in each resistor ~~and voltage drop across each resistor~~ for given circuit.

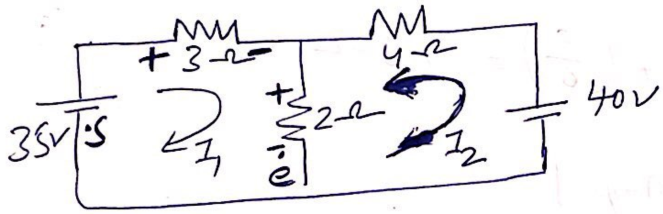


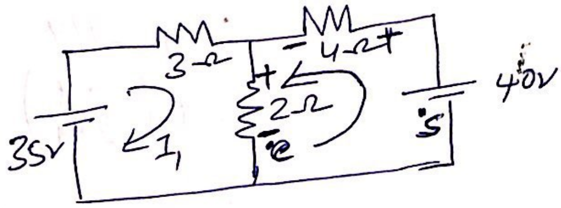
Sol Applying KVL to Loop 1:-

$$35 - 3I_1 - 2(I_1 + I_2) = 0$$
$$35 - 3I_1 - 2I_1 - 2I_2 = 0$$
$$35 - 5I_1 - 2I_2 = 0$$
$$5I_1 + 2I_1 - 35 = 0$$
$$\boxed{5I_1 + 2I_1 = 35} \rightarrow (1)$$

Applying KVL to Loop 2:-

$$40 - 4I_2 - (I_1 + I_2)2 = 0$$
$$40 - 4I_2 - 2I_1 - 2I_2 = 0$$
$$40 - 2I_1 - 6I_2 = 0$$
$$2I_1 + 6I_2 = 40$$
$$\boxed{I_1 + 3I_2 = 20} \rightarrow (2)$$





Solving I_1 & I_2 by cramer's rule:-

$$\begin{bmatrix} 5 & 2 \\ 1 & 3 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 35 \\ 20 \end{bmatrix}$$

$$\Delta = \begin{bmatrix} 5 & 2 \\ 1 & 3 \end{bmatrix} = 15 - 2 = 13 \quad ; \quad \Delta_1 = \begin{bmatrix} 35 & 2 \\ 20 & 3 \end{bmatrix} = 105 - 40 = 65$$

$$\Delta_2 = \begin{bmatrix} 5 & 35 \\ 1 & 20 \end{bmatrix} = 65$$

$$\boxed{\therefore I_1 = \frac{\Delta_1}{\Delta} = 5\,\text{Amp}} \qquad \boxed{I_2 = \frac{\Delta_2}{\Delta} = 5\,\text{Amp.}}$$

$\therefore$ The current through 3Ω is I_1 = 5 Amp

The current through 4Ω is I_2 = 5 Amp

" " " 2Ω is $(I_1 + I_2)$ = 10 Amp.

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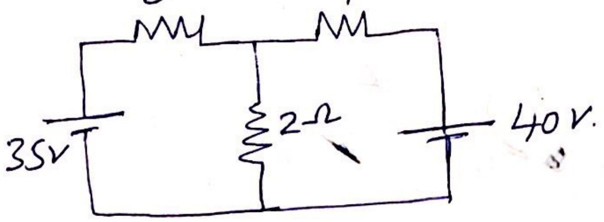
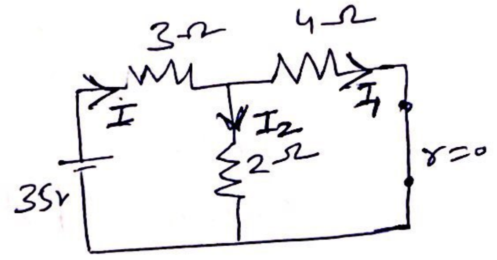
(1Q) By using Superposition Theorem, find the current in ~~4~~ 4Ω

1-16



Sol Step 1:- operate with one voltage source i.e. 35 volts and other source i.e. 40 volts is replaced by their internal resistance [Short circuit of voltage source i.e $r=0$]



$$\therefore \boxed{I = \frac{V}{R_{eq}}}$$

$R_{eq} = 3$ series with $2 \| 4$

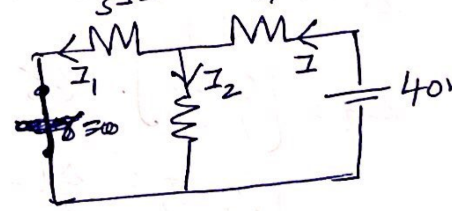
$= 3 + 2\|4$

$= 3 + \left(\frac{2\times4}{2+4}\right) = 3 + \left(\frac{8}{6}\right) = 4.3\,\Omega$

$$\boxed{\therefore I = \frac{35}{4.3} = 8.1 \text{ Amp.}}$$

$\therefore I_1 = I \times \frac{2}{4+2} = 8.1 \times \frac{2}{6} = 2.7$ Amp //.

Step 2 :- operate with one voltage source i.e 40 volts & other source i.e 35 volts is replaced by their internal resistances [Short circuit of voltage source i.e $r=0$]



$$\boxed{\therefore I = \frac{V}{R_{eq}}}$$

$R_{eq} = 4$ series with $3\|2$

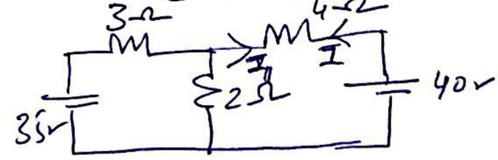
$= 4 + 3\|2$

$= 4 + \left(\frac{3\times2}{3+2}\right) = 4 + \left(\frac{6}{5}\right) = 5.2\,\Omega$

$$\boxed{\therefore I = \frac{40}{5.2} = 7.7 \text{ Amp.}}$$

Step 3:- When two sources operating at a time i.e 40V & 35V then the resultant current in 4Ω is $[I_1 - I]$

$= 7.7 - 2.7 = 5$ Amp.



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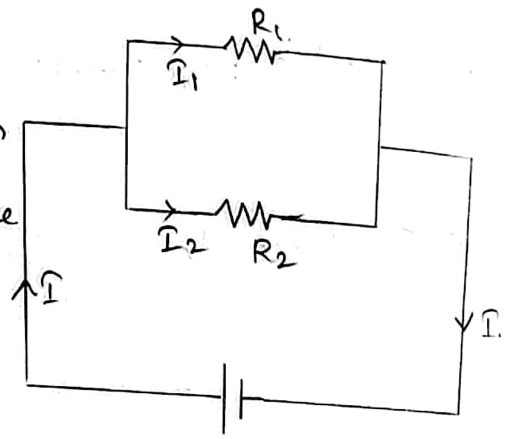
(iv) Reciprocal of Equivalent resistance is equal to the sum of the reciprocals of individual resistances.

1-17

$$\boxed{\frac{1}{R_{eq}} = \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Current Division Rule in Parallel Circuit :-

When two resistors are connected in parallel, then the currents I_1 and I_2 are given by



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

(ii) $I_2 = I \times \frac{R_1}{R_1+R_2}$

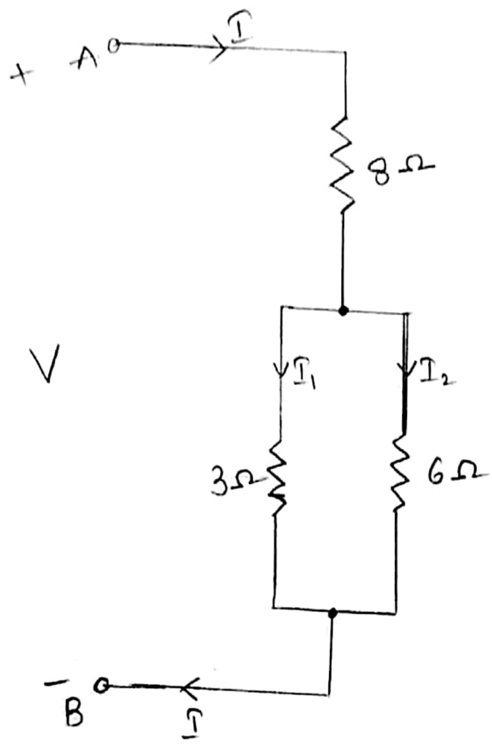
$$\boxed{\text{Individual Current} = \text{Total current} \times \frac{\text{Opposite resistance}}{\text{Total resistance}}}$$

SW

Equivalent Circuit (Equivalent Resistance) :-

Problem: 1

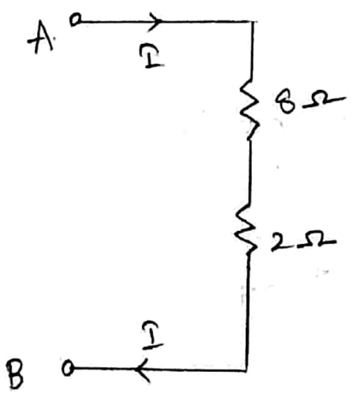
Find the equivalent resistance between the terminals A and B for the given circuit.



→ 3 Ω and 6 Ω are in parallel

$$\therefore \frac{3\times6}{3+6} = \frac{18}{9} = 2\,\Omega$$

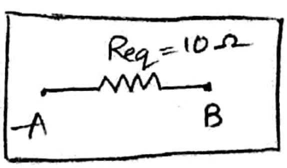
Reduce the circuit diagram



→ 8 Ω and 2 Ω are in series

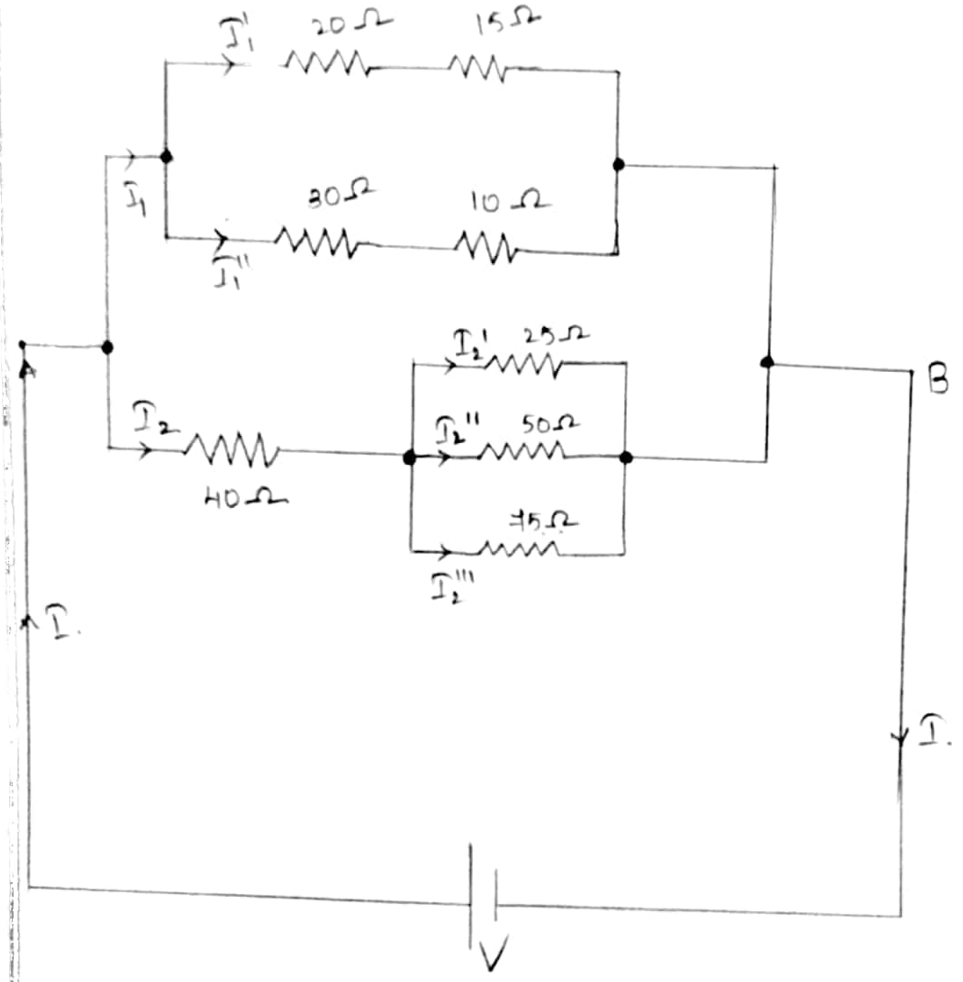
$$8+2 = 10\,\Omega$$

$$\therefore R_{eq} = 10\,\Omega$$



Problem: 2

Determine the equivalent resistance between the terminals A and B for the given circuit.

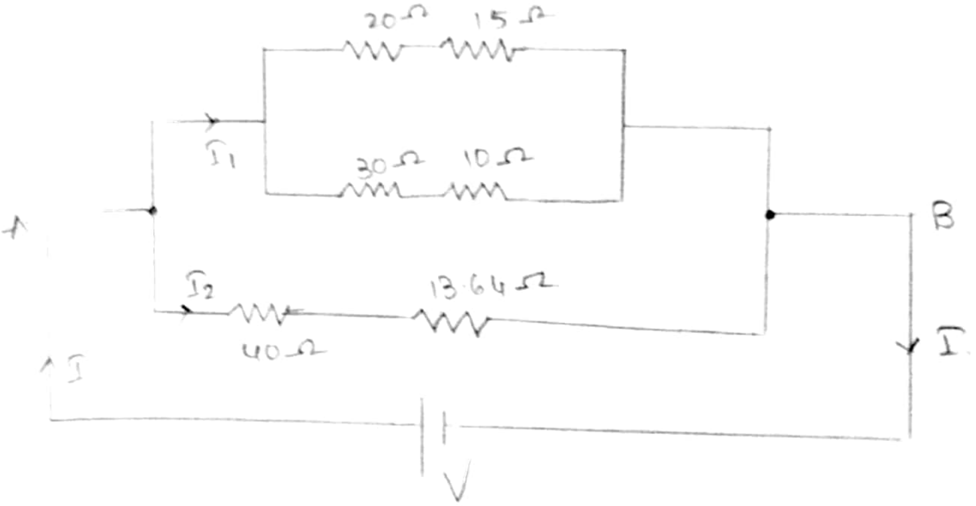


→ 25Ω, 50Ω, 75Ω are in parallel

$$\frac{1}{R_{eq}} = \frac{1}{R_T} = \frac{1}{25} + \frac{1}{50} + \frac{1}{75}$$

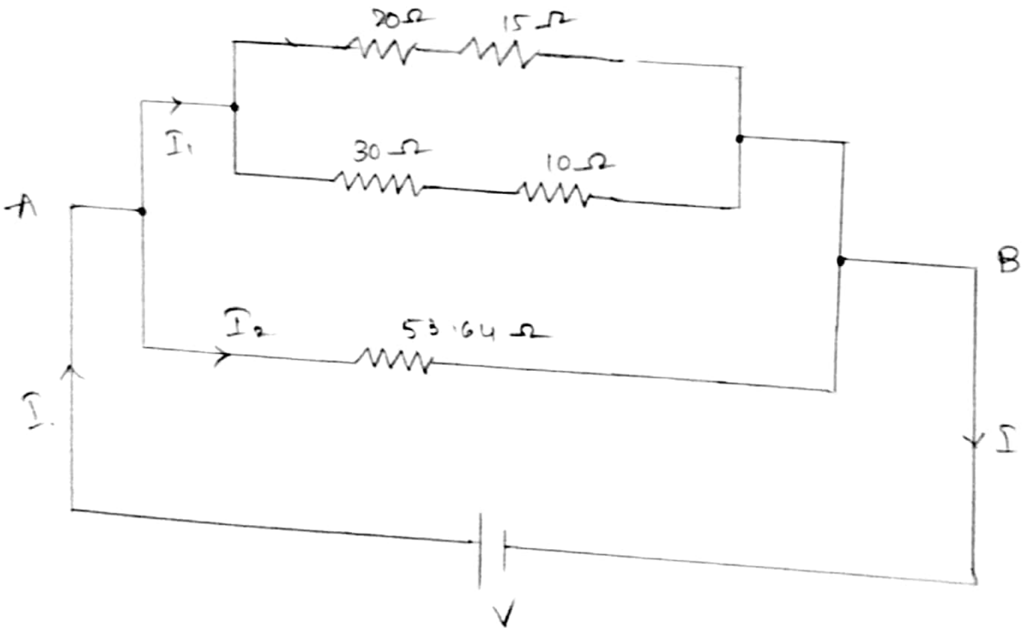
$$R_T = 13.64\,\Omega$$

Reduce the circuit diagram



→ 40 Ω and 13.64 Ω are in series

$R_{eq} = 40 + 13.64 = 53.64\,\Omega$ Reduce the circuit diagram



→ 30 Ω, 10 Ω are in series ⇒ 40

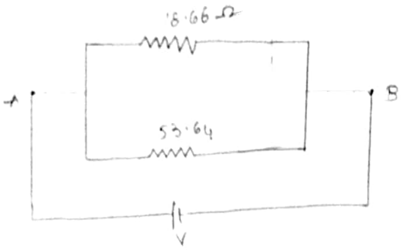
20 Ω, 15 Ω are in series ⇒ 35

~~35 and 40~~

35 and 40 are in parallel

$$R_{eq} = \frac{35 \times 40}{35 + 40} = 18.66\,\Omega$$

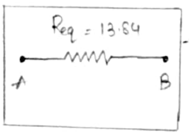
Reduce the circuit diagram



→ 18.66 Ω and 53.64 Ω are in parallel

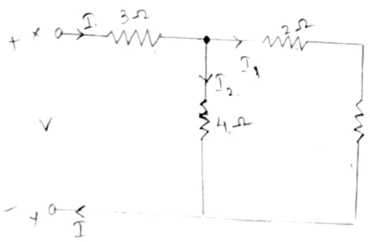
$$R_{eq} = \frac{18.66 \times 53.64}{18.66 + 53.64}$$

$$= 13.84\ \Omega$$



Problem: 3

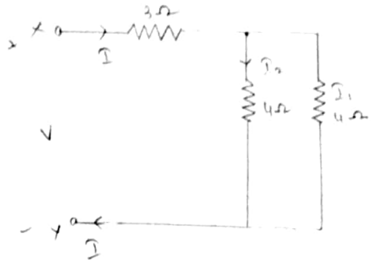
Find the equivalent resistance across the terminals X and Y



→ 2 Ω and 2 Ω are in series

$R_{eq} = 4\ \Omega$

Reduce the circuit diagram

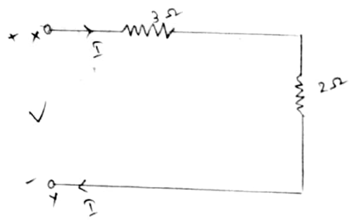


→ 4 Ω and 4 Ω are in parallel

$$\frac{1}{R_{eq}} = \frac{1}{4} + \frac{1}{4} = \frac{2}{4} = \frac{1}{2}$$

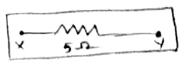
$R_{eq} = 2\ \Omega$

Reduce the circuit diagram



→ 3 Ω and 2 Ω are in series

$R_{eq} = 3 + 2 = 5\ \Omega$



$$R_AR_B + R_BR_C + R_CR_A = \frac{R_1^2R_2R_3}{(R_1+R_2+R_3)^2} + \frac{R_1R_2R_3^2}{(R_1+R_2+R_3)^2} + \frac{R_1R_2^2R_3}{(R_1+R_2+R_3)^2}$$

$$R_AR_B + R_BR_C + R_CR_A = \frac{R_1R_2R_3\,(\cancel{R_1+R_3+R_2})}{(R_1+R_2+R_3)^{\cancel{2}\,1}}$$

$$R_AR_B + R_BR_C + R_CR_A = \frac{R_1R_2R_3}{R_1+R_2+R_3}$$

Dividing by R_A on both sides

$$\frac{R_AR_B + R_BR_C + R_CR_A}{R_A} = \frac{\cancel{R_1}\cancel{R_2}R_3}{\cancel{R_1+R_2+R_3}} \times \frac{\cancel{R_1+R_2+R_3}}{\cancel{R_1R_2}}$$

$$\boxed{R_3 = \frac{R_AR_B + R_BR_C + R_CR_A}{R_A}}$$

Similarly,

$$R_2 = \frac{R_AR_B + R_BR_C + R_CR_A}{R_B}$$

$$R_1 = \frac{R_AR_B + R_BR_C + R_CR_A}{R_C}$$

1-23

Problem: 1

Find the equivalent resistance of the circuit between the points A and B of the figure shown.

$$R_AR_B + R_BR_C + R_CR_A = \frac{R_1^2R_2R_3}{(R_1+R_2+R_3)^2} + \frac{R_1R_2R_3^2}{(R_1+R_2+R_3)^2} + \frac{R_1R_2^2R_3}{(R_1+R_2+R_3)^2}$$

$$R_AR_B + R_BR_C + R_CR_A = \frac{R_1R_2R_3\,(R_1 \cancel{+ R_3 + R_2})}{(R_1+R_2+R_3)^{\cancel{2}\,1}}$$

$$R_AR_B + R_BR_C + R_CR_A = \frac{R_1R_2R_3}{R_1+R_2+R_3}$$

Dividing by R_A on both sides

$$\frac{R_AR_B + R_BR_C + R_CR_A}{R_A} = \frac{\cancel{R_1}R_2R_3}{R_1\cancel{+R_2}+R_3} \times \frac{R_1\cancel{+R_2}+R_3}{\cancel{R_1}R_2}$$

$$\boxed{R_3 = \frac{R_AR_B + R_BR_C + R_CR_A}{R_A}}$$

Similarly,

$$R_2 = \frac{R_AR_B + R_BR_C + R_CR_A}{R_B}$$

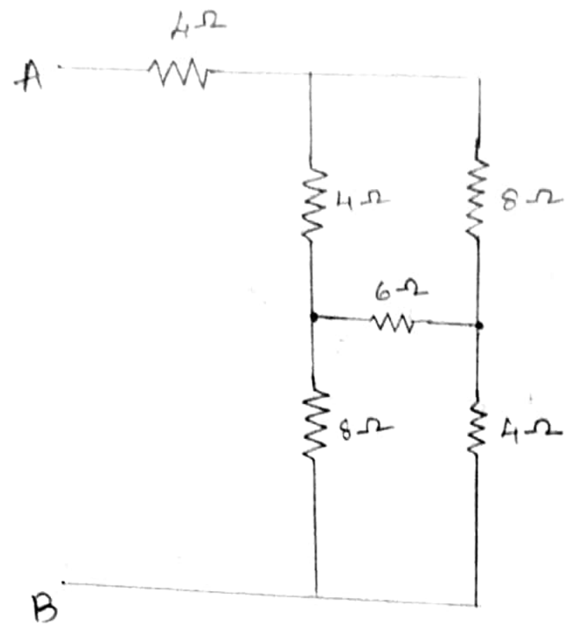
$$R_1 = \frac{R_AR_B + R_BR_C + R_CR_A}{R_C}$$

1-23

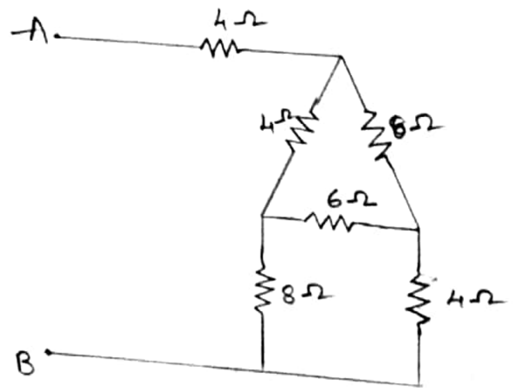
Problem: 1

Find the equivalent resistance of the circuit between the points A and B of the figure shown.

1-24



→ Top one, bend 4Ω, 8Ω and 6Ω



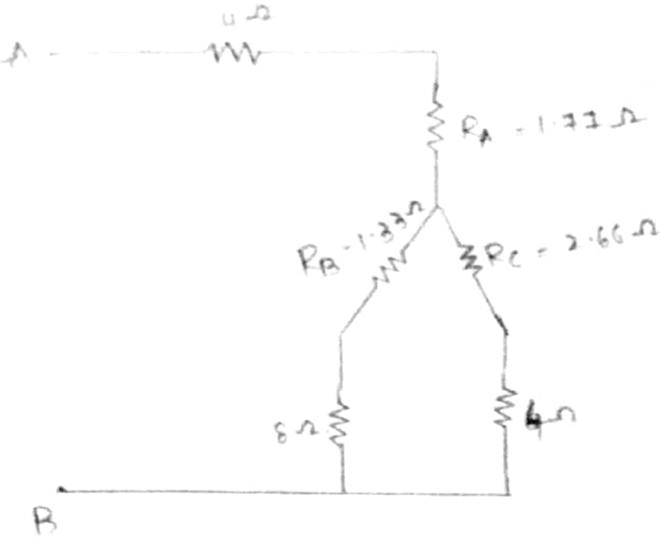
→ 4Ω, 8Ω, 6Ω top one is in Δ - shape. Apply Δ-Y Technique

$$R_A = \frac{4\times 8}{4+6+8} = \frac{\cancel{32}^{16}}{\cancel{18}_{9}} = 1.77\,\Omega$$

$$R_B = \frac{4\times 6}{4+6+8} = \frac{\cancel{24}^{\cancel{12}^{4}}}{\cancel{18}_{\cancel{9}_{3}}} = 1.33\,\Omega$$

$$R_C = \frac{8\times 6}{4+6+8} = \frac{\cancel{48}^{\cancel{24}^{8}}}{\cancel{18}_{\cancel{9}_{3}}} = 2.66\,\Omega$$

Reduce the circuit diagram

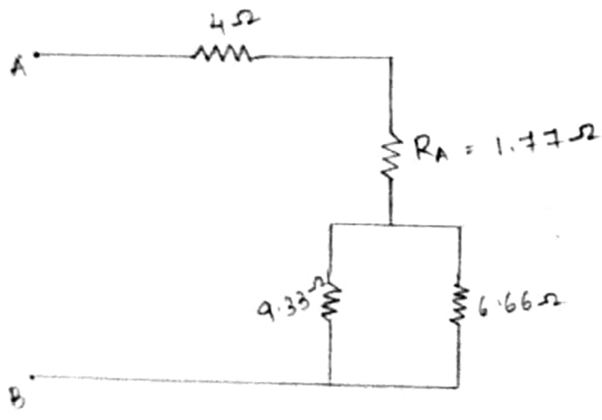


→ R_C = 2.66 Ω and 4 Ω are in series and also R_B = 1.33 Ω and 8 Ω are in series

$$2.66 + 4 = 6.66\ \Omega$$

$$1.33 + 8 = 9.33\ \Omega$$

Reduce the circuit diagram

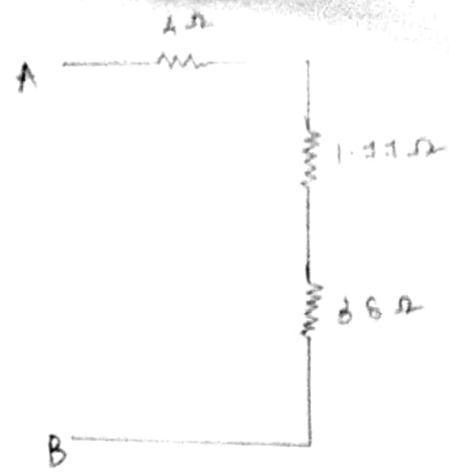


→ 9.33 Ω and 6.66 Ω are in parallel

$$\frac{9.33 \times 6.66}{9.33 + 6.66} = \cancel{13.32\ \Omega}\ 3.8\ \Omega$$

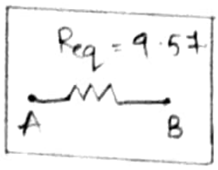
Reduce the circuit diagram

1-26



→ 4Ω, 1.77Ω and 3.8Ω are in series

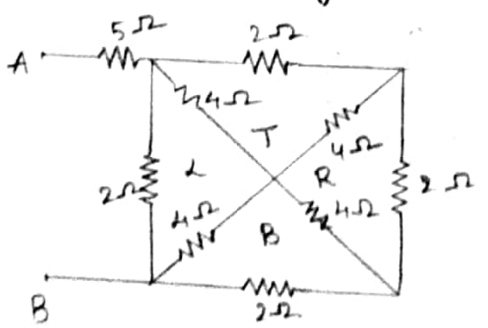
$4 + 1.77 + 3.8 = 9.57\,\Omega$



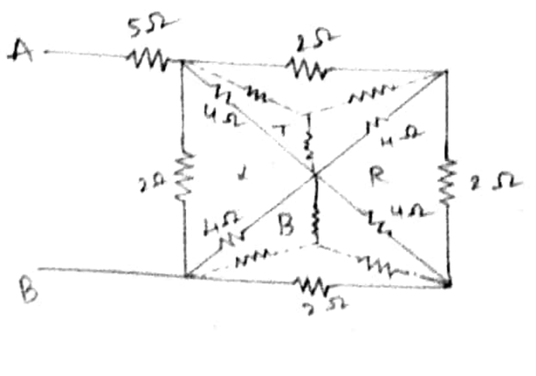
12/1/19

Problem: 2

Find the equivalent resistance between the terminals A, B for the circuit given below.



Sol:-



→ Top one, 4Ω, 2Ω and 4Ω are in Δ

Apply Δ - Y technique,

$$R_A = \frac{4 \times 2}{4+2+4} = 0.8\,\Omega$$

$$R_B = \frac{2 \times 4}{4+2+4} = 0.8\,\Omega$$

$$R_C = \frac{4 \times 4}{4+2+4} = 1.6\,\Omega$$

→ Bottom one 4Ω, 4Ω and 2Ω are in Δ

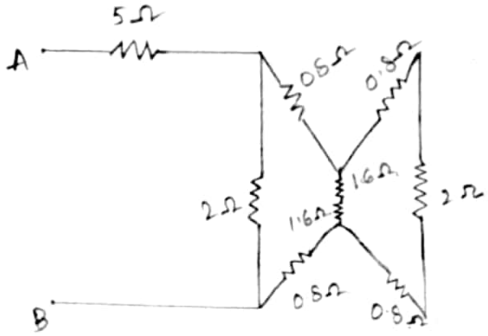
Apply Δ - Y technique.

$$R_D = \frac{4 \times 4}{4+2+4} = 1.6\,\Omega$$

$$R_E = \frac{4 \times 2}{10} = 0.8\,\Omega$$

$$R_F = \frac{4 \times 2}{4+2+4} = 0.8\,\Omega$$

Reduce the circuit diagram

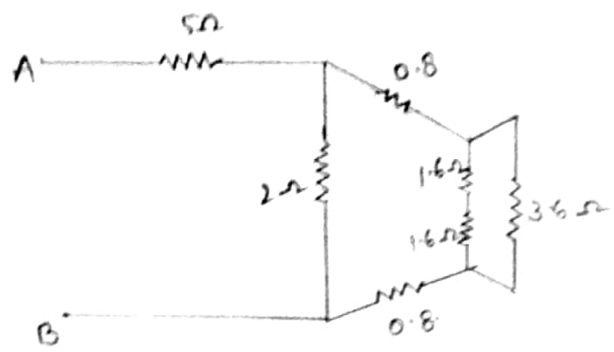


→ $R_B = 0.8\,\Omega$, 2Ω and $R_F = 0.8\,\Omega$ are in Series

$$0.8 + 2 + 0.8 = 3.6\,\Omega$$

Reduce the circuit diagram.

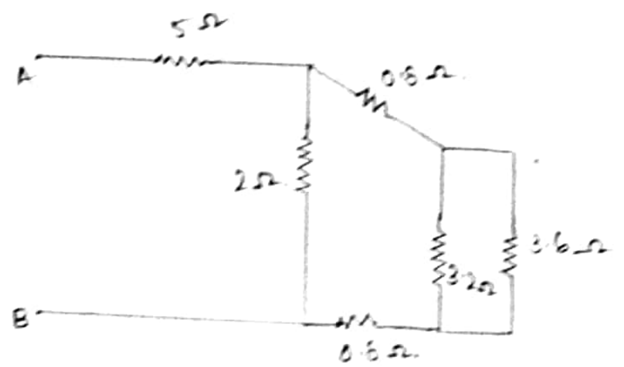
1-28



→ 1.6 Ω and 1.6 Ω are in series

$$1.6 + 1.6 = 3.2\ \Omega$$

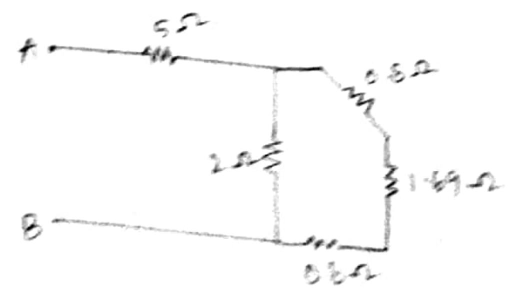
Reduce the circuit diagram



→ 3.6 Ω and 3.2 Ω are in parallel

$$\frac{3.6 \times 3.2}{3.6 + 3.2} = \cancel{16.9\ \Omega}\ 1.69\ \Omega$$

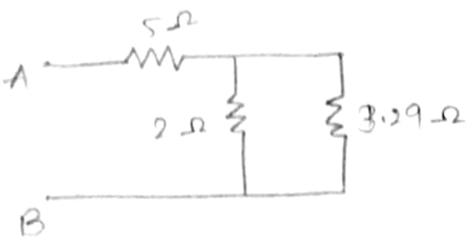
Reduce the circuit diagram.



→ 0.8 Ω, 1.69 Ω and 0.8 Ω are in series

$$0.8 + 1.69 + 0.8 = 3.29\ \Omega$$

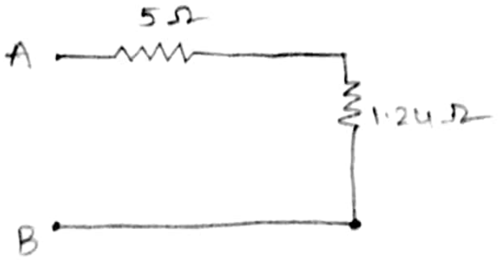
Reduce the circuit diagram



→ 2Ω and 3.29Ω are in parallel

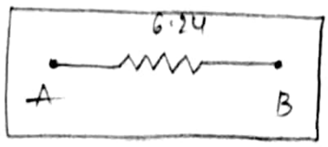
$$\frac{2 \times 3.29}{2 + 3.29} = 1.24\,\Omega$$

Reduce the circuit diagram



→ 5Ω and 1.2Ω are in series

$= 5\Omega + 1.24\Omega = 6.24\,\Omega$

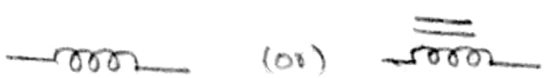


Inductance :-

Definition :-

It is defined as which opposes change in current through the coil.

Symbol:-



(i) Same voltage acts across all parts of the circuit.

(ii) Different inductors have their individual currents.

(iii) Total current is equal to sum of the individual currents i.e.,

$$I = I_1 + I_2 + I_3$$

(iv) The reciprocal of equivalent inductance is equal to sum of reciprocal of individual inductances

i.e., $$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$

Equivalent Inductance :-

Procedure of equivalent inductance = Procedure of equivalent resistance.

1-30

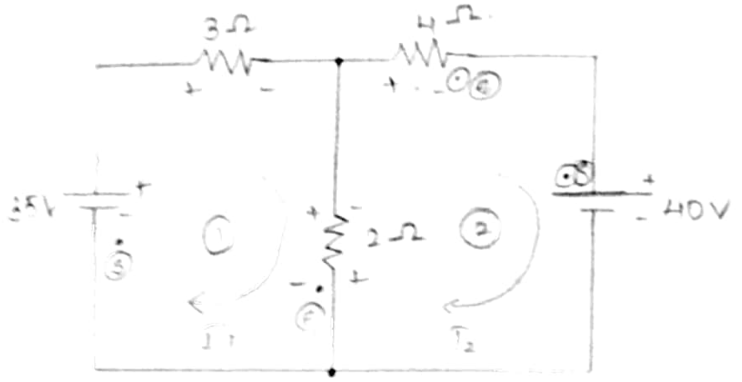
Mesh Analysis :-

(Loop method)

Problem : 1

Find the current through the resistors and voltage drop across each resistor for the network shown in figure.

1-3



Applying KVL to loop ①

$\sum EMF + \sum V.D = 0$

$+35 - 3I_1 - 2(I_1 - I_2) = 0$

$35 - 3I_1 - 2I_1 + 2I_2 = 0$

$35 - 5I_1 + 2I_2 = 0 \Rightarrow 5I_1 - 2I_2 - 35 = 0$ — ①

Applying KVL to loop ②

$-40 - 2(I_2 - I_1) - 4I_2 = 0$

$-40 - 2I_2 + 2I_1 - 4I_2 = 0$

$2I_1 - 6I_2 - 40 = 0$ — ②

Solving I_1 and I_2 by cramer's rule

$$\begin{bmatrix} 5 & -2 \\ 2 & -6 \end{bmatrix}\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 35 \\ 40 \end{bmatrix}$$

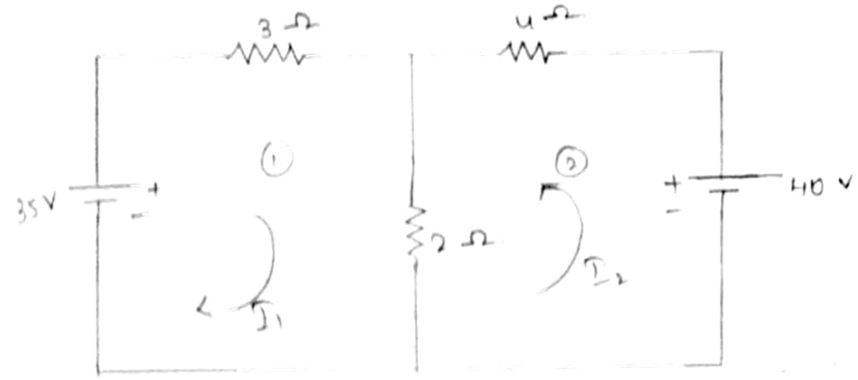
$$\Delta = \begin{bmatrix} 5 & -2 \\ 2 & -6 \end{bmatrix} = -30 + 4 = -26$$

$$\Delta_1 = \begin{vmatrix} 35 & -2 \\ 40 & -6 \end{vmatrix} = -210 + 80 = -130$$

$\Delta_2 = \begin{vmatrix} 5 & 35 \\ 2 & 40 \end{vmatrix} = 200 - 70 = +130 = 130$

$I_1 = \dfrac{\Delta_1}{\Delta} = \dfrac{\cancel{-130}^{\,65}}{\cancel{-26}_{\,13}} = 5 \text{ Amp}$

$I_2 = \dfrac{\Delta_2}{\Delta} = \dfrac{130}{-26} = -5 \text{ Amp}$



The current through 3 Ω is $I_1 = 5$ Amp.

The current through 4 Ω is $I_2 = 5$ Amp.

The current through 2 Ω is $I_1 + I_2 = 10$ Amp

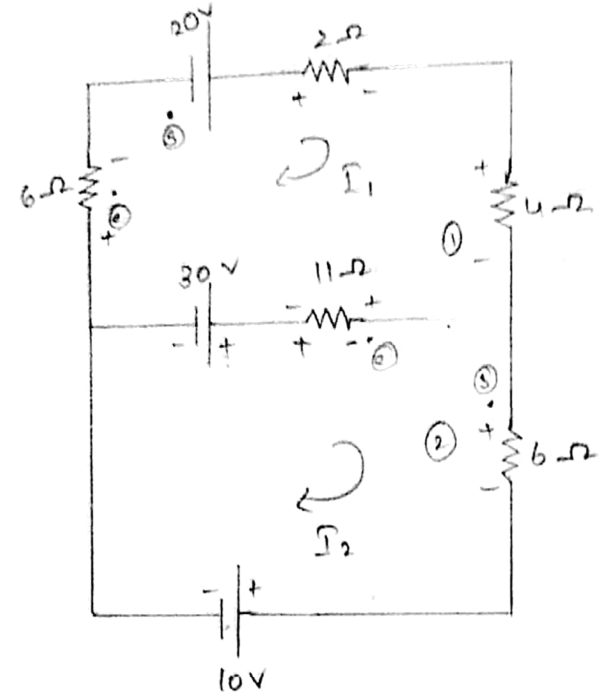
∴ voltage drop across 3 Ω is $I_1 \times 3 = 15$ V

∴ voltage drop across 4 Ω is $I_2 \times 4 = 20$ V

∴ Voltage drop across 2 Ω is $(I_1 + I_2) 2 = 20$ V

Problem: 2

In the circuit shown in figure, determine the currents in each of the batteries.



1-33

Applying KVL to loop ①

$\Sigma EMF + \Sigma V.D = 0$

$20 - 2I_1 - 4I_1 - 11(I_1 - I_2) - 30 - 6I_1 = 0$

$20 - 2I_1 - 4I_1 - 11I_1 + 11I_2 - 30 - 6I_1 = 0$

$-10 - 23I_1 + 11I_2 = 0$

$23I_1 - 11I_2 = -10$ — ①

Applying KVL to loop ②

$-6I_2 - 10 + 30 - 11(I_2 - I_1) = 0$

$-6I_2 - 10 + 30 - 11I_2 + 11I_1 = 0$

$11I_1 - 17I_2 = -20$ — ②

Solving ① and ② using cramer's rule

$$\Delta = \begin{vmatrix} 23 & -11 \\ 11 & -17 \end{vmatrix} = -270$$

$$\Delta_1 = \begin{vmatrix} -10 & -11 \\ -20 & -17 \end{vmatrix} = -50$$

$$\Delta_2 = \begin{vmatrix} 23 & -10 \\ 11 & -20 \end{vmatrix} = -350$$

$$I_1 = \frac{\Delta_1}{\Delta} = \frac{-50}{-270} = 0.18 \text{ Amp}$$

$$I_2 = \frac{-350}{-270} = 1.29 \text{ Amp}$$

$\therefore$ The current through 20V is $I_1 = 0.18$ Amp

$\therefore$ The current through 30V is $I_2 - I_1 = 1.29 - 0.18 = 1.11$ Am

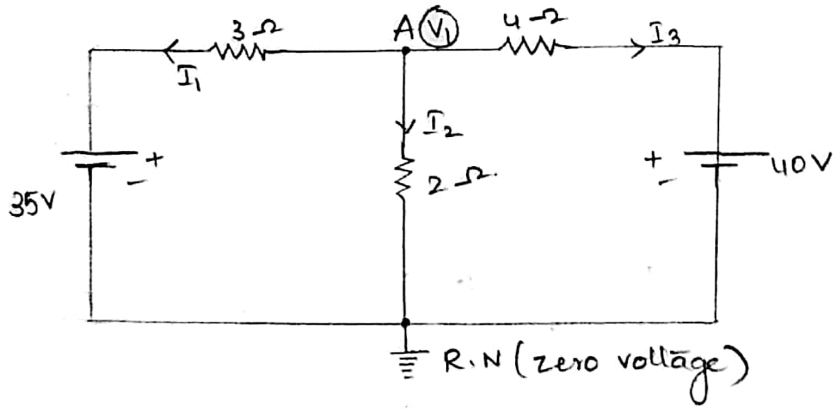
$\therefore$ The current through 10V is $I_2 = 1.29$ Amp.

4/11/19

Nodal Analysis :-
(Junction method)

Problem : 1

Find the current through the given resistors.



Applying KCL at Node A.

$$-I_1 - I_2 - I_3 = 0$$

$I_1 + I_2 + I_3 = 0.$

$$\left(\frac{V_1 - 35 - 0}{3}\right) + \left(\frac{V_1 - 0}{2}\right) + \left(\frac{V_1 - 40 - 0}{4}\right) = 0$$

$$\frac{4V_1 - 140 + 6V_1 + 3V_1 - 120}{12} = 0$$

$$4V_1 + 6V_1 + 3V_1 - 260 = 0$$

$$13V_1 - 260 = 0$$

$$V_1 = \frac{260}{13}$$

$$V_1 = 20V$$

∴ The current through 3Ω is $I_1 = \frac{V_1 - 35 - 0}{3}$

$$= \frac{20 - 35}{3}$$

$$= \frac{-15}{3}$$

$$= -5 \text{ Amp}$$

∴ The current through 4Ω is $I_3 = \frac{V_1 - 40 - 0}{4}$

$$= \frac{20 - 40}{4}$$

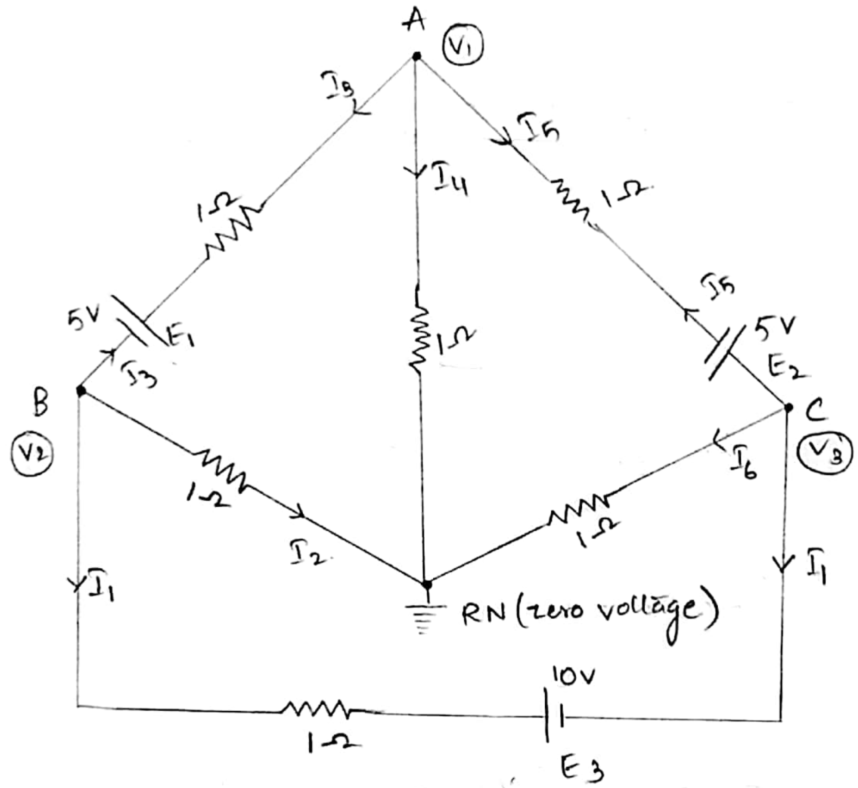
$$= \frac{-20}{4}$$

$$= -5 \text{ Amp}$$

∴ The current through 2Ω is $I_2 = \frac{V_1 - 0}{2} = \frac{20}{2} = 10 \text{ Amp}$

Problem: 2 1236

Find the current through the batteries E_1, E_2 and E_3 for the network given below.



Applying KCL at node B :-

$$-I_1 - I_2 - I_3 = 0$$

$$I_1 + I_2 + I_3 = 0$$

$$\left(\frac{V_2 - 10 - V_3}{1}\right) + \left(\frac{V_2 - 0}{1}\right) + \left(\frac{V_2 + 5 - V_1}{1}\right) = 0$$

$$V_2 - 10 - V_3 + V_2 + V_2 + 5 - V_1 = 0$$

$$-V_1 + 3V_2 - V_3 - 5 = 0$$

$$V_1 - 3V_2 + V_3 = -5 \quad \text{—} (1)$$

Applying KCL at node A:-

$$-I_3 - I_4 - I_5 = 0$$

$$I_3 + I_4 + I_5 = 0$$

$$\left(\frac{V_1 - 5 - V_2}{1}\right) + \left(\frac{V_1 - 0}{1}\right) + \left(\frac{V_1 + 5 - V_3}{1}\right) = 0$$

$$V_1 - 5 - V_2 + V_1 + V_1 + 5 - V_3 = 0$$

$$3V_1 - V_2 - V_3 = 0 \quad — (2)$$

Applying KCL at node C:-

$$-I_1 - I_5 - I_6 = 0$$

$$I_1 + I_5 + I_6 = 0$$

$$\left(\frac{V_3 + 10 - V_2}{1}\right) + \left(\frac{V_3 - 5 - V_1}{1}\right) + \left(\frac{V_3 - 0}{1}\right) = 0$$

$$V_3 + 10 - V_2 + V_3 - 5 - V_1 + V_3 = 0$$

$$-V_1 - V_2 + 3V_3 + 5 = 0$$

$$V_1 + V_2 - 3V_3 - 5 = 0$$

$$V_1 + V_2 - 3V_3 = 5 \quad — (3)$$

Solving (1), (2) and (3) using cramer's rule:-

$$\begin{bmatrix} 1 & -3 & 1 \\ 3 & -1 & -1 \\ 1 & 1 & -3 \end{bmatrix} \begin{pmatrix} V_1 \\ V_2 \\ V_3 \end{pmatrix} = \begin{bmatrix} -5 \\ 0 \\ 5 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 1 & -3 & 1 \\ 3 & -1 & -1 \\ 1 & 1 & -3 \end{vmatrix} = 1(3+1) + 3(-9+1) + 1(3+1)$$

$$= -16$$

$$\Delta_1 = \begin{vmatrix} 5 & 2 & 1 \\ 0 & 1 & 1 \\ 5 & 1 & 2 \end{vmatrix} = 5(2-1) - 2(5) + 1(5) \qquad 1 = 3?$$

$$= 0$$

$$\Delta_2 = \begin{vmatrix} 1 & -5 & 1 \\ -2 & 0 & 1 \\ 1 & 5 & 2 \end{vmatrix} = 1(5) + 5(-4+1) + 1(15)$$

$$= 20$$

$$\Delta_3 = \begin{vmatrix} 1 & -2 & -5 \\ -2 & 1 & 0 \\ 1 & 1 & 5 \end{vmatrix} = 1(5) + 2(15) - 5(2+1)$$

$$= 20$$

$$V_1 = \frac{\Delta_1}{\Delta} = \frac{0}{16} = 0\,V$$

$$V_2 = \frac{\Delta_2}{\Delta} = \frac{20}{16} = 1.25\,V$$

$$V_3 = \frac{\Delta_3}{\Delta} = \frac{20}{16} = 1.25\,V$$

The current through $I_1 = I_2 = \frac{V_2+5-V_1}{1} = \frac{1.25+5-0}{1}$

$= 6.25$ Amp

The current through $I_2 = I_3 = \frac{V_1+5-V_3}{1} = \frac{0+5-1.25}{1}$

$= 6.25$ Amp

The current through $I_3 = I_1 =$

23/1/19

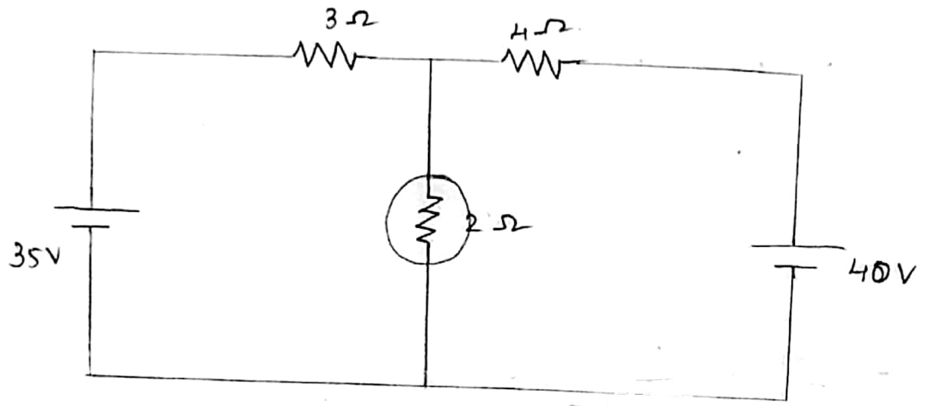
Superposition Theorem :-

volt source - $r=0$
current " - $r=\infty$

Problem : 1

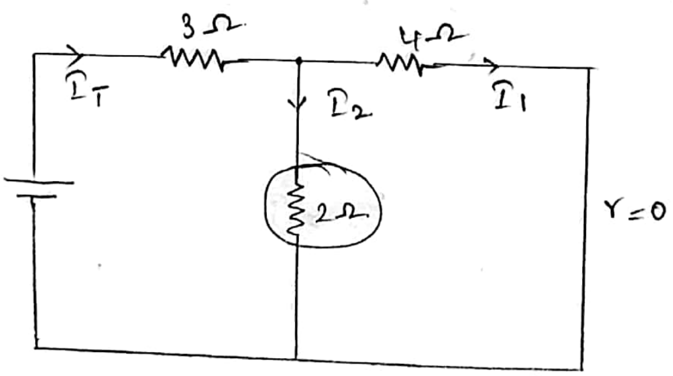
1-39

Find the current in 2Ω resistor by using Superposition Theorem.



Step:1

Operating with one source i.e 35 V source and remaining sources (i.e., 40V source) are replaced by their internal resistance (short circuit, $r=0$)



$V = I_T R_{eq}$

$I_T = \frac{V}{R_{eq}}$

$R_{eq} = 3 + 4 \parallel 2 = \frac{13}{3} = 4.3\ \Omega.$

$I_T = \frac{35}{4.3} = 8.13$ Amp

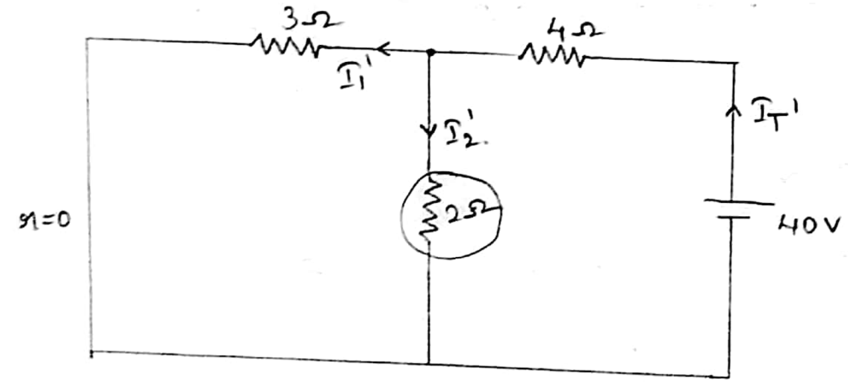
1-40

$I_2 = I_T \times \frac{4}{4+2}$

$I_2 = 5.42$ Amp

Step: 2

Operate with one source i.e 40V and remaining sources (i.e., 35V source) are replaced by their internal resistance (short circuit, r=0)



$V = I_T' R_{eq}$

$I_T' = \frac{V}{R_{eq}}$

$R_{eq} = 3 \| 2 + 4$

$= \frac{3 \times 2}{3+2} + 4$

$= \frac{6}{5} + 4$

$R_{eq} = 5.2\Omega$

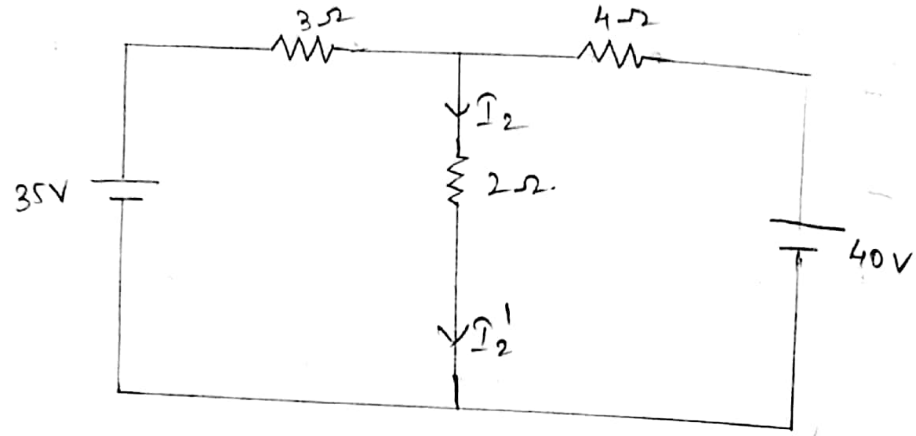
$I_T' = \frac{40}{5.2} = 7.69$ Amp

$I_2' = I_T' \times \frac{3}{5} = 4.614$ Amp

Step: 3

When two sources acting at a time then,

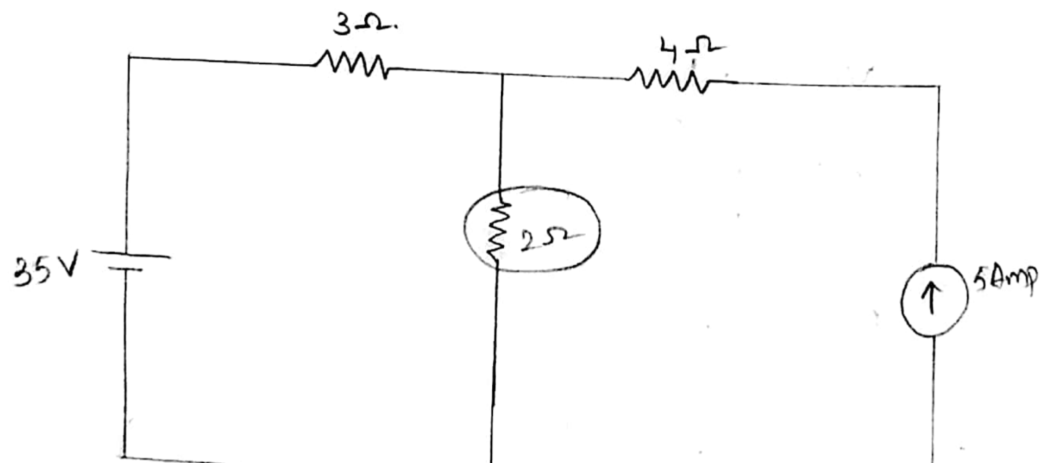
the current through 2Ω is



$\therefore$ Current through $2\Omega = I_2 + I_2' = 10$ Amp.

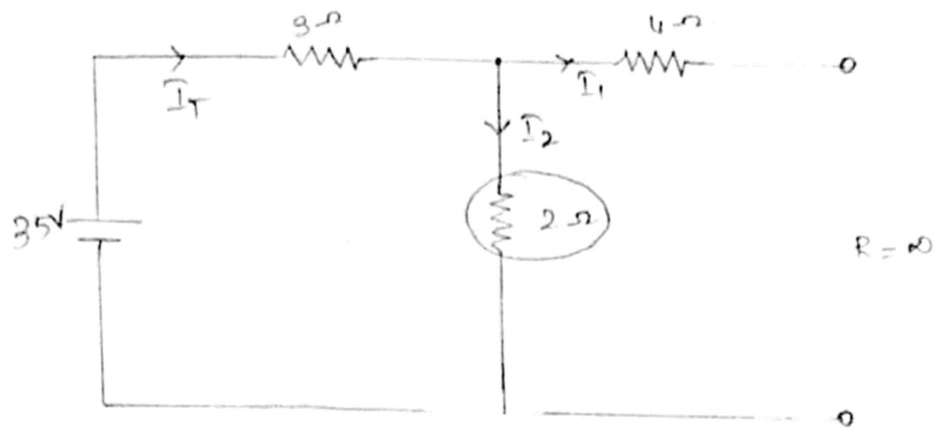
Problem : 2

Find the current through 2Ω by using superposition theorem.



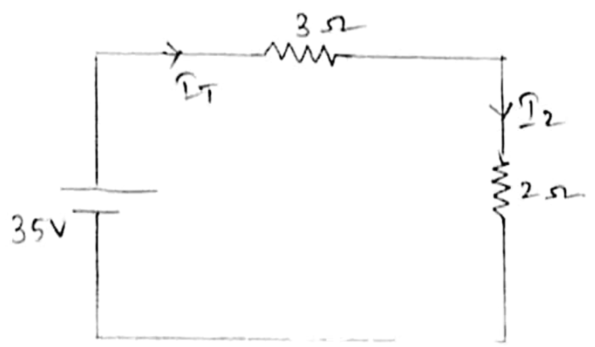
Step : 1

Operating one source (ie. 35V) and remaining sources (i.e., 5Amp current source) are replaced by their internal resistance (open circuit, $r = \infty$).



$V = I_T R_{eq}$

$I_1 = 0$ [∵ open circuit]



3Ω and 2Ω are in series

$\therefore I_T = I_2$

$$I_T = \frac{V}{R_{eq}}$$

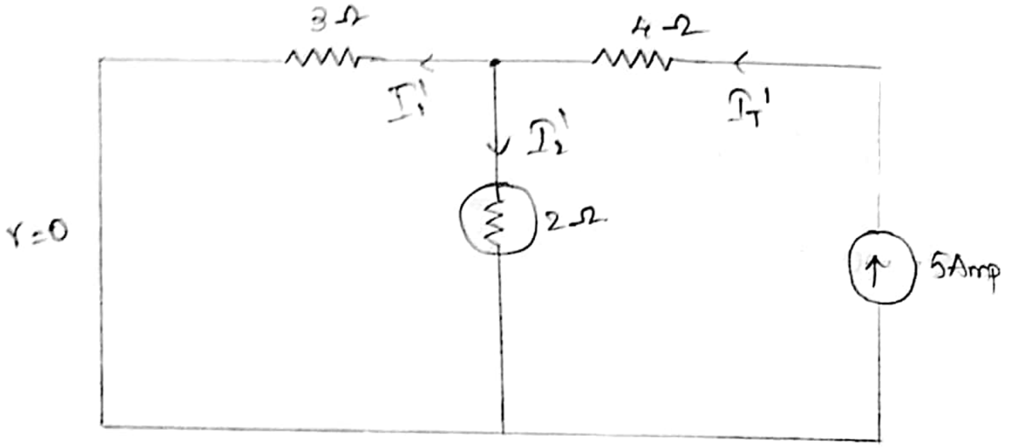
$R_{eq} = 5\Omega$

$$I_T = \frac{35}{5} \text{ Amp} = 7 \text{ Amp}$$

$\therefore I_2 = 7 \text{ Amp}$

Step: 2

Operating one source i.e., 5 Amp current source and remaining sources (i.e., 35 V voltage source) are ~~f~~ replaced by their internal resistance (short circuit, $r = 0$).



$I_T' = 5$ Amp

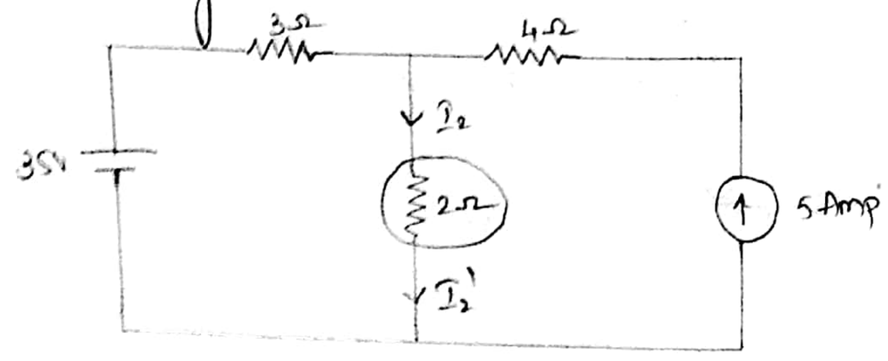
$$I_2' = I_T' \times \frac{3}{5}$$

$$= \frac{5 \times 3}{5}$$

$I_2' = 3$ Amp

Step: 3

When two sources acting at a time, then the current through 2Ω is



∴ Current through 2Ω is $I_2 + I_2' = 10$ Amp

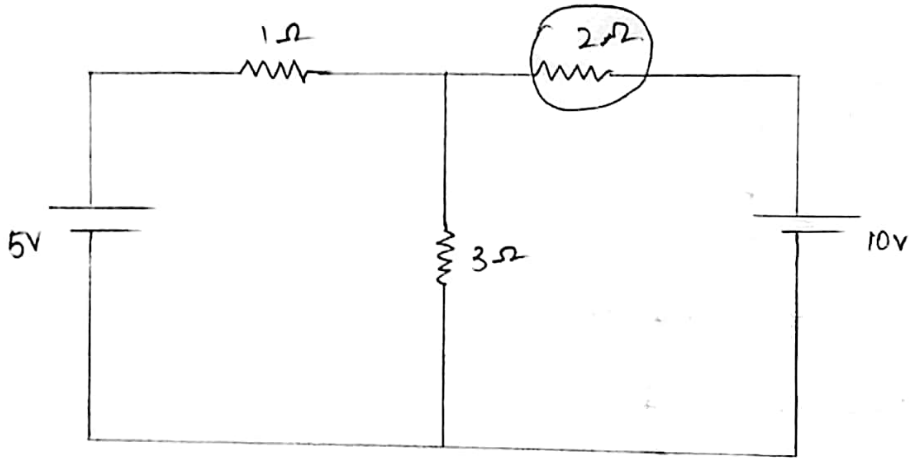
1-44

Statement of Superposition Theorem :-

In a linear network, containing more than one source then, the resultant current in any branch is the algebraic sum of currents that could be produced by when single source acting alone and all other remaining sources are replaced by their internal resistance (if v.s, short circuit r=0, if c.s, open circuit r=∞)

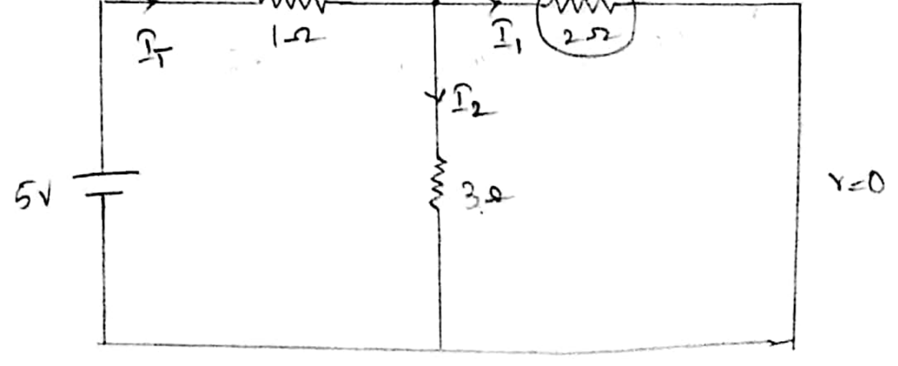
Problem : 3

Find the current through 2Ω using superposition theorem.



Step : 1

Operating one source i.e., 5V and remaining sources (i.e, 10v) are replaced by their internal resistance (short circuit, r=0)



$V = I_T R_{eq}$

$$I_T = \frac{V}{R_{eq}}$$

$$R_{eq} = 1 + 2 \| 3$$

$$= 1 + \frac{2 \times 3}{2+3}$$

$$= 1 + \frac{6}{5}$$

$$= \frac{11}{5}$$

$$= 2.2\ \Omega$$

$$I_T = \frac{V}{R_{eq}}$$

$$= \frac{5}{2.2}$$

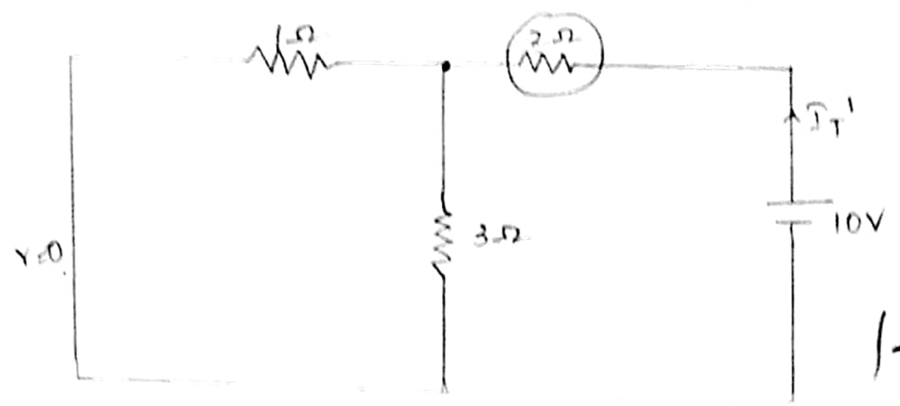
$$= 2.27\ \text{Amp}$$

$$I_1 = I_T \times \frac{3}{5}$$

$$= 1.36\ \text{Amp}$$

Step: 2

Operating one source i.e 10V source and remaining sources (i.e 5V) are replaced by their internal resistance (short circuit, r=0)



1-46

$$I_T' = \frac{V}{R_{eq}}$$

$$R_{eq} = 1 \| 3 + 2$$

$$= \frac{3}{4} + 2$$

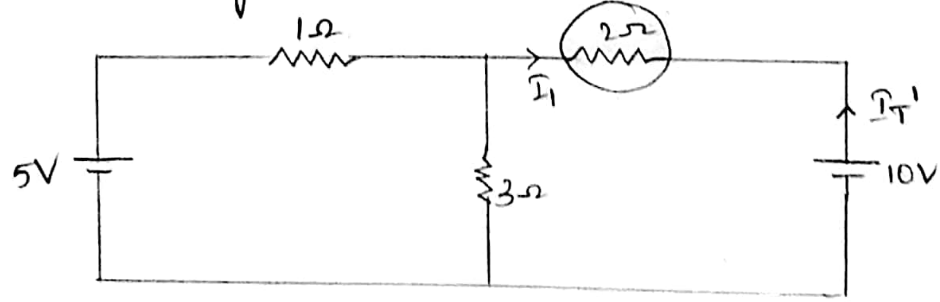
$$= \frac{11}{4}$$

$$= 2.75\,\Omega$$

$$I_T' = \frac{10}{2.75} = 3.63\text{ Amp}$$

Step: 3

~~Opera~~ When two sources acting at a time, then the current through 2Ω is



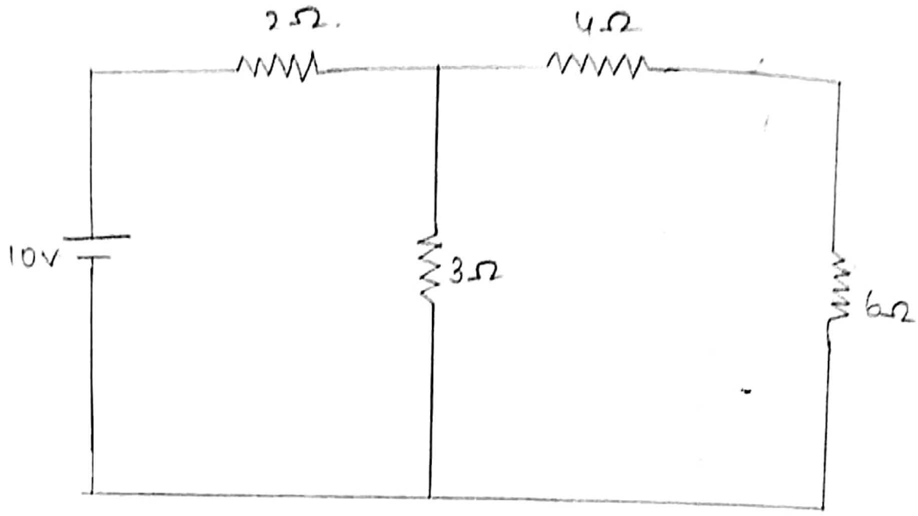
∴ current through 2Ω is $I_T' - I_1 = 3.63 - 1.36$
$= 2.27\text{ Amp}$

Thevenin's Theorem :-

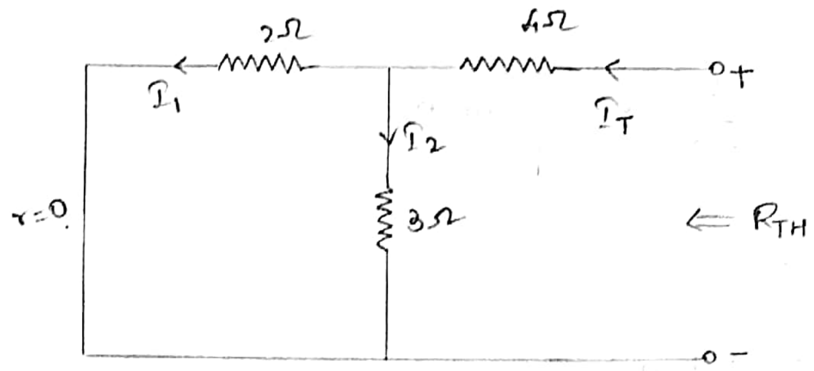
1-47

Problem : 1

Find the current through 6Ω by using Thevenin's Theorem.



R_{TH} :-



$$R_{TH} = 2 \parallel 3 + 4$$

$$= \frac{2 \times 3}{2+3} + 4$$

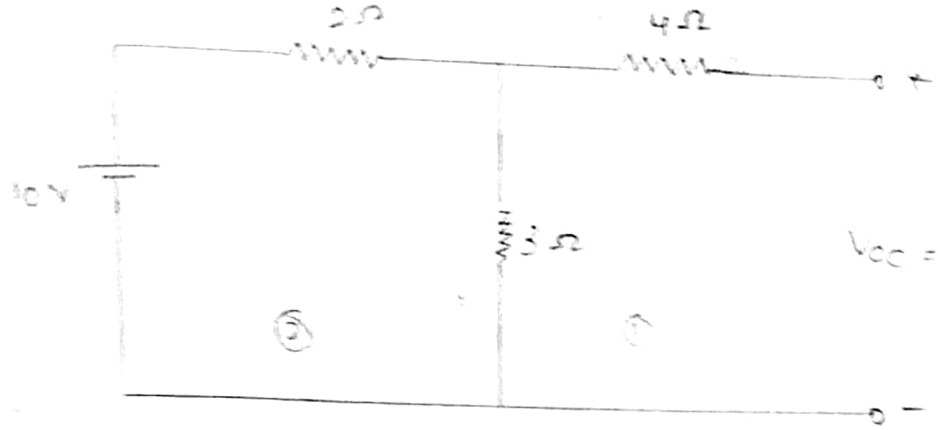
$$= \frac{6}{5} + 4$$

$$= \frac{6+20}{5}$$

$$= \frac{26}{5}$$

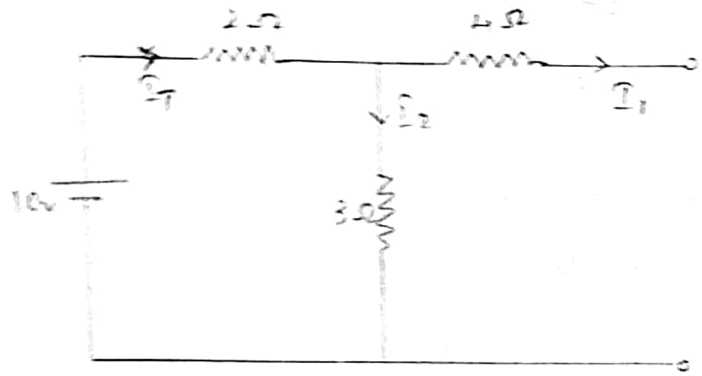
$$R_{TH} = 5.2\Omega$$

V_{TH} :-



Applying KVL to loop ① :-

$\boxed{\Sigma EMF + \Sigma V.D = 0}$

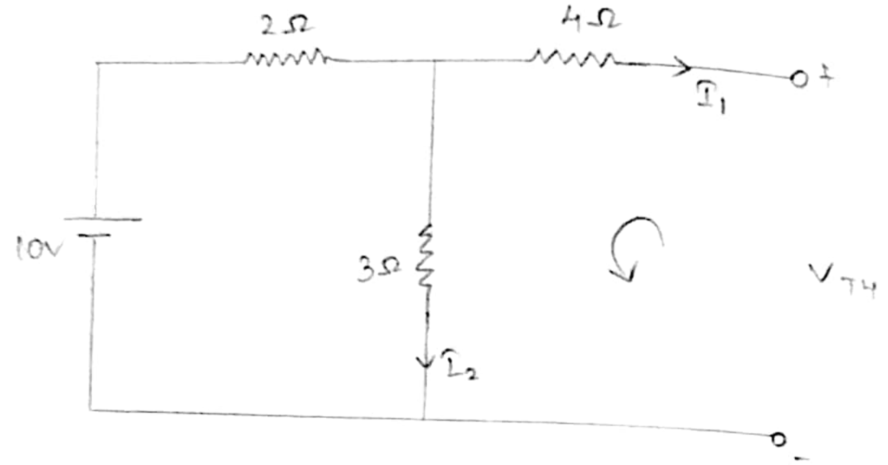


$\boxed{I_1 = 0}$ [∵ Open circuit (oc)]

$I_T = I_2$ [∵ 2Ω and 3Ω are in series]

$$I_T = \frac{V}{R_{eq}}$$

$I_T = \frac{10}{5.2} = 2\ \text{Amp}$



$V_{TH} + I_1 \cdot 4 - I_2 \cdot 3 = 0$

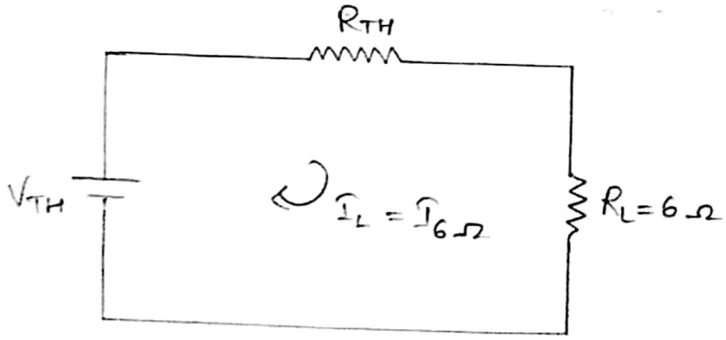
$4I_1 - 3I_2 + V_{TH} = 0$

$V_{TH} = 3I_2 - 4I_1$

$V_{TH} = 3(2) - 0$

$V_{OC} = V_{TH} = 6V$

Theverin's Equivalent Circuit :-



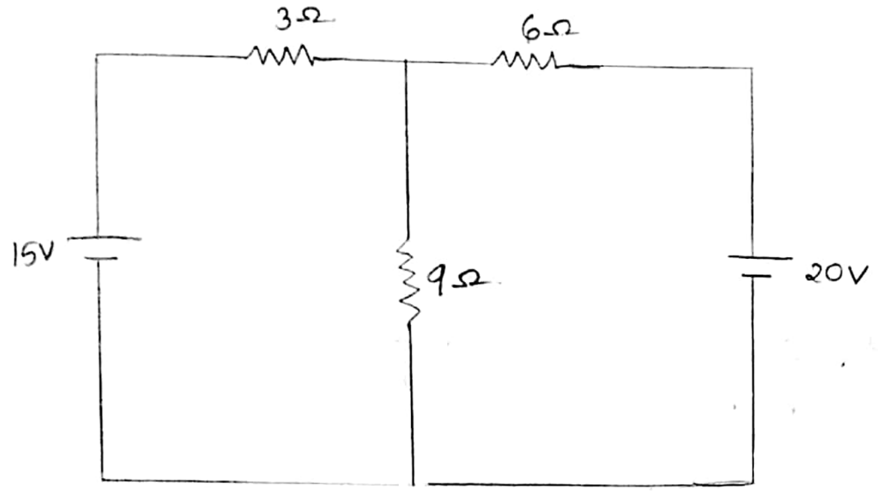
$$I_L = \frac{V_{TH}}{R_{TH} + R_L} = \frac{6}{5.2+6} = \frac{6}{11.2}$$

$I_L = 0.53\ \text{Amp}$

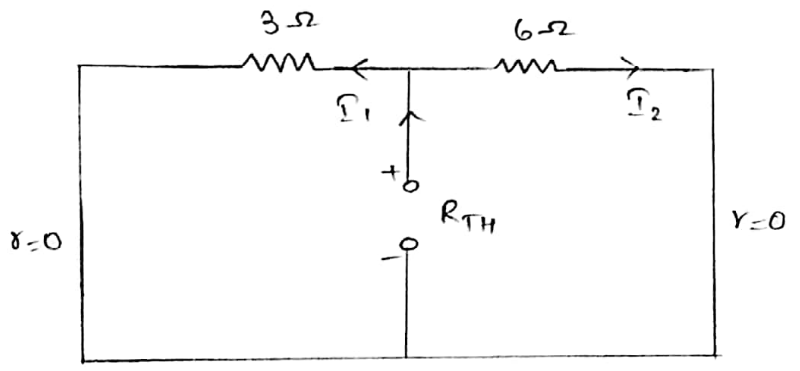
Problem : 2

1-50

Find the current through 9Ω using Thevenin's Theorem.



R_{TH} :-



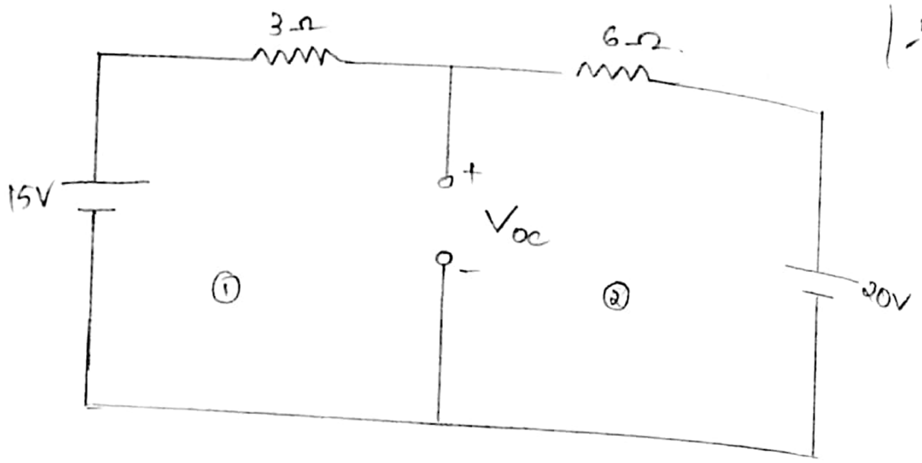
$$R_{TH} = 3 \parallel 6$$

$$= \frac{3 \times 6}{3+6}$$

$$= \frac{18}{9}$$

$$R_{TH} = 2\Omega$$

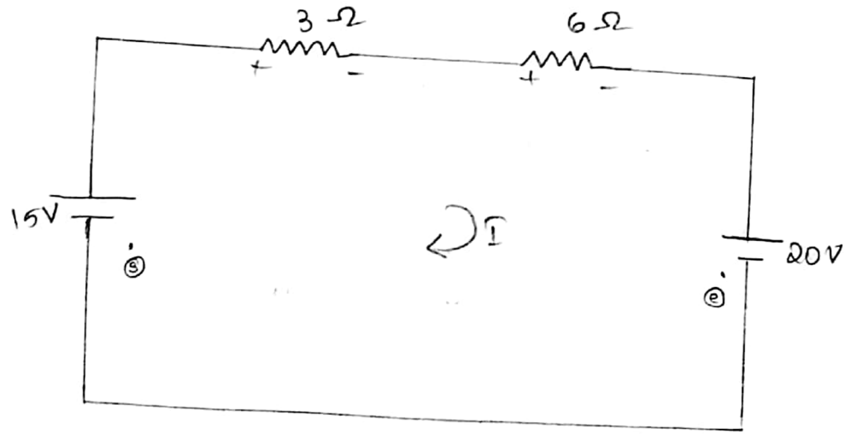
V_{TH} :-



1-5

Applying KVL at loop ②

ΣEMF + Σ V.D = 0



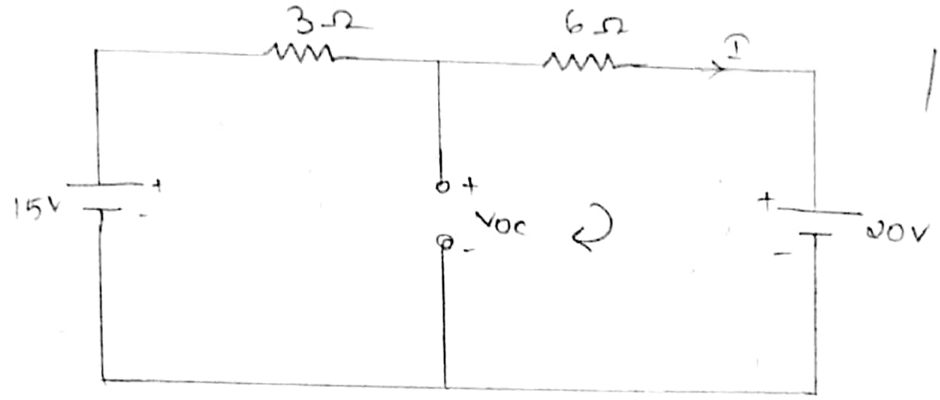
Applying KVL

$15 - 3I - 6I - 20 = 0$

$-9I = 5$

$I = -5/9$

$I = -0.5 \text{Amp}$



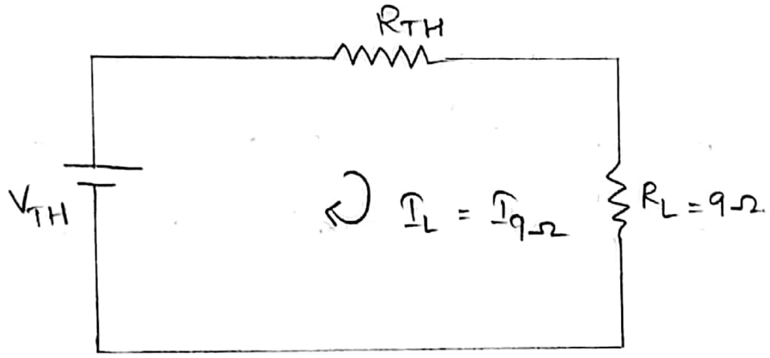
1-52

$$V_{oc} - 6I - 20 = 0$$

$$V_{oc} = 20 + 3$$

$$\boxed{V_{oc} = 23V}$$

Thevenin's Equivalent Circuit :-



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

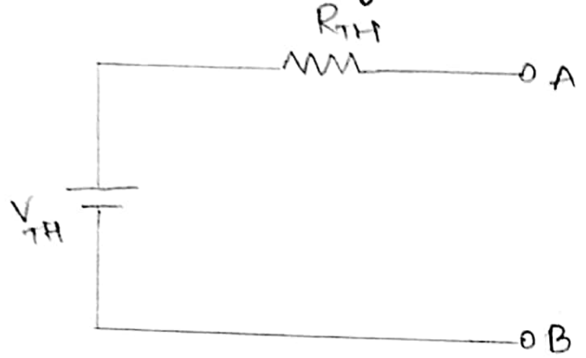
$$= \frac{23}{2+9}$$

$$= \frac{23}{11}$$

$$I_L = 2.08 \text{ Amp}$$

Statement of Thevenin's Theorem :-

In any network having terminals A and B can be replaced by voltage source (V_{TH}) in series with the single resistance (R_{TH})



(i) V_{TH} :- (V_{oc})

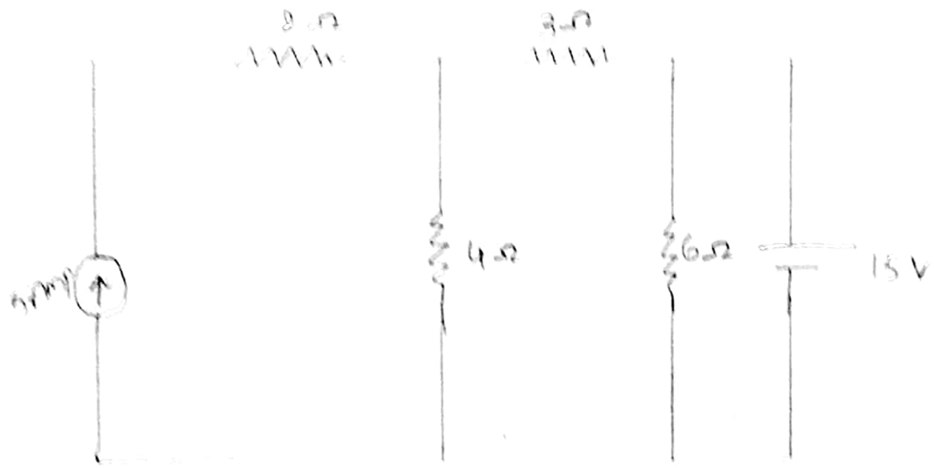
This is the voltage across the terminals A and B if any load removed i.e., open circuit voltage across the terminals. (V_{oc}).

(ii) R_{TH} :-

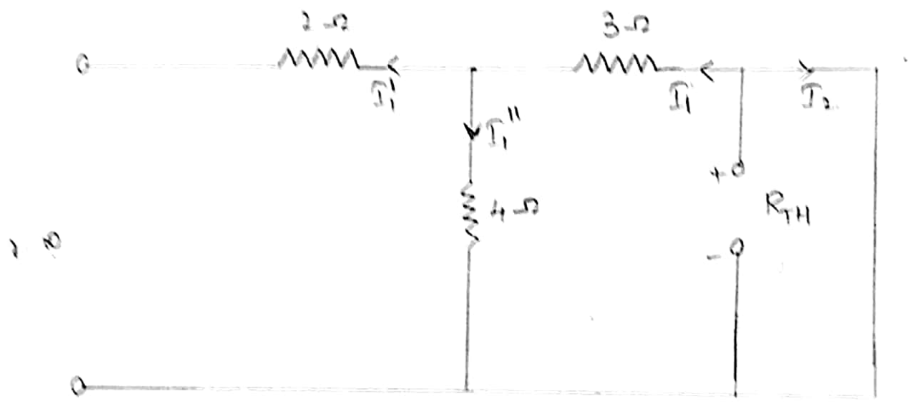
This is the resistance which measured between the terminals A and B if load removed and all other sources replaced by their internal resistances (if voltage source → short circuit ($r = 0$), if current source → open circuit ($r = \infty$))

Problem : 3

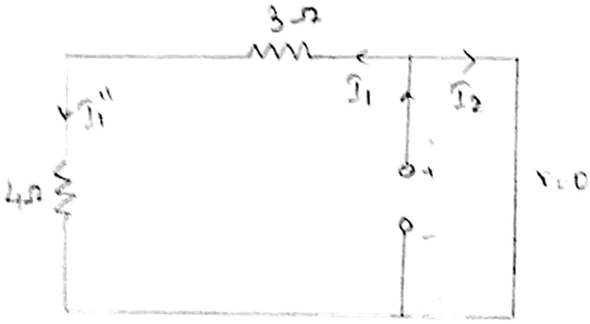
Find R_{TH} when 6Ω is the load



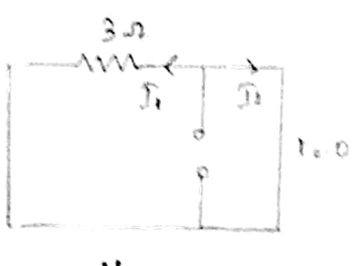
R_{TH} :



$I_1' = 0$ [∵ open circuit]



$I_1 = I_1''$ [∵ In series] $= 4+3 = 7\Omega$

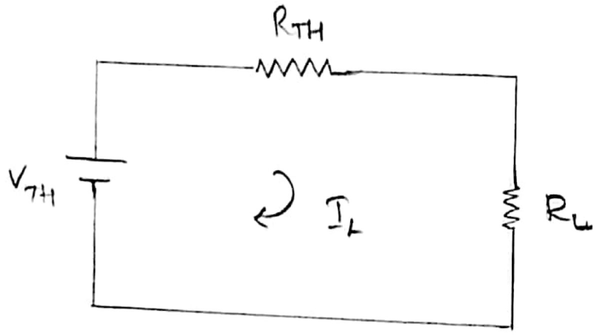


$R_{TH} = 7 \| 0 = 0\Omega$

Maximum Power Transfer Theorem :-

Statement : 1-5

It states that maximum power can be delivered from source to load when load resistance is equal to source resistance ($R_L = R_S$). R_S is nothing but R_{TH}



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

$$I_L = \frac{V_{TH}}{2R_{TH}} \quad [\because R_L = R_{TH}]$$

$$P_{max} = I_L^2 R_L$$

$$= \left[\frac{V_{TH}}{2R_{TH}}\right]^2 R_L$$

$$= \frac{V_{TH}^2}{4R_{TH}^2} \cdot \cancel{R_{TH}}$$

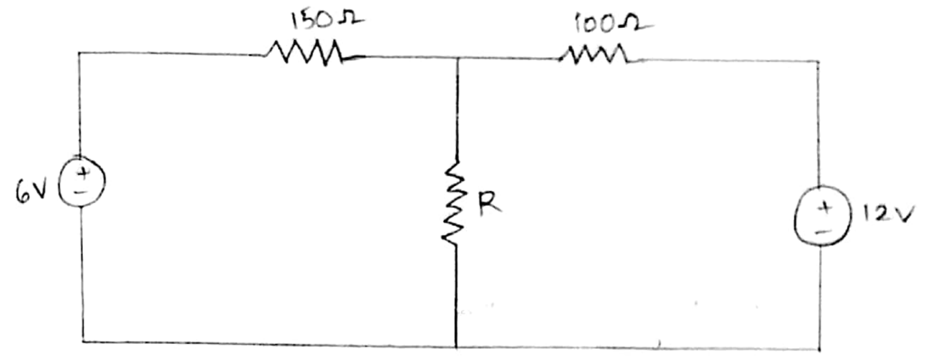
$$\boxed{P_{max} = \frac{(V_{TH})^2}{4R_{TH}}}$$

9/1/19

1-56

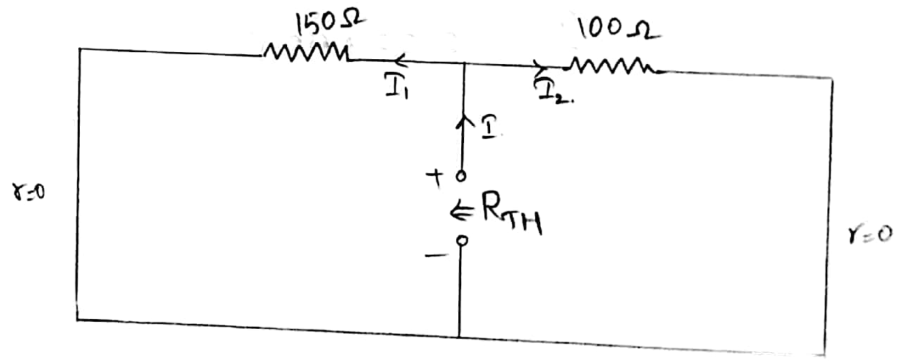
Problem:-

Find the value of R for maximum power transfer in circuit and find maximum power delivered in R.



Maximum power is transferred when $R_L = R_{TH}$

R_{TH} :-

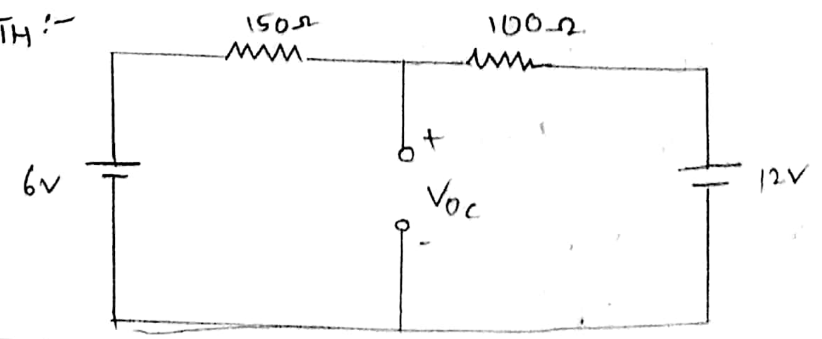


$$R_{TH} = 150 // 100$$

$$= \frac{150 \times 100}{150 + 100}$$

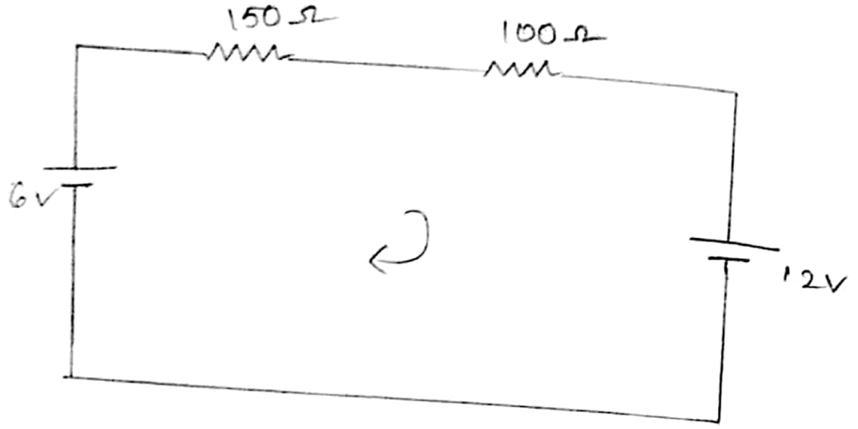
$$= 60\Omega$$

V_{TH} :-



Applying KVL to right loop

$\sum EMF + \sum V.D = 0$



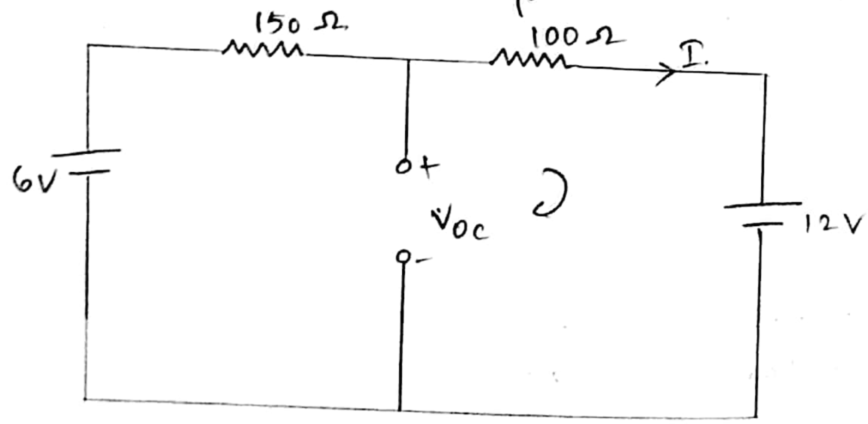
Applying KVL

$6 - 150I - 100I - 12 = 0$

$6 - 250I - 12 = 0$

$-250I = 6$

$I = -0.024$ Amp



Applying KVL to right loop

$V_{oc} - I(100) - 12 = 0$

$V_{oc} = 100I + 12$

$V_{TH} = V_{oc} = 9.6V$

$$P_{max} = \frac{V_{TH}^2}{4R_{TH}}$$

Single phase a.c. series circuit E4, F8, G3, H3, H6

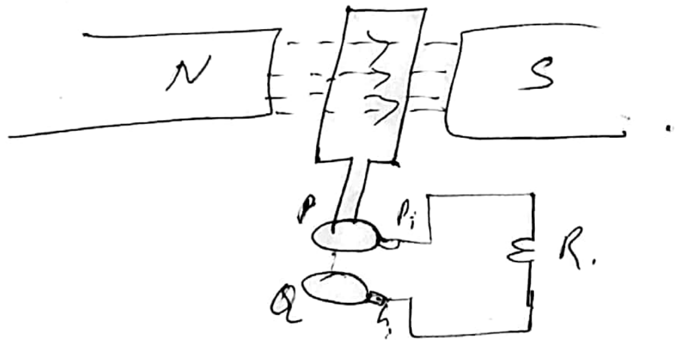
2-1

(1) Generation of Alternating Voltages & currents

An alternating voltage may be generated:

(i) by rotating a coil at constant angular velocity in a uniform magnetic field as shown in fig.

In either case, the generated voltage will be of sinusoidal waveform. The magnitude of generated voltage will depend upon the number of turns of coil, the strength of magnetic field & speed of the rotation.

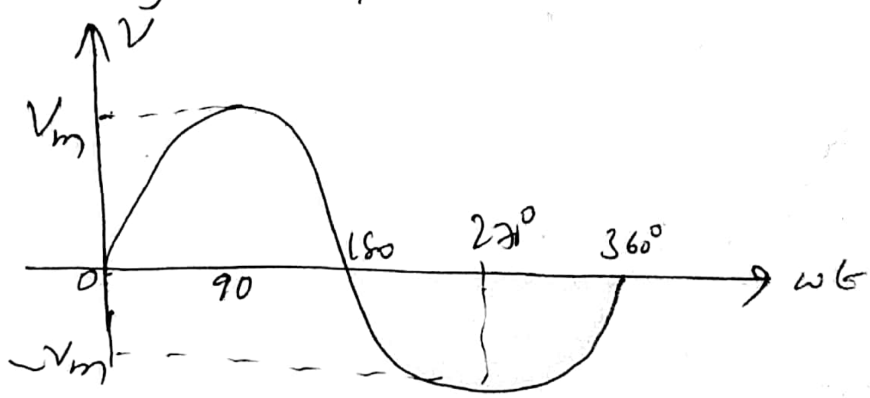


(2) Important A.C Terminology:-

(i) Wave form:- The shape of the curve obtained by plotting the instantaneous values of voltage or current as ordinate against time as abscissa is called its wave-form.

(ii) Instantaneous value:- The value of an alternating quantity at any instant is called instantaneous value. The instan. values of alternating voltage & current are represented by v & i respectively.

(iii) Cycle:- one complete set of positive & negative values of an alternating quantity is known as a cycle.



(iv) Alternation: One half-cycle of an alternating quantity is called an alternation.

(V) Time period:- The time taken in seconds to complete one cycle of an alternating quantity is called its time-period. It is generally represented by T.

(Vi) Frequency:- The number of cycle that occur in one second its called the frequency (f) of the alternating quantity. It is measured in cycles/sec or Hertz.

(Vii) Amplitude. The maximum value (+ve or -ve) attained by an alternating quantity is called its amplitude or peak value. The amplitude of an alternating voltage or current is designated by V_m or I_m.

3 Important relations :-

(i) Time period & frequency:-

$$\boxed{T = \frac{1}{f}}$$

(ii) Angular velocity & frequency:-

$$\boxed{\omega = 2\pi f}$$

(iii) frequency & speed:-

$$\boxed{f = \frac{PN}{120}}$$

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(3Q) Define Average value, RMS value, Form Factor & peak factor. 2-2

Average value :- The average value of an alternating quantity is defined as the arithmetic mean of all the values over one complete cycle.

(i) Symmetrical wave :- In case of symmetrical waves, Avg. value means the average value of half cycle (or) one alternation.

$$\therefore \text{Avg. value} = \frac{\text{Area of one alternation}}{\text{Base length of one alternation}}$$

(ii) Unsymmetrical wave-form :- The avg. value is taken over the full cycle

$$\therefore \text{Avg value} = \frac{\text{Area over one cycle}}{\text{Base length of one cycle.}}$$

→ In general, Avg value, $Y_{avg} = \frac{1}{T}\int_0^T y(t).dt$

RMS Value :- The effective (or) r.m.s value of an alternating current is that steady current (d.c). Which when flowing through a given resistance for a given time produces the same amount of heat as produced by the alternating current when flowing through the same resistance for the same time.

→ In general, RMS value, $Y_{RMS} = \sqrt{\frac{1}{T}\int_0^T y^2(t).dt}$

Form Factor :- The ratio of rms value to the avg. value of an alternating quantity is known as form factor. i.e.

$$\text{Form Factor} = \frac{\text{RMS value}}{\text{Avg. value.}}$$

peak factor :- The ratio of max. value to the rms of an alternating quantity is known as peak factor. i.e

$$\text{Peak Factor} = \frac{\text{Max. value}}{\text{RMS value.}}$$

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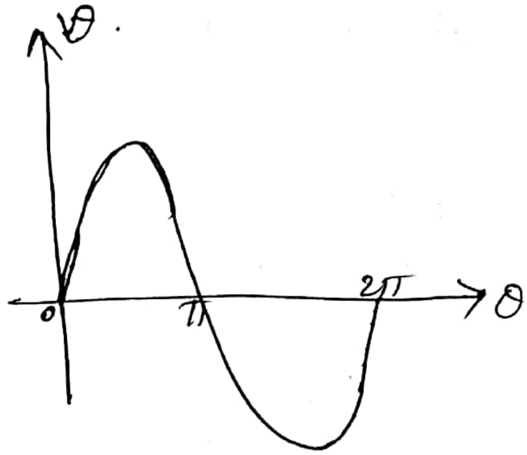
(1Q) Find Average value, RMS value, form factor & peak factor of sinusoidal voltage.

→ The equation of an alternating voltage varying sinusoidally is given by

$v = V_m \sin\theta$



Avg. value:-

$$\boxed{Y_{avg} = \frac{1}{T}\int_0^T y(t)\cdot dt}$$

Where $y(t) = V_m \sin\theta$.

$$\therefore Y_{avg} = \frac{1}{\pi}\int_0^{\pi} V_m \sin\theta \, d\theta$$

$$= \frac{V_m}{\pi}\int_0^{\pi} \sin\theta \, d\theta = \frac{V_m}{\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$= \frac{V_m}{\pi}[1+1] = \frac{2V_m}{\pi} = 0.637 V_m$$

$$\therefore Y_{avg} = 0.637 V_m$$

i.e $\boxed{V_{avg} = 0.637 V_m}$ Where Y = Voltage = V

RMS value:-

$$\boxed{Y_{RMS} = \sqrt{\frac{1}{T}\int_0^T y^2(t)\cdot dt}}$$

Where $y(t) = V_m \sin\theta$.

$$\therefore V_{RMS} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (V_m \sin\theta)^2 d\theta}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V_m^2 \sin^2\theta \, d\theta} = \sqrt{\frac{V_m^2}{2\pi}\int_0^{2\pi} \sin^2\theta \, d\theta}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\int_0^{2\pi}\left(\frac{1-\cos 2\theta}{2}\right)}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\left[\frac{\theta}{2} - \frac{\sin 2\theta}{4}\right]_0^{2\pi}}$$

$$= \frac{V_m^2}{2\pi}\left[\frac{2\pi}{2} - 0 - 0 + 0\right]$$

$$= \frac{V_m}{\sqrt{2}} = 0.707 V_m$$

$$\boxed{\therefore V_{rms} = \frac{V_m}{\sqrt{2}} = 0.707 V_m}$$

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Form Factor:- $F.F = \frac{\text{RMS value}}{\text{Avg. value}}$ 23

$$= \frac{0.707 \times V_m}{0.637 \times V_m} = 1.11$$

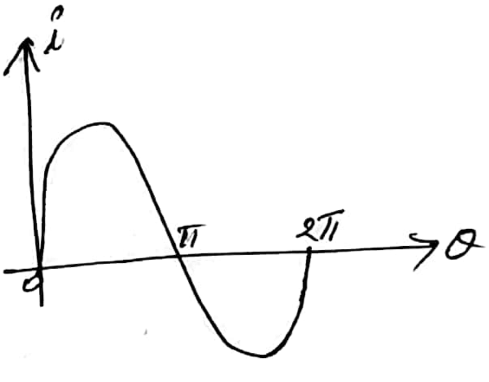
Peak factor:- $P.F = \frac{\text{Max. value}}{\text{RMS value}}$

$$= \frac{V_m}{0.707 V_m} = 1.414$$

(28) Find average value, RMS value, Form factor & peak factor of sinusoidal current

Sol The equation of an alternating current varying sinusoidally is given by

$$\boxed{i = I_m \sin\theta}$$



Avg. value:- $\boxed{Y_{avg} = \frac{1}{T}\int_0^T y(t)\, dt}$

where $y(t) = I_m \sin\theta$.

$$\therefore I_{avg} = \frac{1}{\pi}\int_0^{\pi} I_m \sin\theta \, d\theta$$

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

$$= \frac{I_m}{\pi}[1+1] = \frac{2I_m}{\pi} = 0.637 I_m$$

$$\boxed{\therefore I_{avg} = 0.637 I_m}$$

RMS value:- $\boxed{Y_{RMS} = \sqrt{\frac{1}{T}\int_0^T y(t)\, dt}}$

where $y(t) = I_m \sin\theta$.

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$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(I_m \sin\theta)^2 \cdot d\theta}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2\theta \cdot d\theta}$$

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

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

$$= \sqrt{\frac{I_m^2}{2\pi}\left[\frac{\theta}{2} - \frac{\sin 2\theta}{4}\right]_0^{2\pi}}$$

$$= \frac{I_m^2}{2\pi}\left[\frac{2\pi}{2} - 0 - 0 + 0\right]$$

$$= \frac{I_m}{\sqrt{2}} = 0.707\, I_m$$

$$\boxed{\therefore\ I_{rms} = 0.707\, I_m}$$

Form factor :- $F.F = \frac{\text{RMS value}}{\text{Avg. value}}$

$$= \frac{0.707\, I_m}{0.637\, I_m} = 1.11$$

Peak factor :- $P.F = \frac{\text{Max. value}}{\text{RMS value}}$

$$= \frac{I_m}{0.707\, I_m} = 1.414$$

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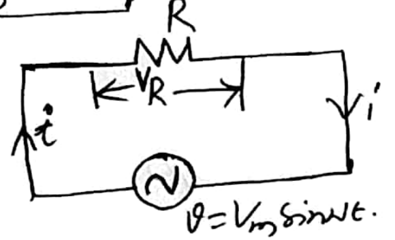
C3 43

(4) Explain analysis of 1-ϕ Resistance circuit

Consider a pure resistor 'R' connected across an alternating voltage source V as shown in fig.

Let the alternating voltage be

$$\boxed{v = V_m \sin\omega t} \quad \text{— (1)}$$

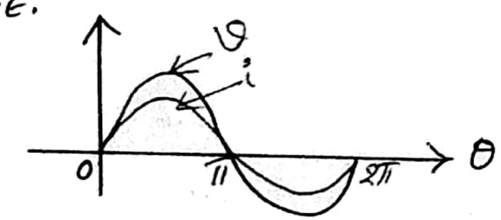


(1) **Current** :- The alternating current 'i' is given by

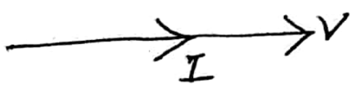
$$i = \frac{v}{R} = \frac{V_m \sin\omega t}{R}$$

$$\boxed{i = I_m \sin\omega t} \text{ — (2) } \left(\because I_m = \frac{V_m}{R}\right)$$

(2) **Wave form** :- From eq (1) & (2), it is clear that the current is in phase with the voltage in a purely resistive circuit.



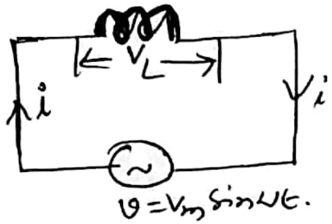
(3) **Phasor Diagram** :-



(5) Explain analysis of 1-ϕ Inductance

Consider a pure Inductor L connected across an alternating voltage v as shown in fig.

Let the alternating voltage $\boxed{v = V_m \sin\omega t}$ — (1)



(1) **Current** :- The alternating current 'i' is given by.

$$i = \frac{1}{L}\int v\,dt$$

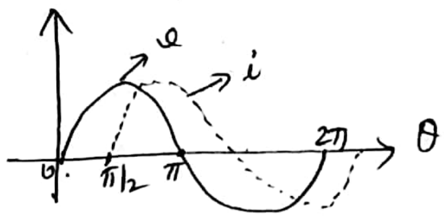
$$= \frac{1}{L}\int V_m \sin\omega t\,dt$$

$$= \frac{V_m}{\omega L}(-\cos\omega t)$$

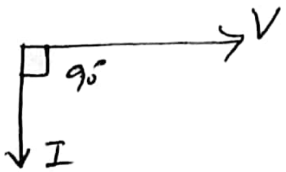
$$= \frac{V_m}{\omega L}\sin(\omega t - \pi/2)$$

$$\boxed{i = I_m \sin(\omega t - \pi/2)} \quad \text{— (2)}$$

(2) **Wave-form** :- From eq (1) & (2), it is clear that the current ~~in phase~~ lags the voltage in a purely ~~resistive circuit~~ inductive circuit.



(3) **Phasor diagram** :-

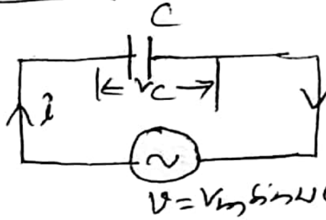


(6) Explain analysis of 1-ϕ capacitance

Consider a pure capacitor C connected across an alternating voltage v as shown in fig.

Let the alternating voltage be

$$\boxed{v = V_m \sin\omega t} \quad \text{— (1)}$$



(1) **Current** :- The alternating current 'i' is given by

$$i = C\frac{dv}{dt}$$

$$= C\frac{d}{dt}(V_m \sin\omega t)$$

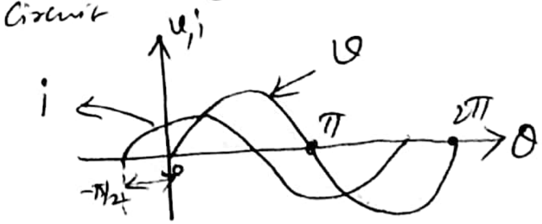
$$= \omega C V_m \cos\omega t$$

$$= \omega C V_m \sin(\omega t + 90^\circ)$$

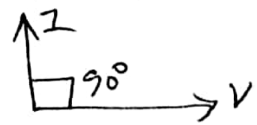
$$\boxed{i = I_m \sin(\omega t + 90^\circ)} \quad \text{— (2)}$$

where $I_m = \omega C V_m$

(2) **Wave-form** :- From eq (1) & (2), it is clear that the current ~~is in phase~~ leads the voltage by 90° in a purely capacitive circuit



(3) **Phasor diagram** :-



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R Circuit

(4) Impedance:-

$$Z = \frac{V}{I} = \frac{V_m}{I_m} = \frac{V_m}{\frac{V_m}{R}} = R$$

$$\boxed{\therefore Z = R}$$

(5) Phase difference:- Since the voltage & current are in phase with each other, the phase difference is zero.

$$\boxed{\phi = 0^\circ}$$

(6) Power Factor:- It is defined as the cosine of the angle b/w the voltage & current phasors.

$$\boxed{\cos\phi = \cos 0 = 1}$$

(7) Power:-

(i) Instantaneous power 'p'

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

The power consists of a constant part $\frac{V_m I_m}{2}$ + fluctuating part $\frac{V_m I_m}{2}\cos 2\omega t$.

(ii) Average power $P = \frac{V_m I_m}{2}$

$$\boxed{P = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} = VI}.$$

Inductance Circuit

(4) Impedance:-

$$Z = \frac{V}{I} = \frac{V_m}{I_m} = \frac{V_m}{\frac{V_m}{\omega L}} = \omega L$$

$$\boxed{Z = \omega L} = X_L$$

The quantity ωL is called inductive reactance (X_L)

(5) Phase difference:- It is the angle b/w the voltage & current phasors.

$$\boxed{\phi = 90^\circ}$$

(6) Power Factor:- It is defined as the cosine of the angle b/w the voltage & current phasors

$$\boxed{\phi = 90^\circ} \rightarrow \boxed{\cos\phi = \cos 90^\circ = 0}$$

(7) Power:-

(i) Instantaneous power p is given by

$$'p' = vi = V_m \sin\omega t \, I_m \sin(\omega t - \pi/2)$$
$$= -V_m I_m \sin\omega t \cos\omega t$$
$$= -\frac{V_m I_m}{2}\sin 2\omega t.$$

(ii) Average power:-

The average power for one complete cycle, $P = 0$.

Capacitance Circuit

(4) Impedance:-

$$Z = \frac{V}{I} = \frac{V_m}{I_m} = \frac{V_m}{\omega C V_m} = \frac{1}{\omega C}$$

$$\boxed{Z = \frac{1}{\omega C} = X_C}$$

The quantity $\frac{1}{\omega C}$ is called capacitive reactance, is denoted by X_C & is measured in Ω.

(5) Phase difference:-

It is the angle b/w voltage & current phasors.

$$\boxed{\phi = 90^\circ}$$

(6) Power factor:- It is defined as the cosine of the angle b/w the voltage & current phasors.

$$\boxed{\cos\phi = \cos 90 = 0}$$

(7) Power:-

(i) Instantaneous power

$$p = vi$$
$$= V_m \sin\omega t \, I_m \sin(\omega t + 90^\circ)$$
$$= V_m I_m \sin\omega t \cos\omega t$$
$$= \frac{V_m I_m}{2}\sin 2\omega t$$

(ii) Average power:-

The average power for one complete cycle, $P = 0$.

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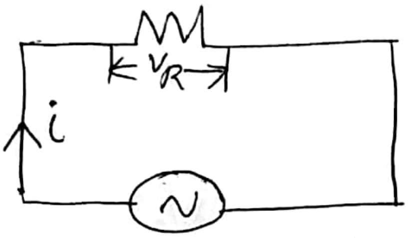
PROBLEMS: 2-5

(1Q) An a.c. circuit consists of a pure resistance of 10 Ω and is connected across an a.c. supply of 230 V, 50 Hz. Calculate (i) current (ii) Power consumed (iii) write down the equations for voltage & current

Sol

$R = 10\,\Omega$



230 V, 50 Hz

Given data:- $R = 10\,\Omega$; $V = 230\,V$; $f = 50\,Hz$.

(i) Current $I = \frac{V}{R} = \frac{230}{10} = 23\,A$

(ii) Power, $P = VI = 230 \times 23 = 5290\,W$

(iii) $V_m = \sqrt{2}\,V_{rms} = \sqrt{2} \times 230 = \cancel{35}\ 325.27\,V$

$I_m = \sqrt{2}\,I_{rms} = \sqrt{2} \times 23 = 32.52\,A$

$\omega = 2\pi f = 2\pi \times 50 = 314\,Hz$

∴ Equations of Voltage & current are:

$$\boxed{\begin{aligned} v &= 325.27 \sin 314t \\ i &= 32.52 \sin 314t \end{aligned}}$$

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(2) A pure inductive coil allows a current of 10A to flow from a 230V, 50 Hz supply. Find (i) Inductive reactance (ii) Inductance of the coil (iii) power absorbed. Write down the equations for voltage & current. (12)

Sol:- (i) circuit current, $I = V/X_L$

$\therefore$ Inductive reactance, $X_L = \frac{V}{I} = \frac{230}{10} = 23\Omega$

(ii) Now, $X_L = 2\pi f L$

$L = \frac{X_L}{2\pi f} = \frac{23}{2\pi \times 50} = 0.073\ H$

(iii) power absorbed = zero

(iv) $V_m = \sqrt{2} \times 230 = 325.27V$

$I_m = \sqrt{2} \times 10 = 14.14\ A$

$\omega = 2\pi \times 50 = 314$

$\therefore\ v = 325.27 \sin 314t$

$i = 14.14 \sin (314t - \pi/2)$

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pr. 11.63 page NO. 545 V.K.Mehta

(3) A 318 μF capacitor is connected across a 230V, 50Hz system. Determine (i) the capacitive reactance (ii) rms value of current (iii) equations for voltage & current.

Sol:- (i) capacitive reactance, $X_C = \frac{1}{2\pi f C} = \frac{10^6}{2\pi \times 50 \times 318} = 10\Omega$

(ii) R.M.S value of current, $I = \frac{V}{X_C} = \frac{230}{10} = 23A$

(iii) $V_m = \sqrt{2} \times 230 = 325.27$ volts

$I_m = \sqrt{2} \times 23 = 32.53\ A$

$\omega = 2\pi \times 50 = 314$

$\therefore$ equations for voltage & current are

$v = 325.27 \sin 314t$

$i = 32.53 \sin (314t + \pi/2)$

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7 R-L Series circuit

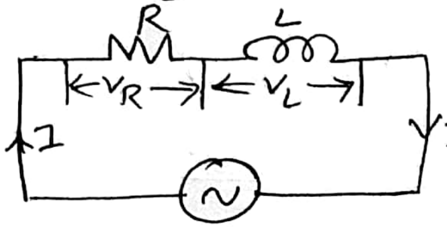
Fig shows a pure resistor R connected in series with a pure inductor 'L' across an alternating $\boxed{v = V_m \sin \omega t}$

→ voltage drop across resistor = $V_R = IR$

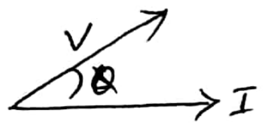
→ " " " Inductor = $V_L = IX_L$

→ The voltage V_R is in phase with I

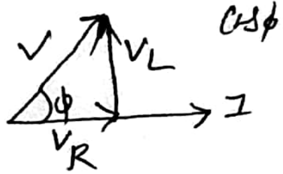
→ " " V_L leads the current I by 90°.



(1) **Phasor diagram** :-



(2) **voltage triangle**



$\cos\phi = \frac{V_R}{V}$

(3) **Impedance** :-

$V = V_R + V_L = RI + jIX_L$

$V = I(R + jX_L)$

$\boxed{V = IZ}$

8 R-C Series circuit

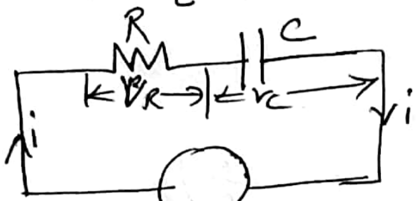
Fig. Shows a pure ~~inductor~~ resistor connected in series with a pure capacitor 'C' across an alternating voltage $\boxed{v = V_m \sin \omega t}$.

→ voltage drop across resistor = $V_R = RI$

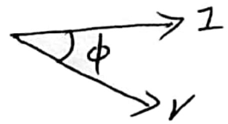
→ voltage drop across ~~inductor~~ capacitor = $V_C = IX_C$

→ The voltage V_R is in phase with I.

→ " " V_C lags behind I by 90°.



(i) **phasor diagram** :-



(2) ~~voltage triangle~~ :- **Impedance**

$V = V_R + V_C = RI - jX_C I$

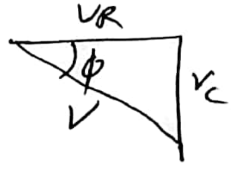
$= (R - jX_C) I$

$\boxed{V = ZI}$

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

$\phi = \tan^{-1}\left(\frac{X_C}{R}\right)$, where $X_C = \frac{1}{\omega C}$.

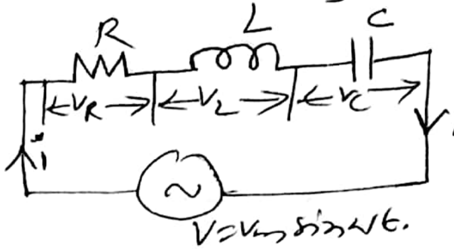
(2) **voltage triangle**



$\cos\phi = \frac{V_R}{V}$

9 R-L-C Series Circuit

Fig. Shows a pure resistor R, pure Inductor L, & pure C connected in series across an alternating $v = V_m \sin \omega t$.



→ $V_R = IR$

→ $V_L = X_L I$

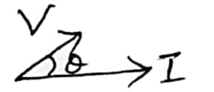
→ $V_C = IX_C$

2-6

(1) **phasor Diagram**

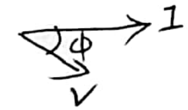
Case(i)

(i) $X_L > ~~X_C~~$



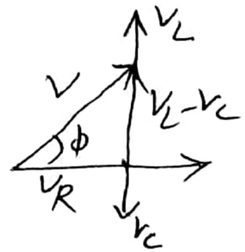
Case(ii)

(ii) $X_C > X_L$

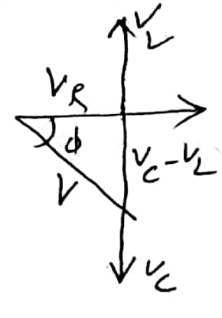


(2) **Voltage Triangle**

(i) $X_L > X_C$



(ii) $X_C > X_L$



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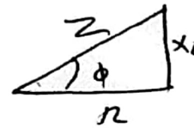
R-L Series Circuit

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

$\phi = \tan^{-1}\left(\frac{X_L}{R}\right)$

Where $X_L = \omega L$

(4) Impedance Triangle:-



$\cos\phi = \frac{R}{Z}$

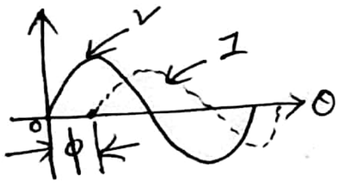
(5) Current:- It is clear that ~~that~~ current I lags behind the voltage V by an angle ϕ.

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

Where $I_m = \frac{V_m}{Z}$

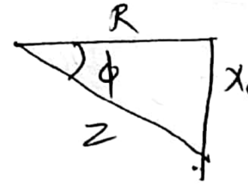
and $\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$

(6) Wave-form:-



R-C- Series Circuit

(4) Impedance Triangle



$\cos\phi = \frac{R}{Z}$

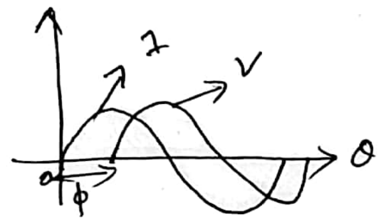
(5) Current:- It is clear that the current I leads the voltage V by angle ϕ.

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

Where $I_m = \frac{V_m}{Z}$

$\phi = \tan^{-1}\left(\frac{X_C}{R}\right)$

(6) Wave-form:-



(7) Power:-

Active power, $P = VI\cos\phi$
$= I^2 R$

Reactive power, $Q = VI\sin\phi$
$= I^2 X_C$

Apparent power $S = VI = I^2 Z$

R-L-C- Series Circuit

(3) Impedance

$V = V_R + V_L + V_C$

$= IR + jIX_L - jIX_C$

$= I[R + j(X_L - X_C)]$

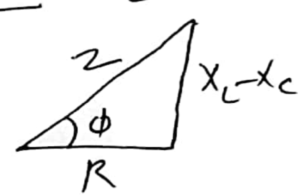
$$\boxed{V = IZ}$$

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

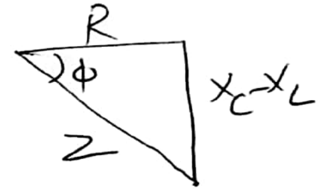
$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$

(4) Impedance Triangle:-

Case(i):- $X_L > X_C$



Case(ii):- $X_C > X_L$



(5) Current:- If the applied voltage is given by $v = V_m \sin\omega t$ then current equation will be $i = I_m[\sin(\omega t \pm \phi)]$

'—' sign is used when $X_L > X_C$

'+' sign is used when $X_C > X_L$

(6) Wave form:-

case(i) $X_L > X_C$

case(ii) $X_C > X_L$

R-L series circuit

(7) Power:-

(i) Inst. power (P)

$$p = vi$$
$$= V_m \sin\omega t \, I_m \sin(\omega t - \phi)$$
$$= V_m I_m \sin\omega t \sin(\omega t - \phi)$$
$$= V_m I_m \left[\frac{\cos\phi - \cos(2\omega t - \phi)}{2}\right]$$
$$= \frac{V_m I_m}{2}\cos\phi - \frac{V_m I_m}{2}\cos(2\omega t - \phi)$$

Power consists of two parts

Constant part $= \frac{V_m I_m}{2}\cos\phi$

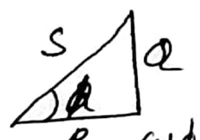
fluctuating part $= \frac{V_m I_m}{2}\cos(2\omega t - \phi)$

(ii) Average power, P

$$P = \frac{V_m I_m}{2}\cos\phi = \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos\phi$$
$$\boxed{P = VI\cos\phi}$$

(8) Power triangle:-

$\cos\phi = \frac{R}{Z}$ & $V = IZ$



$\cos\phi = \frac{P}{S}$

Active power, $P = VI\cos\phi$
$= I^2R$

Reactive power, $Q = VI\sin\phi$
$= I^2X_L$

Apparent power, $S = VI = I^2Z$

(9) Power factor:-

From voltage triangle, $P.f = \frac{V_R}{V}$

" impedance " $P.f = \frac{R}{Z}$,

R-C series circuit

(8) Power Triangle:-

$\cos\phi = \frac{P}{S}$

(9) Power factor:-

From voltage triangle, $\cos\phi = \frac{V_R}{V}$

From Z triangle, $\cos\phi = \frac{R}{Z}$

From power triangle $\cos\phi = \frac{P}{S}$

R-L-C series circuit

(6) Power:-

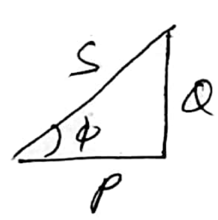
Avg. power $P = VI\cos\phi = I^2R$

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

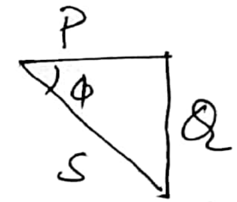
Apparent power $S = VI = I^2Z$

(7) Power Triangle:-

Case (i) $X_L > X_C$



Case (ii) $X_C > X_L$



(8) Power factor:-

$\cos\phi = \frac{V_R}{V}$ from voltage triangle

$\cos\phi = \frac{R}{Z}$ from Z Triangle

$\cos\phi = P/S$ From Power Triangle.

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11Q Define Impedance, admittance, reactance, susceptance and power factor.

(i) Impedance:-(Z):- The total opposition offered to the flow of alternating current is called Impedance. 2-8

→ It is represented by Z

→ It is measured in ohm (Ω)

$$Z = R + jX_L$$

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

$$\phi = \tan^{-1}\left(\frac{X_L}{R}\right)$$

(ii) Admittance (Y):- Admittance is defined as the reciprocal of the Impedance.

→ It is denoted by Y.

→ It is measured in mho ($\mho$)

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

$$\boxed{Y = G = jB} \rightarrow \text{In complex form.}$$

(iii) Susceptance (B)

→ The reciprocal of reactance is called susceptance

→ The susceptance of an Inductive is called Inductive susceptance (B_L) where as that of a capacitance is called capacitive susceptance (B_C)

$$\boxed{B = \frac{1}{X}} \ \mho$$

→ B_L & B_C are measured in $\mho$.

(iv) Reactance (X):-

→ Inductive reactance:- The opposition offered by Inductive to current flow is ωL. This quantity 'ωL' is called Inductive reactance 'X_L' of the coil.

→ It is measured in Ω.

$$\boxed{X_L = 2\pi f L = \omega L} \ \Omega$$

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→ Capacitive reactance :- The opposition offered by capacitance to current flow is $1/\omega C$. This quantity $1/\omega C$ is called the capacitive reactance X_C of the capacitor.

→ It is measured in Ω

$$\boxed{X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}} \ \Omega$$

Power factor :-

The power factor (i.e. $\cos\phi$) of a circuit can be defined in one of the following ways.

(i) $\cos\phi$ = cosine of angle between voltage & current

(ii) power factor $= \cos\phi = R/Z$

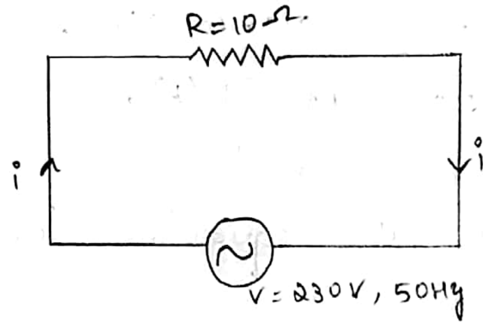
(iii) power factor $= \dfrac{VI\cos\phi}{VI} = \dfrac{P}{S}$.

(10Q) Comparision between a.c series & parallel circuit

A.C series circuit	A.C. parallel circuit
① current is same	① voltage is same
② There is voltage drop in series circuit	② There is current division in parallel circuit
③ Impedance (Z) can be calculated	③ Admittance (Y) can be calculated
④ Reactance (X) can be calculated	④ Susceptance (B) can be calculated.
⑤ Here $Z = R \pm jX$	⑤ Here $Y = G \mp jB$
⑥ Impedance, reactance, resistance are in measured in Ω	⑥ Admittance, susceptance & conductance is measured in $\mho$.
⑦ connection for RL series circuit	⑦ connection for RL series circuit

Problem: 1 Pure resistor

An AC circuit consists of a pure resistance of 10Ω and is connected across an AC supply of 230V, 50Hz. Calculate (i) current (ii) Power consumption (iii) Write the equations for voltage and current.



(i) current:-

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

$$I = \frac{230}{10}$$

$$I = 23 \text{ Amp}$$

(ii) Power Consumption:-

$$P = VI\cos\phi$$

$$P = VI$$
$$= 230 \times 23$$
$$= 5,290 \text{ W}$$

(iii) $V = V_m \sin\omega t$

$i = I_m \sin\omega t$

$V_m = V_{rms} \times \sqrt{2} = 230 \times \sqrt{2} = 325.27 \text{ V}$

$I_m = I_{rms} \times \sqrt{2} = 32.52 \text{ Amp}$

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$\omega = 2\pi f = 314$

$v = 325.27 \sin(314t)$

$i = 32.52 \sin(314t)$

Problem: 2 Pure inductor

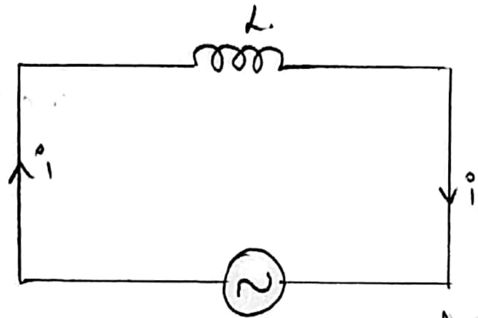
A pure inductive coil allows a current of 10 Amp to flow from a 230V, 50Hz supply.

Find (i) Inductive reactance (X_L).

(ii) Inductance of coil (L),

(iii) Power consumed

(iv) Write the equations for voltage and curren



$v = 230V$, $f = 50hz$

Given data:-

$v = 230V$

$f = 50 Hz$

$I = 10 A$

(i) X_L :-

$V = IZ$

$V = IX_L$

$X_L = \frac{V}{I} = 23\,\Omega$

(ii) $X_L = \omega L$

$L = \frac{X_L}{\omega} = 0.073$ Henry

(iii) $P = 0$ $[\because P.F = IV\cos\phi]$

(iv) $v = V_m \sin\omega t$ — ①

$i = I_m \sin(\omega t - \pi/2)$ — ②

$V_m = V_{rms} \times \sqrt{2} = 325.27V$

$I_m = I_{rms} \times \sqrt{2} = 14.14\ Amp$

$\omega = 2\pi f = 2 \times \pi \times 50 = 100\pi = 314$

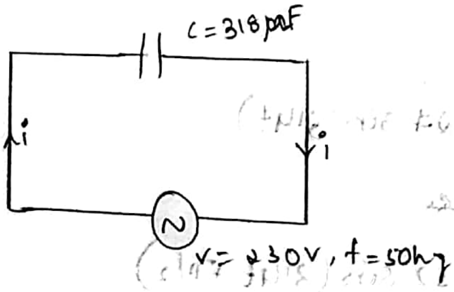
$v = 325.27 \sin(314t)$

$i = 14.14 \sin(314t - \pi/2)$

Problem: 3

to Pure capacitance

A 318 μF capacitor is connected across a 230V, 50Hz supply. Calculate (i) Capacitive reactance (X_c) (ii) RMS value of current (iii) Power consumed (iv) Write the equations for voltage and current.



Given data:-

$C = 318 \times 10^{-6} F$

$V = 230V$

$f = 50\ Hz$ $\omega = 2\pi f = 314$

(i) X_c :-

$$X_c = \frac{1}{\omega C} = \frac{1}{314 \times 318 \times 10^{-6}} = 10\Omega$$

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(ii) I_{rms} :-

$$V = IZ$$

$$I_{rms} = \frac{V}{Z}$$

$$I_{rms} = \frac{V}{X_C}$$

$$= \frac{230}{10}$$

$$I_{rms} = 23 \text{ Amp}$$

(iii) $P = VI\cos\phi$

$$P = 0$$

(iv) $V = V_m \sin\omega t$

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

$V_m = V_{rms} \times \sqrt{2} = 230 \times \sqrt{2} = 325.27V$

$I_m = I_{rms} \times \sqrt{2} = 23\sqrt{2} = 32.52 \text{ Amp}$

$\omega = 314$

$V = 325.27 \sin(314t)$

$\cancel{I = I_m \sin}$

$I = 32.52 \sin(314t + \pi/2)$

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R-L Series Circuit.

2-22

Problem:

An alternating voltage $(80+j60)V$ is applied to a circuit and the current flowing is $(4-j2)$ Amp find (a) Impedance (b) Phase angle (c) Power factor (d) Power consumed.

(i) Impedance (Z):-

$V = IZ$

Given data:-

$V = (80+j60) = \text{shift Rec}(80, 60) = 100 \angle 36.86$

$I = (4-j2) = \text{shift Pol}(4, -2) = 4.47 \angle -26.56$

(i) Z :-

$V = IZ$

For multiplication & division use polar form

$Z = \frac{V}{I} = \frac{100 \angle 36.86}{4.47 \angle -26.56}$

$Z = 22.37 \angle 63.42$

$Z = 22.37\,\Omega$

(ii) Phase angle (ϕ):-

$\phi = 63.42$ (From impedance)

(iii) Power factor:-

$\cos\phi = \cos(63.42) = 0.447$ (Lags).

(iv) Power consumed:-

$P = VI\cos\phi = 100 \cancel{\angle 36.86} * 4.47 * 0.44 = 196.68W$

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Problem:-

The voltage and current in a circuit is given by $V = 150\angle 30^\circ$ in polar form and current $I = 2\angle -15^\circ$. If the circuit works on a 50Hz supply, Determine (a) Impedance (b) Resistance (c) Reactance (d) Power Factor (e) Power loss. Considering the circuit as a simple series circuit.

Given data,

$$V = 150\angle 30^\circ = 129.90 + j75 = 130 + 75j$$

$$I = 2\angle -15^\circ = 1.93 - j0.517$$

$$f = 50Hz$$

(a) Impedance (Z):-

$$V = IZ$$

$$Z = \frac{V}{I} = \frac{150\angle 30^\circ}{2\angle -15^\circ} = 75\angle 45$$

$$Z = 53.03 + j53.03$$

$$Z = 53 + j53 = R + JX_L$$

$$\therefore Z = 75\,\Omega$$

(b) Resistance (R) :-

From Impedance,

$$R = 53\,\Omega$$

(c) Reactance :-

$$X_L = 53\,\Omega$$

(d) power factor :-

$$\cos\phi = \cos 45^\circ = 0.707 \text{ [lags]}.$$

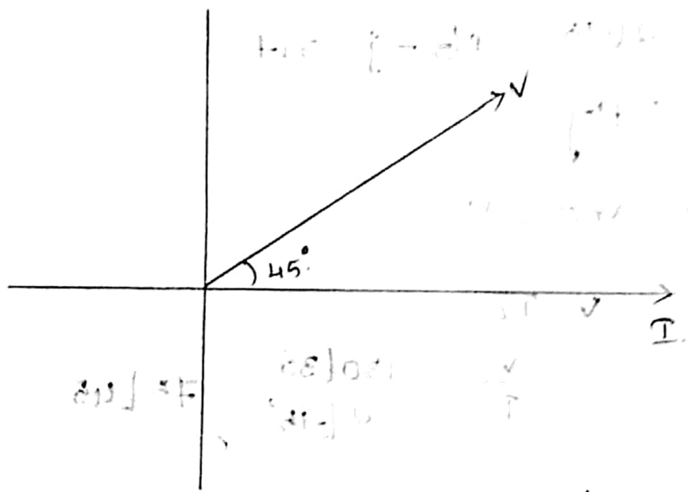
(e) Power loss or Power Consumption:-

$$P = VI\cos\phi$$

$$= 300 \times 0.707$$

$$P = 212.1\ W$$

(f) Phasor Diagram :-



R-C Series Circuit

Problem:-

The voltage applied to a circuit is $e = 100\sin(\omega t + 30^\circ)$ and the current is $i = 15\sin(\omega t + 60^\circ)$. Determine (a) Impedance (b) Resistance (c) Reactance (d) Power factor (e) Power consumed.

Given data:-

$$e = 100\sin(\omega t + 30^\circ)$$

$$i = 15\sin(\omega t + 60^\circ)$$

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$V_m = 100V$, $i = 15$ Amp

$V_{rms} = \frac{V_m}{\sqrt{2}} \angle 30^\circ = 70.71 \angle 30^\circ = 61.2 + j35.3V$

$I_{rms} = \frac{I_m}{\sqrt{2}} \angle 60 = 10.60 \angle 60^\circ = 5.3 + j9.1$ Amp

(a) Impedance :-

$V = IZ$

$Z = \frac{V}{I} = \frac{70.71 \angle 30^\circ}{10.60 \angle 60^\circ} = 6.67 \angle -30^\circ = 5.77 - j3.33$

$\therefore Z = 6.67 \Omega$

(b) Resistance :-

$R = 5.77 \Omega$

(c) Reactance :-

$X_C = 3.33$

(d) Power factor :-

$\cos\phi = \frac{\sqrt{3}}{2} = 0.86$ (leads)

(e) Power consumed :-

$P = VI\cos\phi = 644.59W$

Problem:-

A series circuit consumes 2000W at 0.5 leading Power-factor when connected to a 230V, 50hz supply. Calculate (a) current (b) KVA (c) KVAR

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Given data :-

$P = 2000W$

$V = 230V$

$f = 50 Hz$

$\cos\phi = 0.5 \Rightarrow \phi = 60^\circ$

(a) Current :-

$P = VI\cos\phi$

$2000 = 230 I \times 0.5$

$I = \frac{2000}{230 \times 0.5}$

$I = 17.39$ Amp

(b) KVA :-

$\cos\phi = \frac{P}{S}$

$S = \frac{P}{\cos\phi}$

$S = 4000VA = 4KVA.$

(c) KVAR :-

$Q = VI\sin\phi$

$= 3463.84$

$= 3.46 KVAR$

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R-L-C Series Circuit

Problem:-

A ~~series~~ circuit consists of resistance of 20Ω, inductor of $0.05H$, and capacitor of $50\mu F$ are connected in series. A supply voltage $230V$, $50Hz$ is connected across series combination. Calculate

(a) Impedance (b) current (c) Phase difference

(d) Power factor (e) Active and reactive power.

Given data:-

$R = 20\Omega$

$L = 0.05H$

$C = 50\mu F = 50\times10^{-6}F$

$V = 230V$

$f = 50Hz$

(a) Impedance:-

$Z = R + j(X_L - X_C)$

$X_L = \omega L = 15.7\,\Omega$

$X_C = \frac{1}{\omega C} = 63.69\,\Omega$

$Z = 20 + j(15.7 - 63.69)$

$Z = 20 - j\,47.99$

$Z = 51.99 \angle -67.37$

$\therefore\ Z = 51.99\,\Omega$

2-28

(b) Current:-

$$V = IZ$$

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

$$I = 4.42 \angle -67.37$$

$$I = 4.42 \angle -67.37$$

(c) Phase difference:-

67.37

(d) Power factor:-

$\cos\phi = 0.384$ (leads)

(e) Active and Reactive Power:-

~~Retive~~ Active $P = VI\cos\phi = 391.16\,W$

Reactive $P = VI\sin\phi = 938.33\,W$.

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Instant ab.

D.C. Generators

① 3-1

Principle of operation of a D.C. generator:-

Statement:- It states that, 'whenever the number of magnetic lines of forces i.e. flux linking with a conductor or a coil changes, an electromotive force is set up in that conductor or coil.

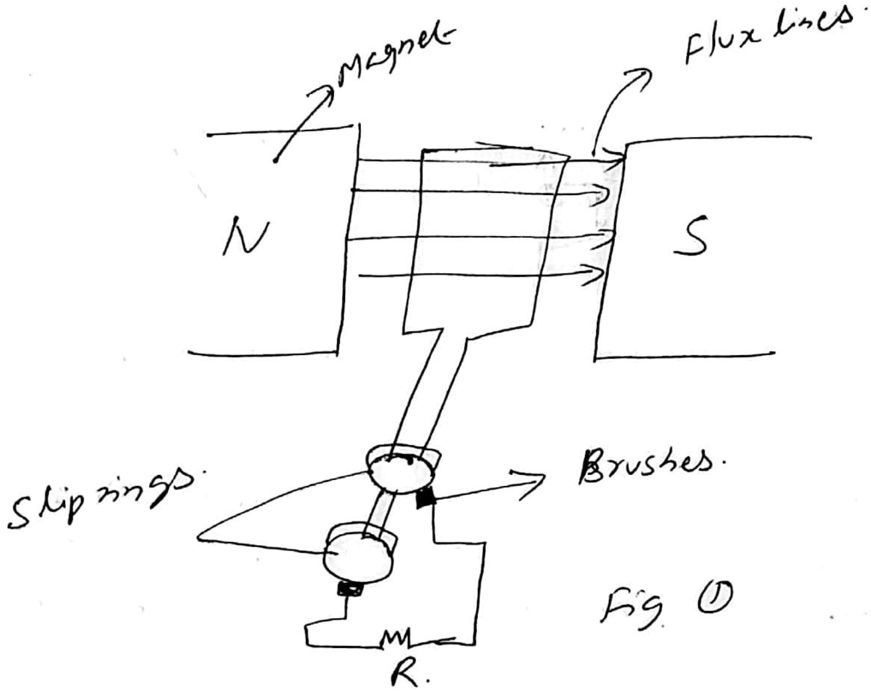

Fig ①

Instant 1:- Let the initial position of the coil as shown in fig. The plane of the coil is perpendicular to the direction of the magnetic field. The instantaneous component of velocity of conductors ab & cd, is parallel to the magnetic field as shown and there cannot be the cutting of the flux lines by the conductors. Hence no emf will be generated in the conductors ab & cd and no current will flow through the external resistance R. This position can be represented by considering the front view of Fig ① as shown in Fig ②.

Instant 2:- When the coil is rotated in anticlockwise direction through some angle θ, then the velocity will have two components $V\sin\theta$ perpendicular to flux lines & $V\sin\theta$ parallel to the flux lines. Due to $V\sin\theta$ component, there will be cutting of the flux & proportionally there will be an induced emf in the conductor ab & cd.

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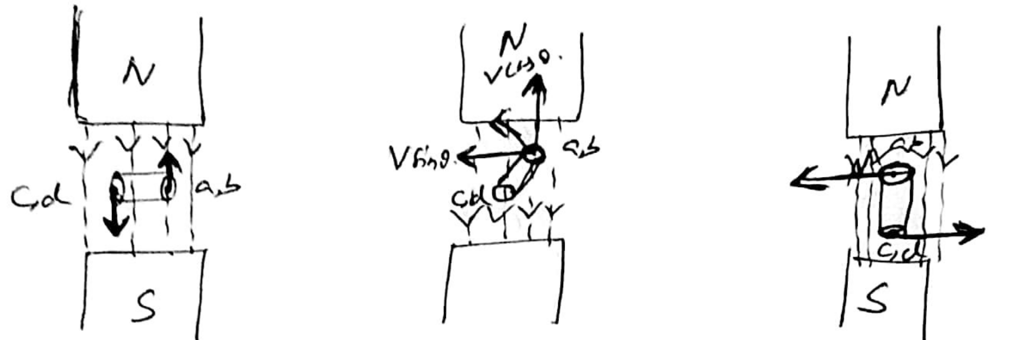
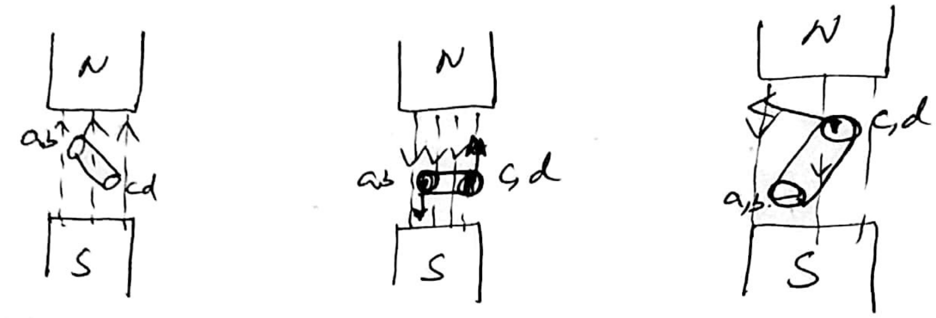


(a) $\theta = 0°$ (b) $0° < \theta < 90°$ (c) $\theta = 90°$



(d) $90° < \theta < 180$ (e) $\theta = 180°$ (f) $180° < \theta = 270°$

Instant 3:- As angle 'θ' increases, the component of velocity acting perpendicular to flux, lines increases, hence induced emf also increases. At $\theta = 90°$, the plane of the coil is parallel to the plane of the magnetic field while the component of velocity cutting the lines of flux is at its maximum. So induced emf in this position, is at its maximum value.

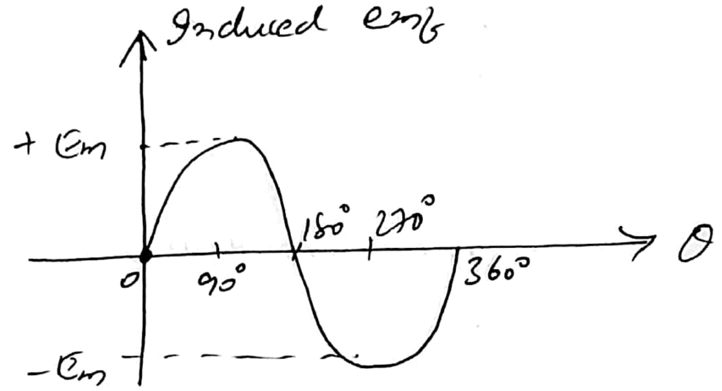
Instant 4:- As the coil continues to rotate further from $\theta = 90°$ to $180°$, the component of velocity, perpendicular to magnetic field starts decreasing hence gradually decreasing the magnitude of the induced emf. This is shown in the fig (d)

Instant 5:- In this position, the velocity component is fully parallel to the lines of flux similar to the Instant 1. Hence there is no cutting of flux & hence no induced emf in both the conductors. Hence the current through external circuit is also zero.

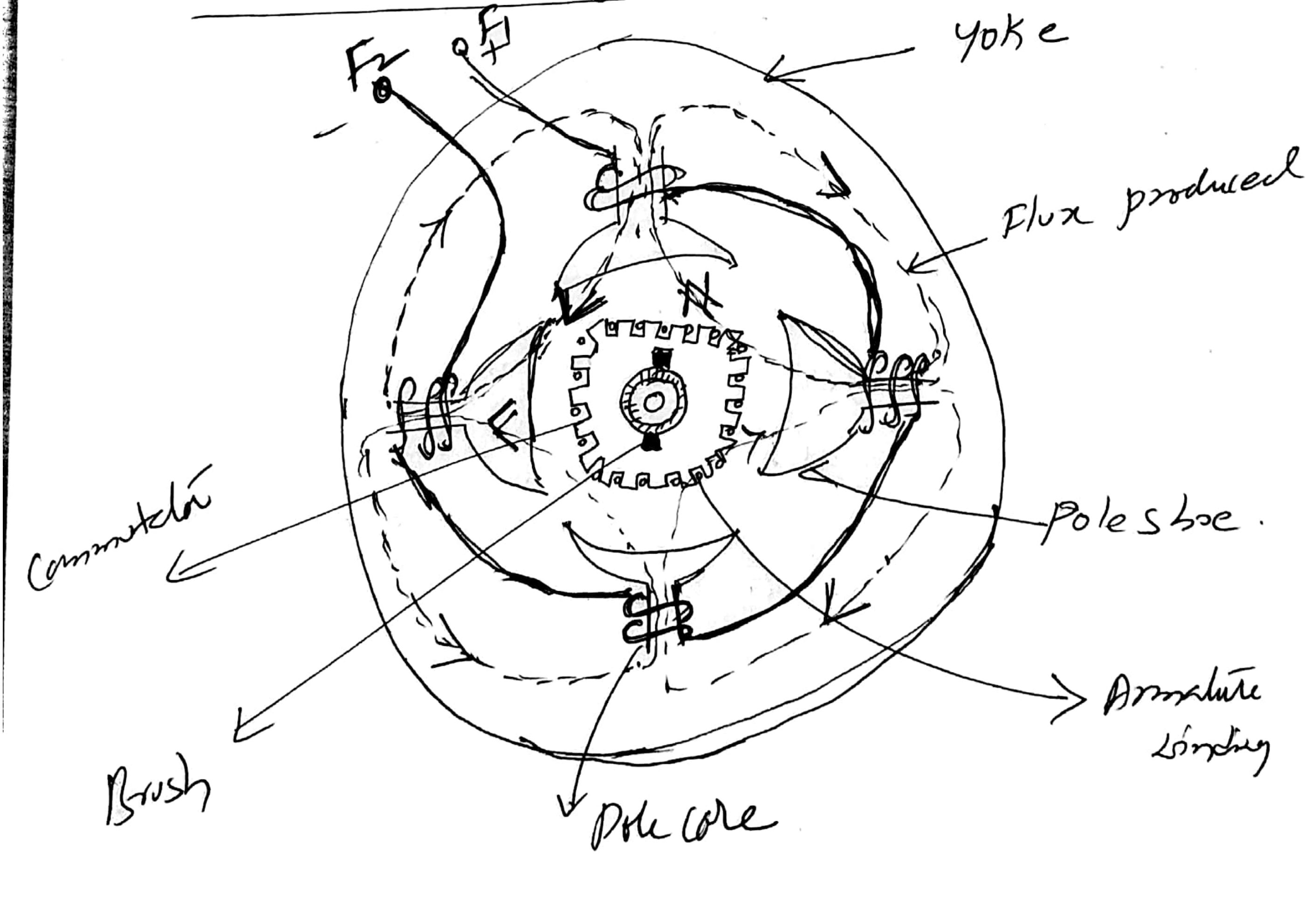
Instant 6:- As the coil rotates beyond $\theta = 180°$, the conductors ab upto now cutting flux lines in one particular direction reverses the direction of cutting the flux lines. Similar is the behaviour of the conductor cd. So direction of induced emf in conductor ab is opposite to the direction of induced emf in it for the rotation of $\theta = 0°$ to $180°$. Similarly the direction of induced emf in conductor cd also reverses. This change in direction of induced emf occurs because the direction of rotation of conductors ab & cd reverses with respect to the field as θ varies from $180°$ to $360°$.

3 1/2

(2)



Construction of a practical D.C. Machine:-



Yoke:-

Function:-

1. It serves the purpose of outermost cover of the d.c. machines. So that the insulating materials get protected from harmful atmospheric elements like moisture, dust & various gases like SO_2, acidic fumes etc.
2. It provides mechanical support to the poles.

Choice of material:-

For small machines :- cast iron
For large machines :- cast steel, silicon steel.

POLES:-

Each pole is divided into two parts namely
1. pole core
2. pole shoe.

Function of pole core & pole shoe:

1. pole core basically carries a field winding which is necessary to produce the flux.
2. It directs the flux produced through air gap to armature core, to the ~~next~~ pole.
3. Pole shoe:- It enlarges the area of armature core to come across the flux, which is necessary to produce larger induced emf.

Choice of material:-

It is made up of magnetic material like cast iron or cast steel.

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Field Winding :- (F1-F2)

(3) 3-3

~~the fien~~

Functions :

(1) To carry current due to which pole core, on which the field winding is placed behaves as an electro-magnet, producing necessary flux.

Choice of material :- aluminium (or) copper

Armature :-

It is further divided into two parts namely.

(1) Armature core (2) Armature winding

(I) Armature core :- Armature core is cylindrical in shape mounted on the shaft. It consists of slots on its periphery & the air ducts to permit the air flow through armature which serves cooling purpose.

Functions :- Armature core provides house for armature winding i.e. armature conductors.

Choice of material :- cast iron (or) cast steel.

(II) Armature winding :-

Functions :-

(1) Generation of emf takes place in armature winding in case of generators.

Choice of material :- copper.

Commutator :-

Functions :-

(1) To facilitate the collection of current from the armature conductors.

(2) To convert internally developed alternating emf to unidirectional (d.c) emf.

Choice of material :- copper segments.

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Brushes :-

Function :- to collect current from commutator & make it available to the stationary external circuit

Choice of material :- Brushes are normally made up of soft material like carbon.

EMF Equation of D.c Generators :-

Let P = Number of poles of the generator
ϕ = Flux produced by each pole in webers (wb)
N = Speed of armature in r.p.m
Z = total number of armature conductors.
A = Number of parallel paths in which the Z number of conductors are divided

$A = P$ for lap type of winding
$A = 2$ for wave type of winding

From Faraday's law of EMI :-

$$e = \frac{d\phi}{dt}$$

Where $d\phi$ = In one revolution, conductor will cut total flux produced by all the poles. i.e $\phi \times P$

dt = While time required to complete one revolution is $\frac{60}{N}$ seconds as speed in N. rpm.

$$e = \frac{\phi P}{\frac{60}{N}} = \phi P \frac{N}{60}.$$

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∴ Total emf can be expressed as

E = Avg. value of emf induced in each armature conductor $\times \frac{Z}{A}$

∴ $E = e \times \frac{Z}{A}$

$$\boxed{E = \frac{\phi P N}{60} \times \frac{Z}{A}} \quad (a)$$

Problems:-

(1Q) A 4 pole, lap wound, d.c. generator has a useful flux of 0.07 Wb per pole. Calculate the generated emf when it is rotated at a speed of 900 rpm with the help of prime mover. Armature consists of 440 number of conductors. Also calculate the generated emf if lap wound armature is replaced by wave wound armature.

Sol Given data:-

$P = 4, \quad Z = 440, \quad \phi = 0.07\,Wb, \quad N = 900$ rpm

$$\boxed{\therefore E = \frac{\phi P N Z}{60 A}}$$

(i) For lap wound,

$A = P = 4$

$$E = \frac{0.07 \times 900 \times 440}{60} = 462\,V$$

(ii) For wave wound:-

$A = 2$

$$E = \frac{0.07 \times 900 \times 4 \times 440}{120} = 924\,V$$

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(2) A 4 pole, lap wound, d.c generator has 42 coils with 8 turns per coils. It is driven at 1120 rpm. If useful flux per pole is 21 mWb, Calculate the generated emf. Find the speed at which it is to be driven to generate the same emf as calculated above, with wave wound armature.

Sol:- Given data:-

$P = 4$, $\phi = 21\,mWb = 21 \times 10^{-3}\,Wb$, $N = 1120$ rpm.

Coils $= 42$ & turns/coil $= 8$

$\boxed{\text{Total turns} = \text{coils} \times \text{turns/coil}} = 42 \times 8 = 336$

$\boxed{Z = 2 \times \text{total turns}} = 2 \times 336 = 672$

(i) For lap wound:- $A = P$

$$E = \frac{\phi P N Z}{60 A} = \frac{21 \times 10^{-3} \times 4 \times 1120 \times 672}{60} = 263.42\,V$$

(ii) For wave wound:- $A = 2$

$E = 263.42\,V$

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

$$263.42 = \frac{21 \times 10^{-3} \times 4 \times N \times 672}{60 \times 2}$$

$$\boxed{N = 560 \text{ rpm}}$$

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D. C. Motor

(5)

Principle of operation of a D.C Motor

STATMENT :- When a current carrying conductor is placed in a magnetic field, it experiences a mechanical force.

Consider a single conductor placed in a magnetic field as shown in fig. The magnetic field is produced by a parmanent magnet but in a practical d.c motor. It is produced by the field winding when it carries a current.

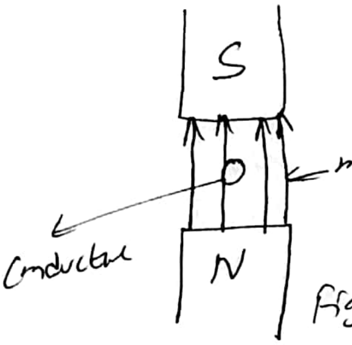

Fig (a)

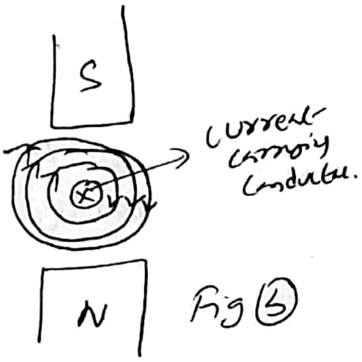

Fig (b)

Now this conductor is excited by a separate supply so that it carries a current in a particular direction. Consider that it carries a current away from an observer as shown in fig a. Any current carrying conductor produces its own magnetic field. around it, hence this conductor also produces its own flux, around. The direction of this flux can be determined by right hand thumb rule. For direction of current considered, the direction of flux around a conductor is clockwise.

Now there are two fluxes present

(1) The flux produced by the permanent magnet called main flux

(2) The flux produced by the current carrying conductor.

These are shown in fig(c). From this it is clear that on one side of the conductor, both the fluxes are in the same direction. In this case, on the left of the conductor there is gathering of the flux lines as two flux helps each other. As against this, on the right of the conductor, the two fluxes are in opposite direction & hence try to cancel each other.

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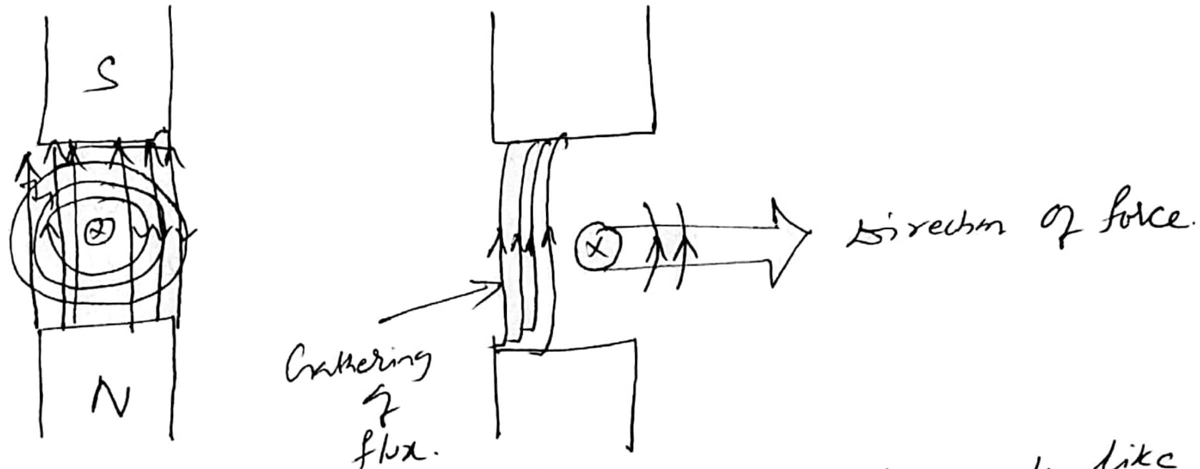
Due to this, the density of the flux lines in this area gets weakened. So on the left, there exists high flux density area while on the right of the conductor there exists low flux density area as shown in fig. (d)



This flux distribution around the conductor acts like a stretched rubber band under tension. This exerts a mechanical force on the conductor which acts from high flux density area towards low flux density area, i.e from left to right for the case considered as shown in

Fig. (d)

Direction of Rotation of Motor

The magnitude of the force experienced by the conductor in a motor is given by

$$\boxed{F = BlI} \text{ Newtons}$$

B = Flux density due to the flux

l = Active length of the conductor

I = Magnitude of the current passing through the conductor.

Fleming's Left Hand rule:-

It states that "Outstretch the three fingers of the left hand namely the first finger, middle finger & thumb such that they are mutually perpendicular to each other. Now point the first finger in the direction of magnetic field & the middle finger in the direction of current then the thumb indicates direction of rotation.

Significance of Back EMF:-

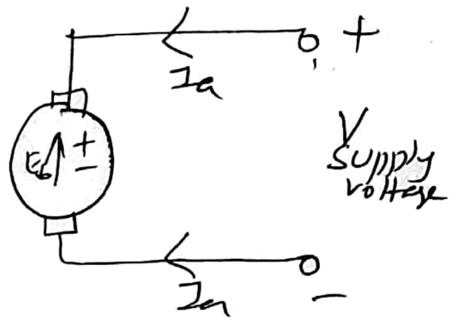
(1) After a motoring action, there exists a generating action. There is an induced emf in the rotating armature conductors according to Faraday's law of electromagnetic induction. This induced emf in the armature always acts in the opposite direction of the supply voltage. This is according to the Lenz's law.

(2) In a d.c. motor, electrical input i.e. the supply voltage is the cause & hence this induced emf opposes the supply voltage. This emf tries to set up a current through the armature which is in opposite direction to that which supply voltage is forcing through the conductor.

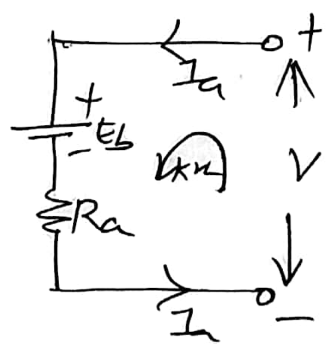
(3) So as this emf opposes the supply voltage. it is called "back emf" and denoted as E_b.

(4) So its magnitude can be determined by the EMF equation

$$\boxed{E_b = \frac{\phi P N Z}{60A}} \text{ volts.}$$



(a) Back emf in a D.C. Motor



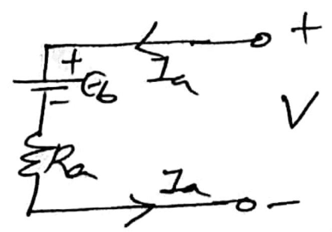
(b) Equivalent circuit

Voltage equation of a D.C Motor

Applying KVL to loop equivalent circuit ~~above~~

$$V - E_b - I_a R_a = 0$$

$$\boxed{V = E_b + I_a R_a} \text{ V.}$$



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Hence from the voltage equation, we can write

$$\boxed{I_a = \frac{V - E_b}{R_a}} \text{ Amp.}$$

(1Q) A 220V, d.c. Motor has a armature resistance of 0.75Ω. It is drawing an armature current of 30A, driving a certain load. Calculate the Induced emf in the motor under this condition.

Sol:- $V = 200V$, $I_a = 30A$, $R_a = 0.75\Omega$

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

$$220 = E_b + 30 \times 0.75$$

$$\boxed{E_b = 197.5} \text{ volts}$$

(2Q) A 4-pole d.c. Motor has lap connected armature winding. The flux per pole is 30 mWb. The number of armature conductors is 250. When connected to 230V. d.c. supply it draws an armature current of 40 A. Calculate the back emf & the speed with which motor is running. Assume armature resistance is 0.6Ω

Sol Given data:-

$P = 4$,

$A = P = 4$

$V = 230V$

$Z = 250$

$\phi = 30 mWb = 30 \times 10^{-3} Wb$

$I_a = 40 A$

From voltage equation

$$V = E_b + I_a R_a$$

$$230 = E_b + 40 \times 0.6$$

$$\boxed{E_b = 206 V}$$

and also :- $E_b = \frac{\phi P N Z}{60 A}$

$$206 = \frac{30 \times 10^{-3} \times 4 \times N \times 250}{60 \times 4}$$

$$\boxed{N = 1648 \text{ r.p.m}}$$

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POWER Equation of a D.C. Motor (7)

The voltage equation of a. d.c. motor is given by

$$V = E_b + I_a R_a$$

Multiplying both sides by I_a, we get

$$\boxed{V I_a = E_b I_a + I_a^2 R_a} \quad \text{— (1)}$$

This equation is called power equation of a d.c.M

Where:-

$V I_a$ = Net electrical power input to the armature measured in watts

$E_b I_a$ = electrical equivalent of gross mechanical power developed by armature (P_m)

$I_a^2 R_a$ = power loss due to the resistance of the armature called armature copper loss.

Condition for max. power:-

From Eq (1) $\quad E_b I_a = V I_a - I_a^2 R_a$

$$P_m = V I_a - I_a^2 R_a$$

From max.power, we have to differentiate with respect to I_a & equate to zero

$$\frac{dP_m}{dI_a} = 0$$

$$V - 2 I_a R_a = 0$$

$$\boxed{I_a R_a = \frac{V}{2}} \quad \text{— (2)}$$

Substituting the value of eq (2) in voltage equation.

$$V = E_b + I_a R_a$$

$$V = E_b + \frac{V}{2}$$

$$\boxed{E_b = V/2}$$

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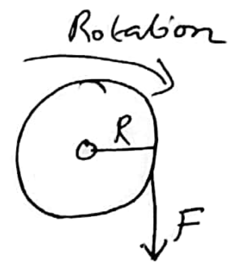
Torque Equation of a D.C Motor:-

It is the turning (or) twisting force about an axis is called torque.



Consider a wheel of radius R meters acted upon by a circumferential force F newtons as shown in fig.

The wheel is rotating at a speed of N rpm

$$\boxed{\omega = \frac{2\pi N}{60} \text{ rad/sec}}$$

So workdone in one revolution is

W = F x distance travelled in one revolution

$= F \times 2\pi R$ Joules.

$$P = \text{Power developed} = \frac{\text{workdone}}{\text{time for 1 rev}}$$

$$= \frac{F \times 2\pi R}{\cancel{\text{time for 1 rev}} \left(\frac{60}{N}\right)}$$

$$= (F \times R) \times \left(\frac{2\pi N}{60}\right)$$

$$\boxed{P = T \times \omega}$$

$\therefore$ **Power in armature = Armature Torque $\times\ \omega$**

$$E_b I_a = T_a \times \frac{2\pi N}{60}$$

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

$$\boxed{T_a = 0.159\, \phi I_a \cdot \frac{PZ}{A}} \quad N\text{-}m$$

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TRANSFORMER (Working Principle of a Transformer).

A transformer is a static piece of equipment used either for raising or lowering the voltage of an a.c. supply with a corresponding decrease or increase in current. It essentially consists of two windings, the primary and secondary, wound on a common laminated magnetic core as shown in fig. The winding connected to the a.c. source is called primary winding (or primary) and the one connected to load is called secondary winding (or secondary). The alternating voltage V_1 whose magnitude is to be changed is applied to the primary. Depending upon the number of turns of the primary (N_1) and secondary (N_2), an alternating e.m.f E_2 is induced in the secondary. This induced e.m.f. E_2 in the secondary causes a secondary current. consequently, terminal voltage V_2 will appear across the load. If $V_2 > V_1$ it is called a step-up transformer. On the other hand, if $V_2 < V_1$, it is called a step-down transformer.

Working: When an alternating voltage V_1 is applied to the primary, an alternating flux ϕ is . in the ~~coil~~ core. This alternating flux links both the windings and induces e.m.f.s E_1 and E_2 in the

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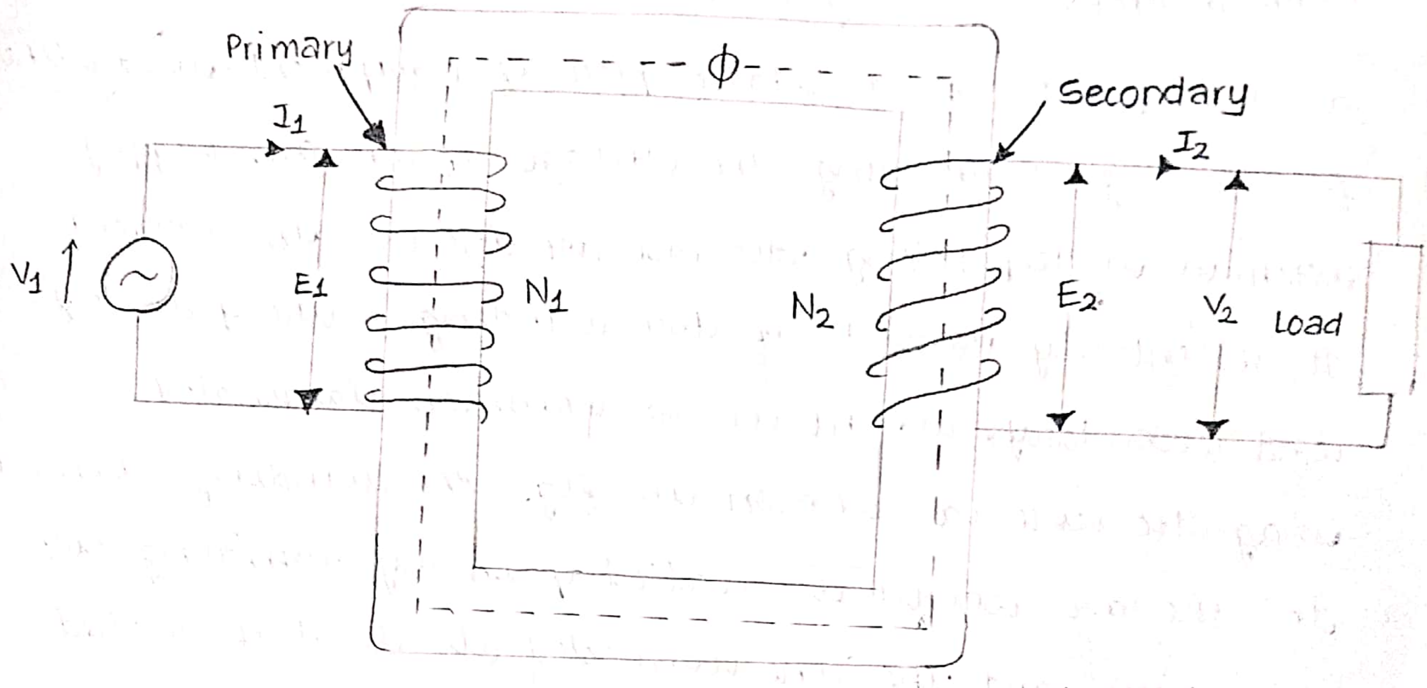

according to Faraday's laws of electromagnetic induction. The e.m.f. E_1 is termed as primary e.m.f. and e.m.f. E_2 is termed as secondary e.m.f.

clearly,

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

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

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

Note that magnitudes of E_2 and E_1 depend upon the number of turns on the secondary and primary resp. If $N_2 > N_1$, then $E_2 > E_1$ (or $V_2 > V_1$) and we get a step up transformer. On the other hand, if $N_2 < N_1$ then $E_2 < E_1$ (or $V_2 < V_1$) and we get a step down transformer. If load connected across the secondary winding, the secondary e.m.f. E_2 will cause a current I_2 to flow.

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through the load. Thus a transformer enables us to transfer a.c. power from one circuit to another with a change in voltage level.

The following points may be noted carefully:

(i) The transformer action is based on the laws of electromagnetic induction

(ii) There is no electrical connection between the primary and secondary. The a.c. power is transfered from primary to secondary through magnetic flux.

(iii) There is no change in frequency i.e, output power has the same frequency as the input power.

(iv) The losses that occur in a transformer are:

a) core losses - eddy current and hysteresis losses.

b) copper losses - in the resistance of the windings.

(v) In practice, these losses are very small so that output secondary power is nearly equal to the input primary power. In other words, a transformer has very high efficiency.

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Problems on EMF Equ. of a Transformer

Q2) A 2000/200V, 20kVA transformer has 66 turns in the secondary. Calculate (i) primary turns (ii) primary and secondary full-load currents. Neglect the losses.

Sol Given data

$V_1 = 2000V$

$V_2 = 200V$

$S = 20kVA$

$N_2 = 66$

$$\boxed{\therefore K = \frac{V_2}{V_1} = \frac{200}{2000} = \frac{1}{10}}$$

(i) $\frac{N_2}{N_1} = K$

$N_1 = N_2 \times 10 = 66 \times 10$

$\boxed{N_1 = 660 \text{ turns}}$

(ii) $V_1 I_1 = V_2 I_2 = S$

$V_1 I_1 = 20 \text{ kVA}$

$I_1 = \frac{20 \times 10^3}{2000}$

$\boxed{I_1 = 10A}$

$V_2 I_2 = S$

$I_2 = \frac{20 \times 10^3}{200}$

$\boxed{I_2 = 100 A}$

Q3) A single phase 2200/250, 50Hz transformer has a net core area of 36 cm² & a maximum flux density of 6 Wb/m². Calculate the number of turns of primary & secondary.

Sol:- Given data

$V_1 = 2200 = E_1$

$V_2 = 250 = E_2$

$f = 50Hz$

$a = 36 cm^2 = 36 \times 10^{-4} m^2$

$B_m = 6 Wb/m^2$

$$\boxed{\begin{aligned}\phi_m = B_m \times A &= 6 \times 36 \times 10^{-4} \\ &= 0.0216 \text{ Wb}\end{aligned}}$$

(i) $E_1 = 4.44 f N_1 \phi_m$

$N_1 = \frac{E_1}{4.44 f \phi_m}$

$N_1 = \frac{2200}{4.44 \times 50 \times 0.0216} = 459$

(ii) $E_2 = 4.44 f N_2 \phi_m$

$N_2 = \frac{E_2}{4.44 f \phi_m}$

$N_2 = \frac{250}{4.44 \times 50 \times 0.0216} = 52$

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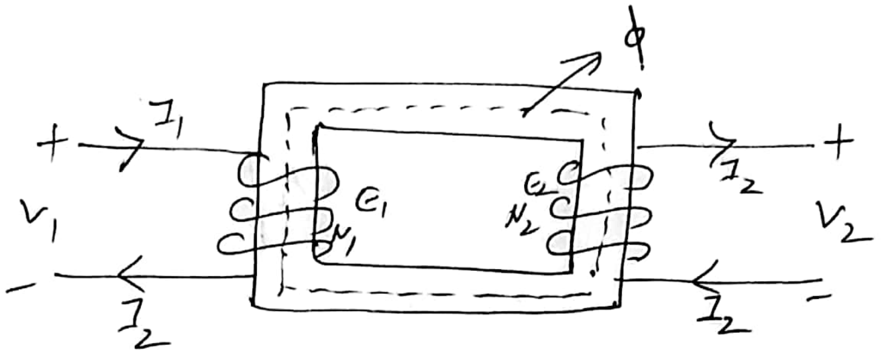
EMF Equations of a Transformer:

Consider that an alternating voltage V_1 of frequency f is applied to the primary as shown in fig. The sinusoidal flux ϕ produced by the primary can be represented as:

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



The instantaneous emf e_1 induced in the primary is

$$e_1 = -N_1 \frac{d\phi}{dt}$$

$$= -N_1 \frac{d(\phi_m \sin\omega t)}{dt}$$

$$= -\omega N_1 \phi_m \cos\omega t$$

$$= -2\pi f N_1 \phi_m \cos\omega t$$

$$e_1 = 2\pi f N_1 \phi_m \sin(\omega t - 90^\circ)$$

It is clear from the above equation, that maximum value of induced emf in the primary is

$$E_{m1} = 2\pi f N_1 \phi_m$$

The r.m.s. value E_1 of the primary emf is

$$\frac{E_{m1}}{\sqrt{2}} = \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$$

$$\boxed{E_1 = 4.44 f N_1 \phi_m.} \text{ Volt}$$

Similarly

$$\boxed{E_2 = 4.44 f N_2 \phi_m} \text{ Volt}$$

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Voltage Transformation Ratio (K)

from the above equations of induced emf, we have

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

The constant K is called Voltage Transformation ratio.

For an ideal T/F :-

(i) $E_1 = V_1$ & $E_2 = V_2$ as there is no voltage drop in the winding

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

(ii) There are no losses,

Input power = output power

$$V_1 I_1 = V_2 I_2$$

$$\boxed{\frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{1}{K}}$$

problems:-

(1) A single-phase, 50 Hz T/F has 80 turns on the primary winding & 400 turns on the secondary winding. The net cross-sectional area of the core is 200 cm^2. If the primary winding is connected to a 240V, 50 Hz supply, determine

(i) The emf Induced in the secondary winding

(ii) The max. value of the flux density in the core

Sol :- Given data :-

$N_1 = 80$

$N_2 = 400$

$f = 50 Hz$

$a = 200\ cm^2 = 200 \times 10^{-4} m^2$

$E_1 = 240V$.

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

$\frac{E_2}{240} = \frac{400}{80}$

$\boxed{E_2 = 1200V}$

(ii) $E_1 = 4.44 f \phi_m N_1$

$240 = 4.44 \times 50 \times \phi_m \times 80$

$\phi_m = \frac{240}{4.44 \times 50 \times 80} = 0.01351\ Wb$

$\boxed{\therefore B_m = \frac{\phi_m}{a} = \frac{0.01351}{200 \times 10^{-4}} = 0.675\ Wb/m^2}$

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Construction of a Transformer:

Design of a transformer is such that it approaches the characteristics of an ideal transformer.

→ The core is made of silicon steel which has low hysterisis loss & high permeability. Core is laminated inorder to achieve eddy current loss. These features considerably reduce iron losses and no load current.

→ Instead of placing primary on one limb and secondary on the other, it's usual practise to wind one-half of each winding on one limb. This ensures tight coupling b/w two windings. consequently, leakage flux is considerably reduced.

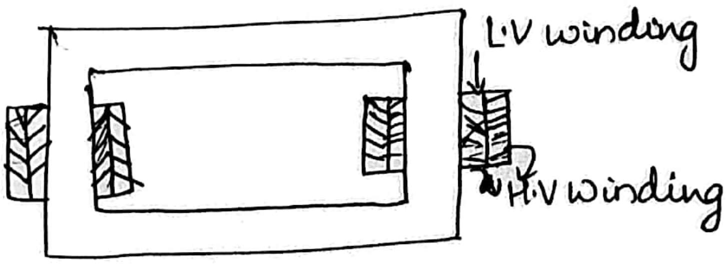
→ Winding resistance R_1 & R_2 are minimised to reduce I^2R loss and resulting rice in temperature & to ensure high efficiency.

TYPES: Depending upon manner in which primary & secondary are wound on core, transformers are of two types

(i.) Core-type transformer.

(ii.) Shell type transformer

CORE TYPE TRANSFORMER: Half of primary winding & half of secondary winding are placed round each limb. This reduces leakage flux. Generally low voltage winding below the high voltage winding for mechanical considerations.



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SHELL-Type TRANSFORMER: Involves use of a double magnetic circuit. Both windings are placed around central limb. Other two limbs acting simply as a low reluctance flux path

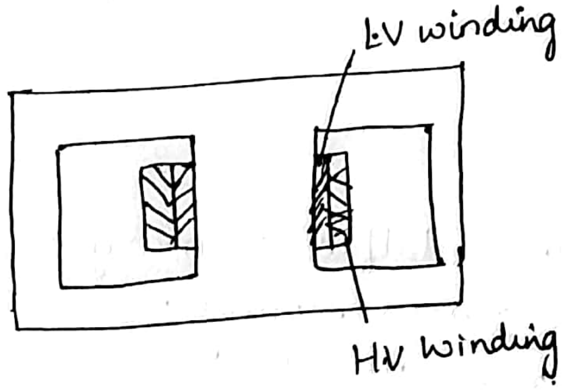
→ Choice of type (either core or shell) will not effect the efficiency of transformer greatly. core type is generally more suitable for high voltage and small or while shell type is more suitable for low voltage and high output.

→ Heat is produced in a transformer by iron losses in core & I^2R loss in winding to prevent undue temperature rise, heat is removed by cooling.

→ In small transformer (Below 50 KVA) Natural air cooling is employed.

→ Medium size cooling is done by housing them in tanks filled with oil.

→ Large transformer, external radiators are added.



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Three phase Induction Motor (11)

Working principle of 3ϕ Induction Motor

When a three phase supply is given to the 3-ϕ stator winding, a rotating magnetic field of constant magnitude is produced. The speed of this rotating magnetic field is synchronous speed, N_s r.p.m.

This rotating field produces an effect of rotating poles around a rotor. Let direction of rotation of this rotating magnetic field is clockwise as shown in fig.

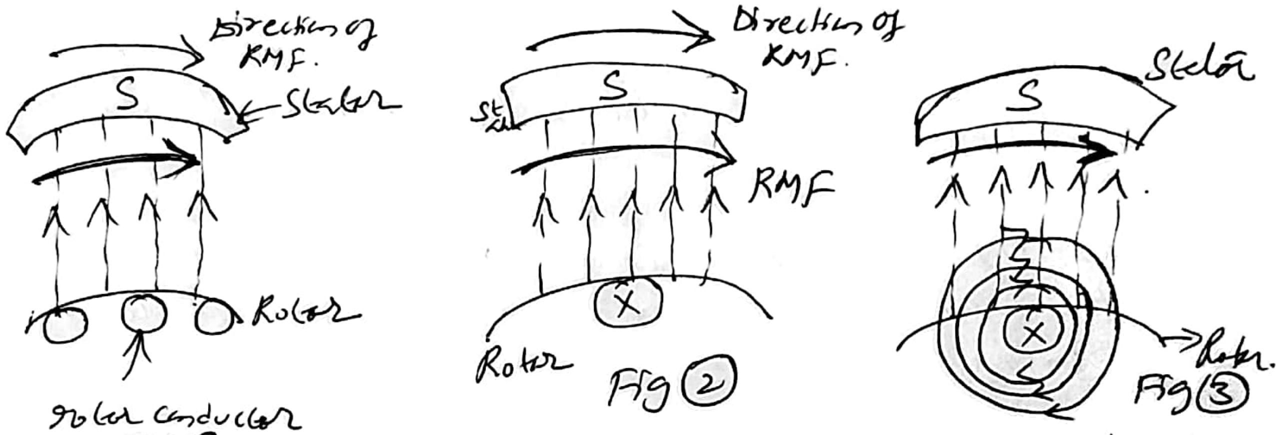

Fig ① Fig ② Fig ③

Now at this instant rotor is stationary & stator flux RMF is rotating. So its obvious that there exists a relative motion b/w the RMF & rotor conductors. Now the RMF gets cut by rotor conductors as RMF sweeps over rotor conductors. Whenever conductors cuts the flux, emf gets induced in it. So emf gets induced in the rotor conductors called rotor induced emf. This is electro-magnetic Induction. As rotor forms closed circuit, induced emf circulates current through rotor called rotor current as shown in Fig②

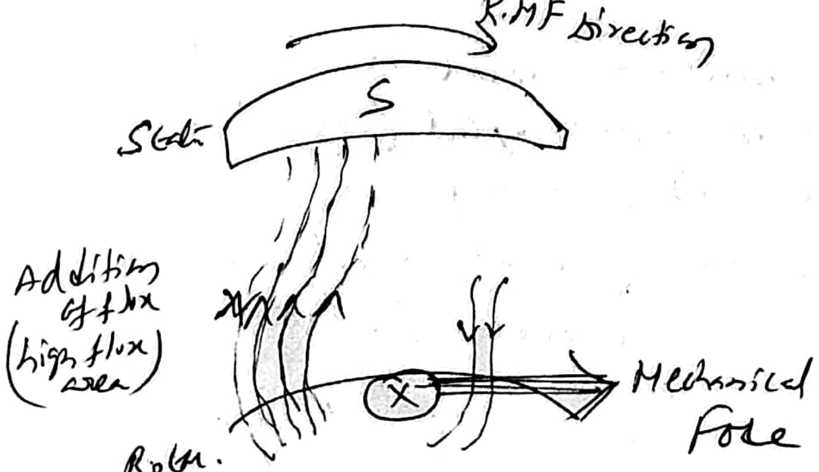

Fig (4)

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Any current carrying conductor produces its own flux. So rotor produces its flux called rotor flux. For assumed direction of rotor current, the direction of rotor flux is clockwise as shown in Fig (3). This direction can be easily determined using right hand thumb rules. Now there are two fluxes, one RMF & other rotor flux. Both the fluxes interact with each as shown in Fig (4). On left of rotor conductor, two fluxes are in same direction hence add up to get high flux area. On right side, two fluxes cancel each other to produce low flux area. As flux lines act as stretched rubber band, high flux density area exists a push on rotor conductor towards low flux density area. So rotor conductor experiences a force from left to right in this case, as shown in the Fig (5) due to interaction of the two fluxes.

As all the rotor conductors experience a force, the overall rotor experiences a torque & starts rotating.

So, N_S = speed of rotating magnetic field in rpm

N = Speed of rotor i.e. motor in rpm

$N_S - N$ = Relative speed b/w the two

∴ Rotor always rotates in same direction as that of RMF.

Slip of Induction Motor :-

Slip of Induction motor is defined as the difference b/w the synchronous speed (N_S) & actual speed of rotor i.e. motor (N) expressed as a fraction of the syn. speed N_S. This is also called absolute slip (or) fractional slip & is denoted as 'S'

$$\boxed{S = \frac{N_S - N}{N_S}}$$

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(12)

(Q1) A 4 pole, 3-ϕ Induction motor is supplied from 50Hz supply. determine its synchronous speed. on full load, its speed is observed to be 1410 rpm. calculate its full load slip.

Sol Given data

$P = 4$, $f = 50Hz$, $N = 1410$ rpm.

$$N_S = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm.}$$

$$S = \frac{N_S - N}{N_S} = \frac{1500 - 1410}{1500} = 0.06.$$

$$\% S = 0.06 \times 100 = 6\%$$

Rotor current Frequency:-

For a rotor speed N, the relative speed b/w the rotating flux & the rotor is $N_S - N$. Consequently, the rotor current frequency f' is given by

$$\boxed{f' = Sf}$$

(Q2) A 3-phase Induction motor is wound for 4 poles and is supplied from 50Hz system. Calculate (i) the synchronous speed (ii) the speed of the motor when slip is 4%. (iii) the rotor current frequency when the motor runs at 600rpm.

Sol:- Given data:-

(Q3)

$P = 4$ poles

$f = 50Hz$

(i) $N_S = \frac{120f}{P} = 120 \times \frac{50}{4} = 1500$ rpm

(ii) $S = 4\%$. then $S = \frac{N_S - N}{N_S} \times 100$

$$4 = \frac{1500 - N}{1500} \times 100$$

$$\boxed{\therefore N = 1440 \text{ rpm}}$$

(iii) when $N = 600$ rpm, then

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

$$S = \frac{1500 - 600}{1500} = 0.6$$

$$\boxed{\begin{aligned} \therefore f' = Sf &= 0.6 \times 50 \\ &= 30Hz \end{aligned}}$$

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~~Construction:-~~

~~Basically, the Indu~~

(03) A 6-pole alternator running at 1000 rpm. supplies an 8 pole Induction motor. Find the actual speed of the motor if the slip is 2.5%.

(04) Sol:- The frequency of 3-ϕ supply fed to the Induction motor is determined from the speed of the alternator and its number of poles.

$$\therefore \text{ supply frequency, } f = \frac{NP}{120} = \frac{1000 \times 6}{120} = 50 Hz.$$

(i) N_S = synchronous sped = $\frac{120 f}{P} = \frac{120 \times 50}{8} = 750$ rpm.

$$S = \frac{N_S - N}{N_S} \times 100$$

$$2.5 = \frac{750 - N}{750} \times 100$$

$$\boxed{N = 731.25 \text{ rpm}}$$

(04) A 50 Hz 4-pole, 3-ϕ Induction motor has a rotor current frequency 2 Hz. Determine (i) the slip and (ii) speed of the motor.

Sol:- Given data

$f = 50 Hz$

$f' = 2 Hz$

$P = 4$

(i) $f' = sf$

$S = \frac{f'}{f} = \frac{2}{50} = 0.04$ (or) 4%.

(ii) Speed of the motor (N)

$N_S = \frac{120 f}{P} = \frac{120 \times 50}{4}$

$= 1500$ r.p.m.

$\therefore S = \frac{N_S - N}{N_S}$

$0.04 = \frac{1500 - N}{1500}$

$$\boxed{N = 1440 \text{ rpm}}$$

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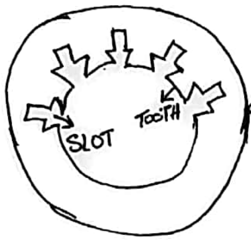
CONSTRUCTION:

-> Induction motor consists of two main parts namely stator & rotor.

STATOR:

-> The stator is made up of a no. of stampings with alternate slot & tooth. stampings are insulated from each other. No. of stampings are stamped togeather to ~~build~~ build stator core.

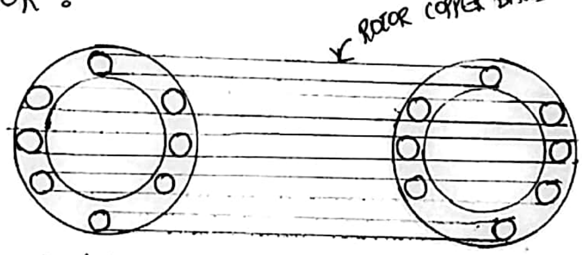
-> Stator core is then fitted in a casted or fabricated steel frame. Slots have the 3-ϕ winding just like 3-ϕ alternator. 3-ϕ winding is called stator winding



ROTOR:

-> Two types of rotors are used in induction motor squirrel cage & slip ring.

SQUIRREL CAGE ROTOR:



-> This is made of cylindrical laminated core with slots to carry rotor conductors. Rotor conductors are heavy bars of copper or aluminium short circuited at Both ends by end rings. Hence called a short circuited rotor.

-> ~~Hence~~ Entire rotor resistance is very small. External resistance cannot be connected in rotor circuit. such motors are extremely rugged in construction. motors using such rotors are called squirrel cage induction motor. majority (most) of induction motors are squirrel cage rotors.

APPLICATIONS:

-> Squirrel cage induction motors are used in lathes, drilling machines, fans, Blowers, water pumps, grinders, printing machines etc.

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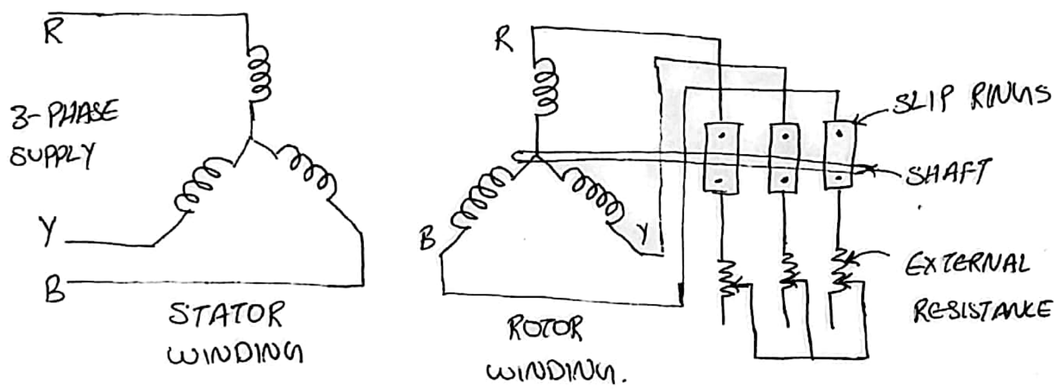
Advantages : of squirrel Cage Rotor

1. cheaper.
2. light weight.
3. Rugged construction (strong).
4. higher efficiency.
5. Requires less maintenance
6. It can be operated in dirty & explosive environment.

Disadvantages:

1. Moderate starting torque.
2. external resistance cannot be connected to rotor circuit. so starting torque cannot be controlled.

SLIP RING OR WOUND ROTOR:



-> In this type of rotor, rotor windings are similar to stator winding. Rotor winding may be star or delta connected, distributed winding, wound for as many no. of poles as stator.

-> 3-ϕ are Brought out & connected to slip rings mounted on rotor shaft. Variable external resistance can be connected in rotor circuit, with the help of Brushes & slip ring arrangements.

-> By varying external resistance in rotor circuit, motor speed & torque can be controlled.

APPLICATION:

-> slip ring induction motors are employed only when speed control or high starting torque is required. Examples are lifts, hoists, cranes, elevators, compressors etc.

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P-N junction Diode:

→ It is formed by two blocks of semiconductor material, one of P-type material + other is n-type material.

→ In p-region holes are majority carriers and electrons are minority carriers.

→ In N-type region holes are minority carriers + electrons are majority carriers.

→ In P-type region holes are represented by small circles + in n-region electrons are represented by dots.

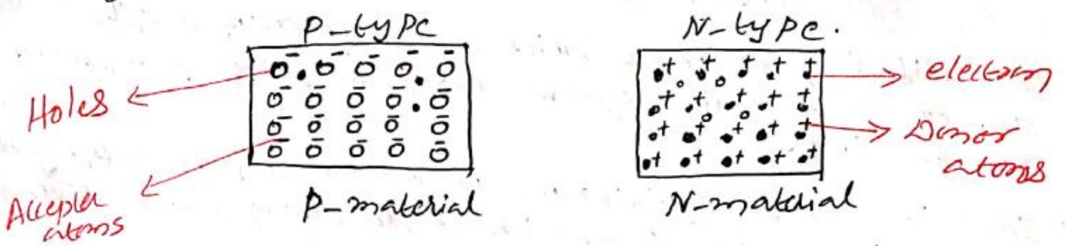
→ Since the concentration of electrons in n-region is more compared to p-side, free electrons from n-side diffuses across the junction + fill the holes on p-side.

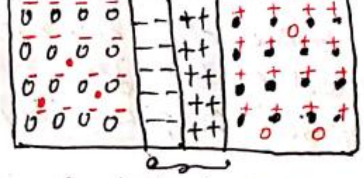
→ Diffusion is a natural process through which charges flow from higher to lower concentration until the difference in concentration is eliminated.

→ Similarly, the holes from p-side diffuse across junction + recombine with electrons in n-side.

→ The free electrons that cross junction create positive ions on N-side. Similarly diffusion of holes in the p-material creates negative ions.

→ Since negative ions are created on p-side of junction, the region close to junction acquires negative charges. Similarly positive ions created on n-side give a positive charge near junction.





PN junction
(Depletion region)

Formation of depletion Region:-

→ In p-n junction, there exist a concentration gradient near junction.

→ There are large no. of holes on p-side while very small no. of holes on n-side near junction. Thus holes start moving from p-side to n-side i.e. high to low concentration this is diffusion.

→ Similarly electrons start moving from n-side to pside i.e, high to low concentration.

→ As holes enter n-region they find no. of donor atoms. The holes recombine with donor atoms. As donor atoms accept additional holes they becomes positively charged immobile ions.

→ As electrons enter p-region they find no. of acceptor atoms. The electrons recombine with acceptor atoms. As acceptor atoms accept additional electrons they becomes negatively charged immobile ions.

→ As more no. of holes diffuse on n-side large positive charge accumulated on n-side near junction.

→ The diffusing holes which are positively charged, get repelled due to accumulated positive charge on n-side & the diffusion of holes stops.

→ As more no. of electrons diffuse on p-side, large negative charge gets accumulated on p-side near the junction.

→ The diffusing electrons which are -vely charged gets repelled due to accumulate negative charge on pside & diffusion of electrons stop.

→ Thus in thermal equilibrium, in the region near the junction there exist a wall of -ve immobile charges on p-side & a wall of +ve immobile charges on side.

→ In this region, there are no. mobile charged carriers, such a region is depleted of the free mobile charge carriers & hence called "depletion region" (or) "depletion layer"

→ In equilibrium condition, the depletion region gets widened upto a point where no further electrons (or) holes can cross the junction, Thus depletion region acts a "Barrier"

Barrier potential:-

→ Near the junction, one one side there are many positive charges. on other side there are many negative charges

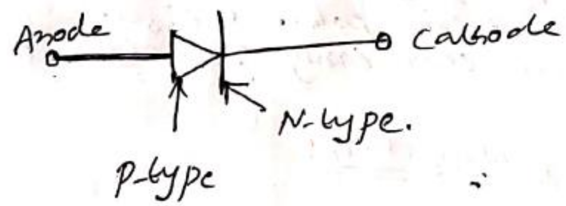
→ According to coulomb's Law, there exist a force b/w these opposite charges. And this force produces an electric field b/w the charges. The direction of electric field is from positive to negative.

→ The opposite charges existing near the junction creates a potential difference across the junction.

→ This potential difference has a fixed polarity & it acts as a barrier to the flow of electrons & holes, across the junction.

→ Hence, this potential is called barrier potential, junction potential or built-in potential barrier of a p-n junction

Symbol:-



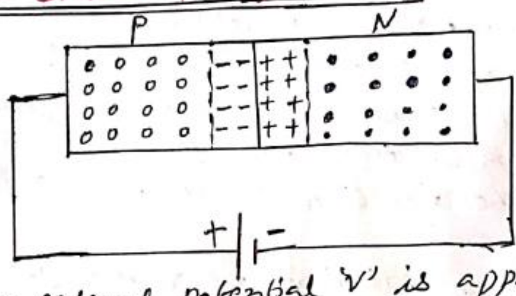
Biasing of P-N junction Diode:

→ Applying external DC voltage to any electronic devices is called Biasing

→ Depending upon the polarity of the DC voltage externally applied to it, the biasing is classified as forward biasing & Reverse biasing

Forward biased P-N junction :-

4-4



→ When an external potential 'V' is applied across the P-N junction such that the positive terminal is connected to p-type material & negative material is connected to N-type material then the diode is said to be forward biased

→ When forward bias is applied to P-N junction the holes in p-side are repelled by the positive terminal of the battery & flow towards the junction.

→ Similarly, the electrons in n-side are repelled by the -ve terminals of the battery & move towards the junction.

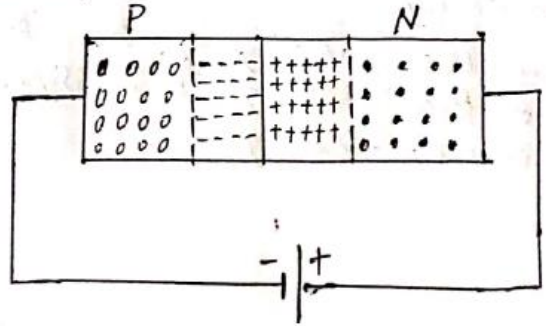
→ The electrons & holes that are driven towards junction recombine with ions near the boundary & reduce width of depletion region.

→ The reduction in width of depletion layer reduces the barrier potential.

→ If the applied voltage is increased further, a stage is reached where the barrier potential effectively disappears & charge carriers can easily flow across the junction.

Reverse Biased P-N junction:

→ If an external potential V is applied across the P-N junction that the positive terminal of diode is connected to n-side material + negative material is connected to p-side material, then the diode said to be reverse biased



4-5

→ The reverse bias forces free electrons in the n-region to move away from the junction towards +ve terminal. These electrons leave more positive ions near the junction.

→ Similarly, the holes in the p-side also move away from the junction towards negative terminal of the battery.

These holes leave more negative ions near the junction.

→ As a result the width of the depletion region increases. The greater the reverse bias, the wide the depletion layer. This increases in the width of depletion region effectively reduces the majority carrier flow.

→ However due to thermal energy limited no. of free electrons + holes are generated in P-side + N-side of PN junction respectively.

→ Electrons in p-side move towards right + cross the junction + holes in n-side move towards left + cross the junction.

→ The movement of Minority carriers constitute a current known as "reverse saturation current". It is denoted by "I_{co}".

→ Hence I_{co} is due to thermally generated minority carriers if it will not increase with increase in reverse voltage. It increase with increase in temperature.

→ Normally I_{co} doubles for every 10°c rise in temperature. The reverse saturation current I_{co} is typically less than 1μA for silicon, while for germanium it may exceed 10μA.

Breakdown Voltage:

- → If the Reverse biased voltage is increased, the velocity of minority charge carriers crossing the junction increases.
- → The greater the reverse bias the faster the electron movement.
- → Since velocity increased, the associated, kinetic energy ($1/2\, mv^2$) also increases
- → When these carriers with high kinetic energy collide with atom the valence electron in the atom absorbs sufficient energy & leave the parent atom.

- → These additional carriers also get sufficient energy from the applied reverse bias & collide with other atoms & generate some more carriers. 4-6
- → This collision & generation of carriers is a cumulative effect which results in large amount of reverse current.
- → This phenomena, known as reverse breakdown occurs at a particular reverse voltage for a P-N junction. This voltage is known as "Reverse Breakdown Voltage."

Reverse Bias ↑, velocity ↑, KE ↑ High KE causes collide → Atom → electron leave → Collide with other atoms ↓ generation of carriers

$\boxed{\text{collision + generation = large reverse current}}$

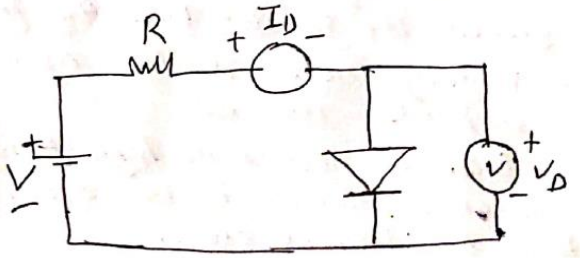
Volt-ampere characteristics of a Diode (V-I Characteristics):-

The response of a diode when connected in an electrical circuit, can be judged from its characteristics known as volt-ampere commonly called V-I chas.

→ The V-I characteristics in the forward biased & reverse biased condition is the graph of voltage across the diode against the diode current.

Forward ch's of pn junction diode:-

(a) Symbol



(b) Ckt diagram to obtain forward bias.

→ The circuit diagram to obtain the V-I ch's of the diode as shown in fig. 4-7

→ It consists of a dc voltage source & a resistor connected in series with a diode.

→ The resistor is used to limit the forward current to a value that will not over heat the diode & cause damage.

→ An ammeter is connected in series with the diode to measure the diode current I_D & voltmeter is connected across the diode to measure voltage across it.

→ By varying the dc voltage source the voltage V_D across the diode and current I_D through the diode can be measured.

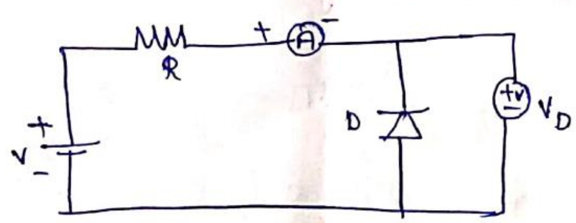
→ When the applied voltage is zero, the voltage across the diode remains zero; hence there is no forward current.

→ When the applied voltage increased gradually, the forward current & the voltage across the diode gradually increase.

→ When applied voltage increases to a value which increases the voltage across diode to barrier potential (0.7V for silicon, 0.3V for germanium), the forward current begins to increase rapidly.

→ We can see that forward current is very low until the voltage across p-n junction reaches approximately 0.7V. After this point the current I_F increases rapidly. But forward voltage remains at 0.7V.

Reverse ch's of p-n junction diode:-

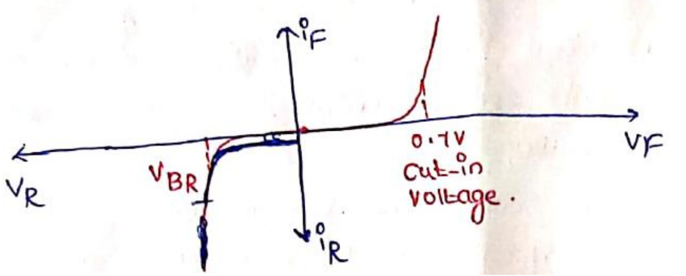


→ To find VI ch's of a diode in reverse bias, we simply reverse the position of diode as shown.

→ The Reverse bias increases from zero, a smaller reverse saturation current flows through the diode & the voltage across the diode increases.

→ When the applied reverse bias reaches a certain value, a reverse avalanche breakdown would occur, then the magnitude of the current increases rapidly as shown. 4-8.

→ This voltage at which the diode current increases rapidly is known as reverse breakdown voltage.



2.4. Diode Current Equation

The mathematical equation, which describes the forward and reverse characteristics of a semiconductor diode is called the **diode current equation.**

Let I = Forward (or reverse) diode current,

I_{RS} = Reverse saturation current,

V = External voltage (It is positive for forward bias and negative for reverse bias),

η = A constant

= 1 for germanium diodes, 2 for silicon diodes for relative *low value of diode current* (*i.e.*, at or below the knee of the curve)

= 1 for germanium and silicon for *higher levels of diode current* (*i.e.*, in the rapidly increasing section of the curve), and

V_T = Volt-equivalent of temperature. Its value is given by the relation, $\dfrac{T}{11600}$,

where T is the absolute temperature

= 26 mV at room temperature (300 K).

For a *forward-biased diode*, the current equation is given by the relation,

$$I = I_{RS}\,[e^{V/(\eta \times V_T)} - 1] \qquad ...(i)$$

Substituting the value of V_T = 26 mV or 0.026 V (at room temperature) in eqn. (*i*), we get

$$I = I_{RS}\,(e^{40V/\eta})$$

$\therefore$ Diode current at or below the knee, for *germanium*,

$$I = I_{RS}\,(e^{40V} - 1) \qquad (\because \quad \eta = 1)$$

and, for *silicon*,

$$I = I_{RS}\,(e^{20V} - 1) \qquad (\because \quad \eta = 2)$$

When the value of applied voltage is greater than unity (*i.e.*, for the diode current in the rapidly increasing section of curve), the equation of diode current for germanium or and silicon,

$$I = I_{RS} \cdot e^{20V} \qquad (\because \quad \eta = 2)$$

The current equation for a reverse biased diode may be obtained from eqn. (*i*) by *changing the sign of the applied voltage (V)*. Thus the *diode current for reverse bias,*

$$I = I_{RS}\,[e^{-V/(\eta \times V_T)} - 1]$$

When $V >> V_T$, then the term $e^{-V/(\eta \times V_T)} << 1$. Therefore $I = I_{RS}$. Thus the *diode current under reverse bias is equal to the reverse saturation current as long as the external voltage is below its breakdown value.*

Example 1. *The current flowing in a certain P-N junction diode at room temperature is 1.8×10^{-7} A, when large reverse voltage is applied. Calculate the current flowing, when 0.12 V forward bias is applied at room temperature.*

Solution. *Given* : $I_{RS} = 1.8 \times 10^{-7}$ A ; $V_F = 0.12$ V

The current flowing through the diode under forward bias is given by,

$$I = I_{RS}\,(e^{40V_F} - 1)$$

or $\quad \mathbf{I} = 1.8 \times 10^{-7}\,(e^{40 \times 0.12} - 1) = 21.69 \times 10^{-6}\text{ A} = \mathbf{21.69\ \mu A.}$ **(Ans.)**

Example 2. *Determine the germanium P-N junction diode current for the forward bias voltage of 0.2 V at room temperature 24°C with reverse saturation current equal to 1.1 mA. Take $\eta = 1$.*

Solution. *Given* : $V_F = 0.2$ V ; $T = 24 + 273 = 297$ K ; $I_{RS} = 1.1\text{ mA} = 1.1 \times 10^{-3}$ A ; $\eta = 1$

We know that, $V_T = \dfrac{T}{11600} = \dfrac{297}{11600} = 0.0256$ V (*i.e.*, 25.6 mV)

$\therefore$ The diode current,

$$\mathbf{I} = I_{RS}\,[e^{V_F/(\eta \times V_T)} - 1]$$

$$= 1.1 \times 10^{-3}\,[e^{0.2/(1 \times 0.0256)} - 1] = \mathbf{2.717\ A.} \quad \textbf{(Ans.)}$$

η = voltage equivalent

1) A silicon diode has a reverse saturation current of 7.12 nA at room temperature of 27°c. Calculate its forward current if it is forward biased with a voltage of 0.7V?

Sol:- Given data,

$I_0 = 7.12\,nA = 7.12 \times 10^{-9} A$

$V = 0.7V$

$\eta = 2$ for silicon diode

$T = 27°C = 27 + 273 = 300°K$

Now $V_T = KT = 8.62 \times 10^{-5} \times 300 = 0.026V$

According to diode current equ

$$I = I_0 \left[e^{V/\eta V_T} - 1 \right]$$

$$I = 7.12 \times 10^{-9} \left(e^{0.7/2 \times 0.026} - 1 \right)$$

$$\boxed{I = 5mA}$$

2) The voltage across a silicon diode at room temperature of (7) 300°K is 0.71V when 2.5mA current flows through it. then $V_T = 26mV$ If voltage increases to 0.8V, calculate new diode current? 4-9

Sol:- Given data,

At 300°k, $V_T = 26mV = 26 \times 10^{-3} V$

$V = 0.71V$ for $I = 2.5mA$ & $\eta = 2$

The current equ of a diode is

$$I = I_0 \left[e^{V/\eta V_T} - 1 \right]$$

$$2.5 \times 10^{-3} = I_0 \left[e^{(0.71/2 \times 26 \times 10^{-3}} - 1 \right]$$

$$\boxed{I_0 = 2.93 \times 10^{-9} A}$$

Now, $V = 0.8V$

$$I = 2.93 \times 10^{-9} \left[e^{0.8/2 \times 26 \times 10^{-3}} - 1 \right]$$

$$\boxed{I = 14.11mA}$$

Effect of temperature on PN junction diode.

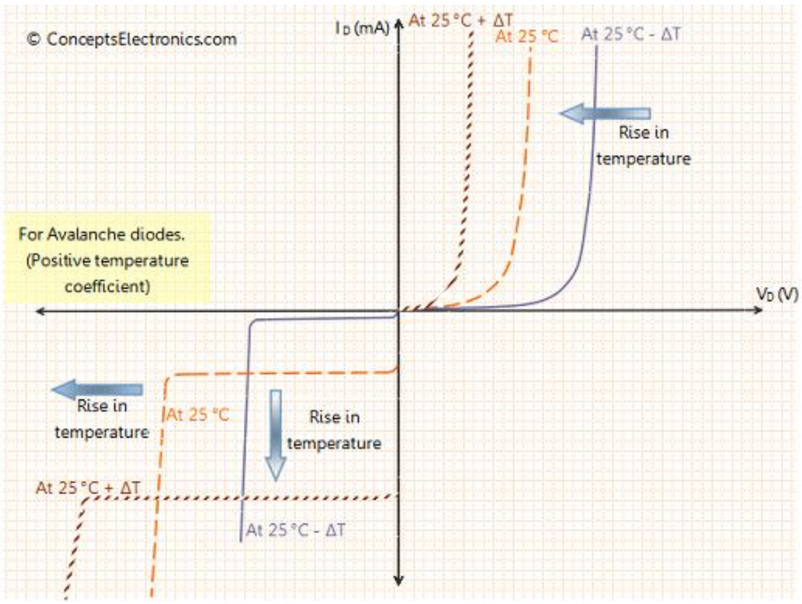
- PN junction diode parameters like cut in voltage , forward current in the forward bias and reverse current, reverse breakdown voltage and reverse saturation current in the reverse bias are dependent on temperature.

- The current that a PN junction diode can conduct at a given voltage is dependent upon the operating temperature. An increased temperature will result in a large number of broken covalent bonds increasing the large number of majority and minority carriers. Rise in temperature generates more electron-hole pair thus conductivity increases and thus increase in current.This amounts to a diode current larger than its previous diode current. The above phenomenon applies both to forward and reverse current.

- Mathematically diode current is given by

$$I = I_{RS}\ [e^{V/(\eta \times V_T)} - 1]$$

Hence from equation we conclude that the current should decrease with increase in temperature but exactly opposite occurs, there are two reasons:



Effect of temperature on avalanche diodes

Forward bias region :

- The effect of increased temperature and decrease in temperature on the forward characteristics curve of a PN junction diode is as shown in above figure. It may be noted that the forward characteristics of silicon diode shift to the left at rate of 2.5 m V per centigrade degree increase in temperature and shift towards right at rate of 25 m V per centigrade degree decrease in temperature.
- The cut-in voltage decreases as the temperature increases. The diode conducts at smaller voltage at large temperature.
- The cut-in voltage increases as the temperature decreases. The diode conducts at larger voltage at lower temperature.

Example:

At 25° C $V_D = 0.7V$

for 100° C Rise in temp. i.e., at 25+100=125°C

now we will find new V_D at 125° C then 100*2.5mV =0.25 V

the new V_D will be reduce by 0.25 V

therefore new V_D = 0.7- 0.25= **0.45 V**

At 25° C $V_D = 0.7V$

for 100° C decrease in temp. i.e., at 25-100= -75°C

now we will find new V_D at 75° C then 100*2.5mV =0.25 V

the new V_D will be increase by 0.25 V

therefore new V_D = 0.7+ 0.25= **0.95 V**

Reverse bias region:

- The effect of increased temperature and decrease in temperature on the reverse characteristics curve of a PN junction diode is as shown in above figure. It may be noted that in the reverse bias region characteristics reverse current of silicon diode shift downwards with the increase in temperature and shift upward with decrease in temperature.
- In the reverse bias region the reverse current of diode doubles for every 10ºC rise in temperature.

. Example:

- For 100° C Rise in temp. i.e., at 25+100=125°C

25° C $\longrightarrow$ 10nA

35° C $\longrightarrow$ 20nA

45° C $\longrightarrow$ 40nA

55° C $\longrightarrow$ 80nA

.

.

.

.

.

.

125° $\longrightarrow$ 10240n A (**OR)** 10.24 µ A

Therefore for 100° C Rise in temp. i.e., at 25+100=125°C the reverse saturation current increases to greater than 10nA

- For 100° C decrease in temp. i.e., at 25-100 = **-**75°C the reverse saturation current reduces to less than 10nA

Static and Dynamic Resistance of a Diode

Static forward resistances (R_F). A diode has a definite value of resistance when forward biased. It is given by the *ratio of the D.C. voltage across the diode to D.C. current flowing through it.*

Mathematically, $R_F = \dfrac{V_F}{I_F}$

R_F may be obtained *graphically* from the diode forward characteristics as shown in Fig. From the operating point P, the static forward resistance,

$$R_F = \frac{0.8}{16} = 0.05\ \Omega.$$

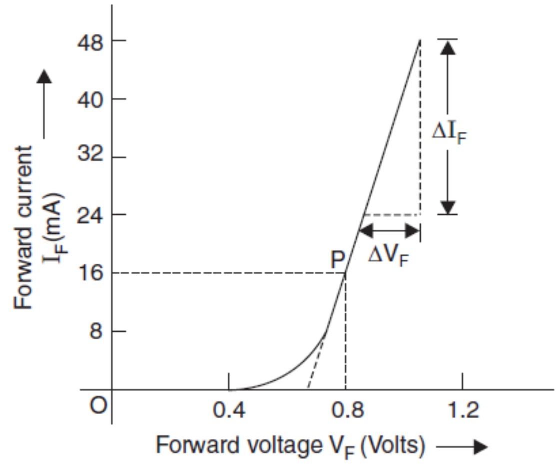


Fig. Static and dynamic forward resistances of a diode from the characteristic curve.

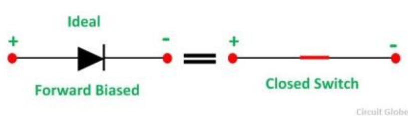
Dynamic or A.C. resistance. In practice we don't use static forward resistance, instead, we use the dynamic or A.C. resistance. The A.C. resistance of a diode, at a particular D.C. voltage, is *equal to the reciprocal of the slope of the characteristic at that point ; i.e,* the A.C. resistance,

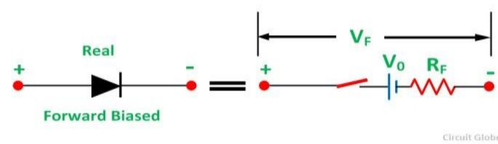
$$r_{\text{A.C.}} = \frac{1}{\Delta I_F/\Delta V_F} = \frac{\Delta V_F}{\Delta I_F} = \frac{\text{Change in voltage}}{\text{Resulting change in current}}.$$

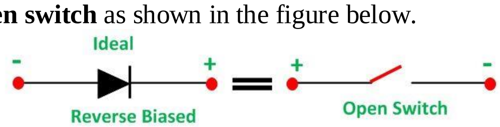
Owing to the non-linear shape of the forward characteristic, the value of A.C. resistance of a diode is in the range of 1 to 25 Ω. Usually it is *smaller than D.C. resistance of a diode.*

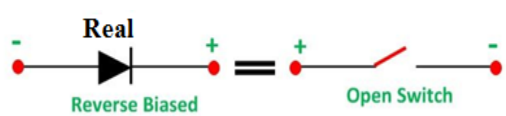
Reverse resistance. When a diode is *reverse biased,* besides the forward resistance, it also possesses another resistance known as *reverse resistance.* It can be either D.C. or A.C. depending upon whether the reverse bias is direct or alternating voltage. Ideally, the reverse resistance of a diode is infinite. However, in actual practice, the reverse resistance is never infinite. It is *due to the existence of leakage current* in a reverse biased diode.

Ideal Diode and Practical Diode

<table>
<tr><th>Ideal Diode</th><th>Practical Diode</th></tr>
<tr>
<td>1)A diode is said to be an Ideal Diode when it is forward biased and acts like a perfect conductor, with zero voltage across it. Similarly, when the diode is reversed biased, it acts as a perfect insulator with zero current through it.</td>
<td>1)A Practical diode contains barrier potential V_0 (0.7 V for silicon and 0.3 V for Germanium) and a forward resistance R_F of about 25 ohms. When a diode is forward biased and conducts a forward current I_F flows through it which causes a voltage drop I_FR_F in the forward resistance. Hence, the forward voltage V_F applied across the Practical diode for conduction, has to overcome the following.
(i) Potential barrier
(ii) Drop in forward resistance
i.e.,
$$V_F = V_0 + I_FR_F$$</td>
</tr>
<tr>
<td>2) When the Ideal diode is forward biased it acts like a closed switch as shown in the figure below. An Ideal diode also acts like a switch


Diode resistance is zero i.e., R_D=0 from ohms law
$V_D= I_DR_D$
Therefore V_D=0</td>
<td>2)The equivalent circuit of the Practical diode under forwarding bias condition is shown below.This circuit shows that a Practical diode still acts as a switch when forward biased, but the voltage required to operate this switch is V_F


$$V_F = V_0 + I_FR_F$$</td>
</tr>
<tr>
<td>3) Where as, if the diode is reversed biased, it acts like an open switch as shown in the figure below.


Diode resistance is infinity i.e., $R_D=\infty$ from ohms law
$V_D= I_DR_D$
Therefore ,I_D=0</td>
<td>3)For all the practical purposes, a diode is considered to be an open switch when reversing biased. It is because the value of reverse resistance is so high (R_R > 100 MΩ) that is considered to be an infinite for all practical purposes.

</td>
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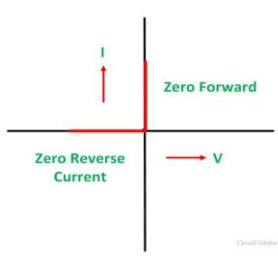
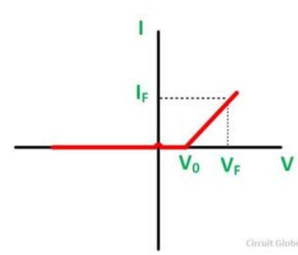
<tr>
<td>4) The V-I characteristics of the Ideal diode are shown in the figure below

</td>
<td>4)The V-I characteristic of the Practical diode is shown below.

</td>
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</table>

Equivalent Diode Circuits

An equivalent circuit is nothing but a combination of elements that best represents the actual terminal characteristics of the device. In simple language, it simply means the diode in the circuit can be replaced by other elements without severely affecting the behavior of circuit.

The diode can be modeled in three different ways depending on the accuracy required. Three models with increasing accuracy are listed below:

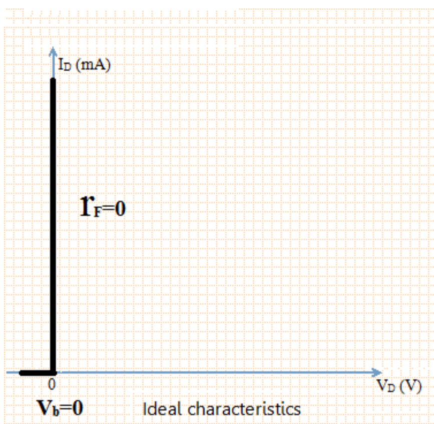
1. Ideal Diode Equivalent Circuit:
2. Constant voltage drop (or) Simplified Equivalent Circuit
3. Piece-Wise Linear Equivalent Circuit

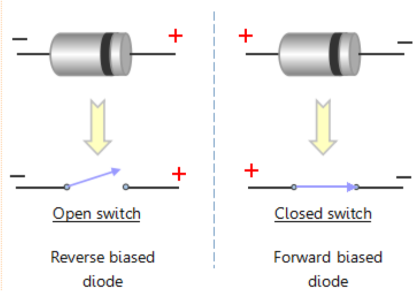
1. Ideal Diode Equivalent Circuit:

Figure indicates that the voltage drop across the diode is zero for any value of diode current. The ideal diode does not allow any current to flow in reverse biased condition. The current flowing through the diode is zero for any value of reverse biased voltage. Taking this into consideration, the ideal diode can be modeled as open or closed switch depending on the bias voltage.

a) Ideal diode allows the flow of forward current for any value of forward bias voltage. Hence, Ideal diode can be modeled as closed switch under forward bias condition. This is shown in the figure.

b) Ideal diode allows zero current to flow under reverse biased condition. Hence it can be modeled as open switch. This is indicated in the figure.

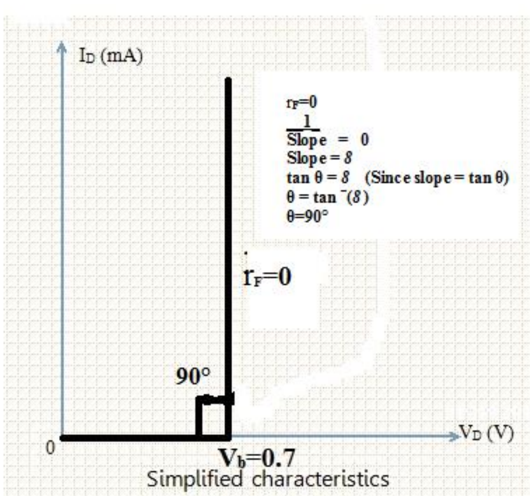


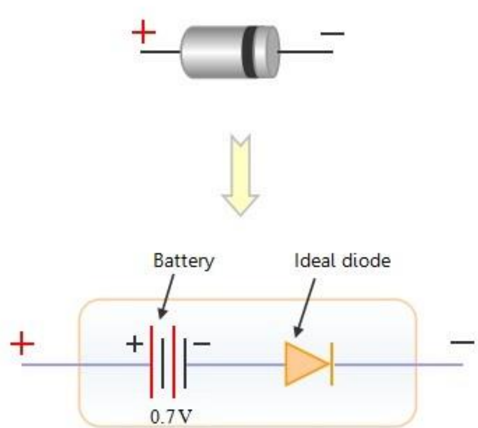


Ideal Equivalent Circuit

2. Constant Voltage Drop (or) Simplified Equivalent Circuit

The equivalent circuit in this case consists of a battery and an ideal diode. Consider the horizontal line from (0 to 0.7 V) in the curve. The horizontal line indicates that the current flowing through diode is zero for voltages between 0 and 0.7 V. To model this behavior, we put a battery of 0.7 V in the equivalent diode model. This does not mean that diodes are a source of voltage. When you measure the voltage across an isolated diode, the instrument will show zero value. The battery simply indicates that it opposes the flow of current in forward direction until 0.7 V. As the voltage becomes larger than 0.7 V, the current starts flowing in forward direction.

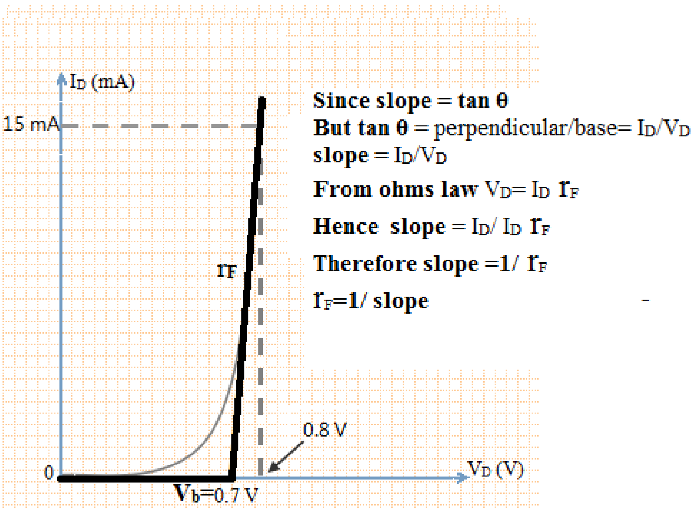




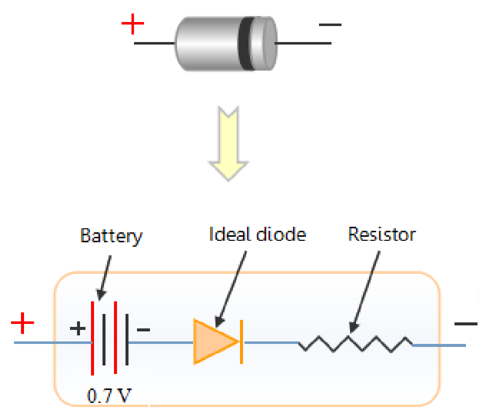
simplified Equivalent circuit

3. Piece-Wise Linear Equivalent Circuit

The piece-wise linear circuit, as the name suggests, is a model in which the characteristics of diode is approximated by "piece-wise linear" line segments. Now consider the straight line in the piece-wise linear characteristics. This straight line indicates constant slope. Slope in the V-I graph indicates resistance. So we add a resistor in the diode model. The value of resistance can be found from the graph. We can see from the graph that the diode current changes from 0 to 15 mA for a voltage change from 0.7 to 0.8 V. Thus the average value of resistance is (0.8 V-0.7 V)/(15 mA - 0 mA) = 6.67 Ω. Thus the value of resistance in the equivalent model is approximately 6.67 Ω. The figure given below shows piece-wise linear characteristics of diode along with its model.



Piecewise-linear characteristics



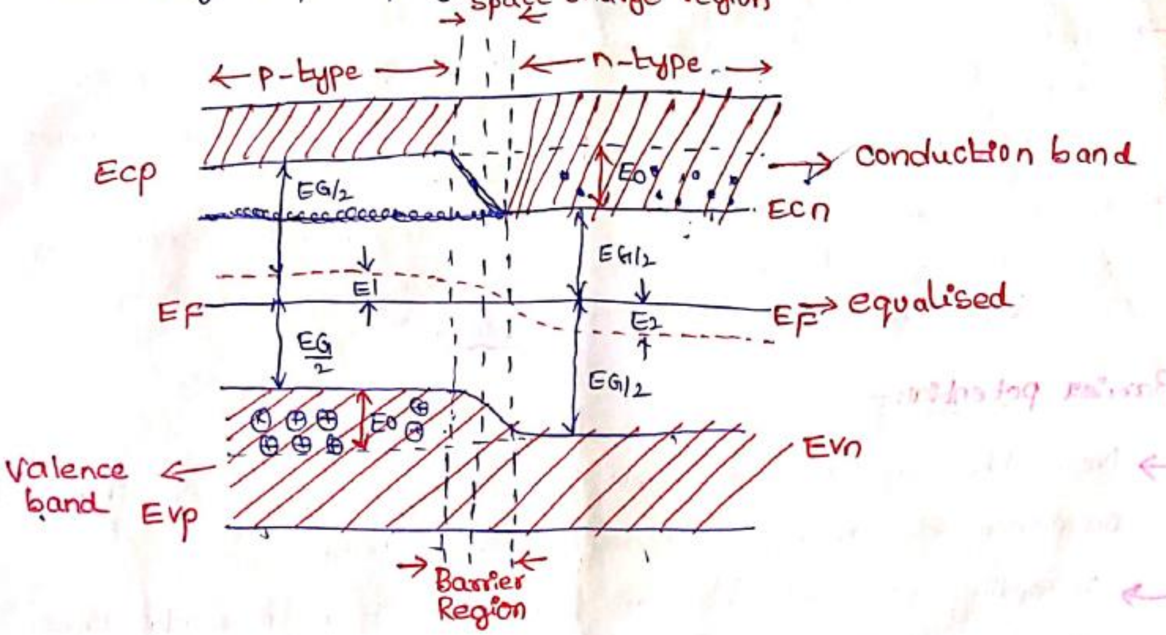
Piecewise linear Equivalent Circuit

In the graph shown on left, the actual characteristics of diode is superimposed by piece-wise linear characteristics (shown in amber color). It is clear that the piece-wise linear characteristics do not exactly represent the characteristics of diode, especially near the knee of the curve. However it provides a good first approximation to the actual characteristics of the diode. Piece- wise linear characteristics can be obtained by replacing the diode in the circuit with a resistor, a battery and an ideal diode. This is shown in the right side of the above figure.

Energy band diagram

Band structure of an open-circuited p-n junction:- 4.1

→ The energy band diagram for a p-n junction is shown, where the Fermi level E_F is closer to conduction band edge E_{cn} in the N-type material, while it is closer to valence band edge E_{vp} in p-type.



Energy Band Structure

→ It is clear that the conduction band edge E_{cp} in p-type material is higher than conduction band edge E_{cp} in p-type.

→ Similarly, the valence band edge E_{vp} in the p-type material is higher than valence band edge E_{vn} in the n-type.

→ E_1 & E_2 indicates shift in fermi level from intrinsic conditions in p & n type materials.

→ Then total shift in energy level E_0 is given by

$$E_0 = E_1 + E_2$$

$$= E_{cp} - E_{cn} \text{ (Conduction band)}$$

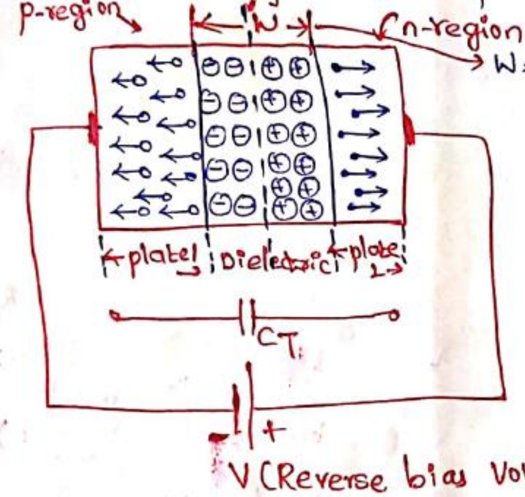
$$= E_{vp} - E_{vn} \text{ (Valence band)}$$

$$\boxed{\because \; E_0 = E_1 + E_2 = E_{cp} - E_{cn} = E_{vp} - E_{vn}}$$

→ This energy E_0 (in eV) is potential energy of the electrons at p-n junction, & is equal to V_0, where V_0 is contact potential (in volt), or contact diff of potential or barrier potential.

Space charge or Transition capacitance (C_T):-

consider a reverse biased p-n junction diode as shown.



→ As seen earlier, when a diode is reverse biased, reverse current flows due to minority carriers.

→ Majority charged particles i.e., electrons in n-region & holes in p-region move away from junction.

→ This increases width of depletion region.

→ The width of depletion region increases as reverse bias voltage increases.

→ As the charged particles move away from the junction there exists a change in charge w.r.to applied reverse voltage

→ So change in charge dQ with respect to the change in voltage dV is nothing but a capacitive effect.

→ Such a capacitance which comes in to picture under reverse biased condition is called "Transition capacitance", "Space-charge capacitance", "barrier capacitance" or "depletion layer capacitance" & denoted as C_T. The magnitude of C_T is given by the eqn,

$$\boxed{C_T = \frac{dQ}{dV}}$$

→ This capacitance is very important as it is not constant but depends on magnitude of reverse voltage.

4-13

→ If W is the width of depletion region then the transition capacitance is

$$\boxed{C_T = \frac{\epsilon A}{W}}$$

Where, A = Area of cross-section of junction

ϵ = permittivity of semiconductor.

Diffusion capacitance (C_D):- (or) storage capacitance:-

→ During forward biased condition, an another capacitance comes in to exist called "diffusion capacitance" or "storage capacitance", denoted as "C_D."

→ In forward biased condition, the width of depletion region decreases & holes from p-side get diffused in n-side while electrons move from n-side to p-side.

→ As applied voltage increases, concentration of injected charged particles increases.

→ This rate of change of injected charge with applied voltage is defined as a capacitance called diffusion capacitance.

$$\therefore \boxed{C_D = \frac{dQ}{dV}}$$

→ The diffusion capacitance can be determined by the expression.

$$\boxed{C_D = \frac{\tau I}{\eta V_T}}$$ where, τ = Mean life time for holes.

→ So diffusion capacitance is proportional to current. For forward biased condition, the value of diffusion capacitance is of the order of nano farads to microfarads while transition capacitance is of the order of pico farads. So, C_D is much larger than C_T.

Power and Current Ratings of a Diode

The power dissipation for a *forward biased diode is given by,*

$$P_{DF} = V_F \times I_F$$

where, P_{DF} = Power dissipated by the diode,

V_F = Forward voltage drop, and

I_F = Forward current.

Similarly, power dissipation for a *reverse biased diode,*

$$P_{DR} = V_R \times I_R$$

where, V_R = Reverse voltage drop, and

I_R = Reverse current.

The maximum value of power, which a diode can dissipate without failure, is called its **rating**. Thus the power dissipation should not exceed power rating in any case, otherwise the diode will get destroyed.

The diode manufacturers more oftenly list the maximum current, which a device can handle, (called *current rating*), rather than power rating. It is because of the fact that it is *easy to measure current rating than power rating.*

Applications of a Diode

An important characteristic of the *P-N* junction diode that it conducts well in forward direction and poorly in reverse direction has made it useful in several applications listed below :

1. As zener diodes in voltage stabilizing circuits.
2. As rectifiers or power diodes in D.C. power supplies.
3. As a switch in logic circuits in computers.
4. As signal diodes in communication circuits.
5. As varactor diodes in radio and T.V. receivers.
6. **P-N junction** forward bias condition is used in all LED lighting **applications**
7. The voltage across the **P-N junction** biased is used to create Temperature Sensors, and Reference voltages.

ZENER DIODE

*A properly doped P-N junction crystal diode which has a sharp breakdown voltage is known as **Zener diode.***

The voltage-regulator diode is commonly called a **'Zener' diode.** It is a *voltage limiting diode* that has some applications in common with the older voltage-regulator gas tubes but serves a much wider field of application, because the devices cover a wide spectrum of voltages and power levels.

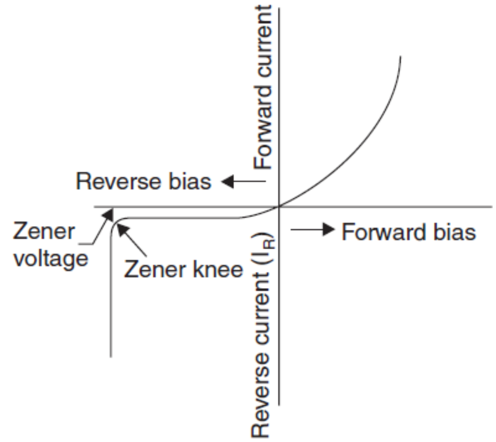


Fig.

Performance/Operation

The electrical performance of a zener diode is based on the *avalanche characteristics* of the *P-N* junction. When a source of voltage is applied to a diode in the *reverse direction* (negative to anode), a reverse current I_R is observed (see Fig.). As the reverse potential is increased beyond the "*Zener knee*" avalanche breakdown becomes well developed at zener voltage V_Z. At voltage V_Z, the high counter resistance drops to a low value and the junction current increases rapidly. The current must of necessity be limited by an external resistance, since the voltage V_Z developed across the zener diode remains essentially constant. *Avalanche breakdown of the operating zener diode is not destructive as long as the rated power dissipation of the junction is not exceeded.*

Externally, the zener diode looks much like other silicon rectifying devices, and electrically it is capable of rectifying alternating current.

The following points about the *Zener diode* are worth noting :

(*i*) It looks like an ordinary diode except that it is properly doped so as to have a sharp breakdown voltage.

(*ii*) It is always reverse connected *i.e.,* it is *always reverse biased.*

(*iii*) It has sharp breakdown voltage, called Zener voltage V_Z.

(*iv*) When forward biased, its characteristics are just those of ordinary diode.

(*v*) It is not immediately burnt just because it has entered the breakdown region (The current is limited only by both external resistance and power dissipation of Zener diode).

- The location of Zener region can be controlled by varying the doping levels. An *increase in doping, producing an increase in the number of added impurities, will decrease the Zener potential.*

- Zener diodes are available having Zener potentials of 1.8 to 200 V with power ratings from $\frac{1}{4}$ to 50 W. *Because of its higher temperature and current capability, silicon is usually preferred in the manufacture of Zener diodes.*

. Equivalent Circuit of Zener Diode

The complete equivalent circuit of the Zener diode in the Zener region includes a small dynamic resistance and D.C. battery equal to the Zener potential, as shown in Fig. :

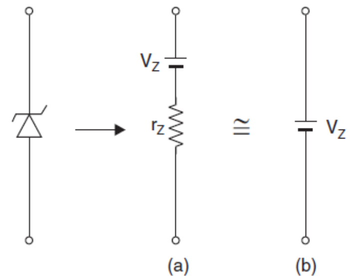


Fig. Zener equivalent circuit : (a) Complete ; (b) Approximately.

"ON" state. When reverse voltage across a Zener diode is equal to or more than breakdown voltage V_Z, the current increases very sharply. In this region curve is almost vertical ; it means that voltage across Zener diode is constant at V_Z even though the current through it changes. Therefore, in the breakdown region, an ideal Zener diode (this assumption is fairly reasonable as the impedance of Zener diode is *quite small in the breakdown region*) can be represented by a battery of voltage V_Z as shown in Fig. (*b*). Under such conditions, the Zener diode is said to be in the "ON" state.

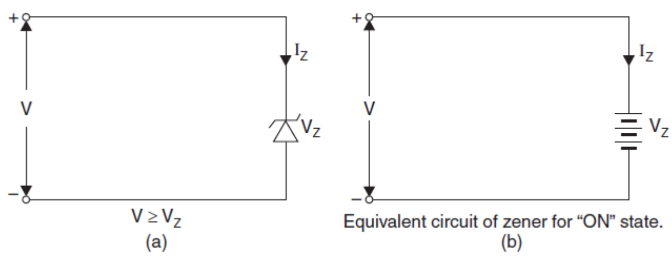


Fig.

"OFF" state. When the reverse voltage across the Zener diode is less than V_Z but greater than 0 V, the Zener diode is in the "OFF" stage. Under such conditions, the Zener diode can be represented by an open circuit as shown in Fig. (*b*).

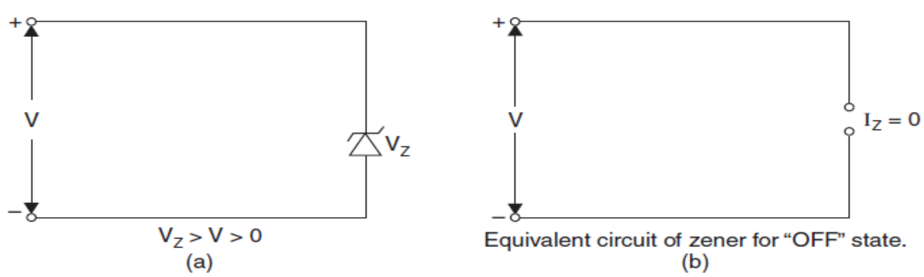


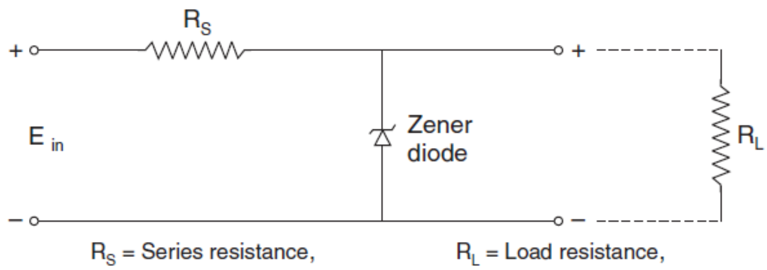
Fig.

3.3. Applications of Zener Diode

Zener diode serves in the following variety of *applications :*

1. **Voltage reference or regulator element :**

The primary use of a zener diode is as a *voltage reference or regulator element*. Fig. 22 shows the fundamental circuit for the Zener diode employed as a shunt regulator. In the circuit, diode element and load R_L draw current through the series resistance R_S. If E_{in} increases, the current through the Zener element will increase and thus maintain an essentially fixed voltage across R_L. This ability to maintain the desired voltage is determined by the temperature coefficient and the diode impedance of the zener device.



R_S = Series resistance, R_L = Load resistance

Fig. 22. Basic Zener-diode regulator circuit.

2. **Shunt transistor regulator :**

The Zener diode may also be used to control the reference voltage of a transistor regulated power supply. An example of this in a shunt transistor regulator is shown in Fig. 23, where Zener element is used to control the operating point of the transistor. The advantage of this circuit over that shown in Fig. 22 are *increased power handling capability and a regulating factor improved by utilizing the current gain of the transistor.*

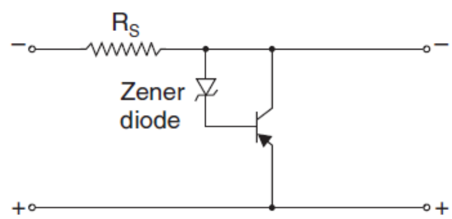


Fig. 23. Shunt transistor regulator.

3. **Audio or r-f applications :**

The Zener diode also finds use in audio or *r-f* (radio frequency) applications where a source of stable reference voltage is required, as in bias supplies. Frequently, *Zener diodes are connected in series package,* with, for example, one junction operating in the reverse within a single direction and possessing a positive temperature V_Z coefficient ; the remaining diodes are connected to operate in the forward direction and exhibit negative temperature V_Z coefficient characteristics. The net result is close neutralization of V_Z drift versus temperature change ; such reference units are frequently used to *replace standard voltage cells.*

4. **Computer circuits :**

Zener diodes also find use in *computer circuits designed for switching about the avalanche voltage of the diode.* Design of the Zener diode permits it to absorb *overload surges and thereby serves the function of protecting delicate circuitry form overvoltage.*

— The usual *voltage specifications* V_Z on Zener diodes are 3.3 to 200 V with ± 1, 2, 5, 10 or 20% tolerances.

— Typical *power dissipation ratings* are 500 mW, 1, 10 and 50 W.

— The temperature coefficient range on V_Z is as low as 0.001% °C.

Example 4. *Determine the current flowing through the Zener diode for the circuit shown in Fig. 24, if R_L = 4000 Ω, input voltage is 50 volts, R_S = 1800 Ω and output voltage is 32 volts.*

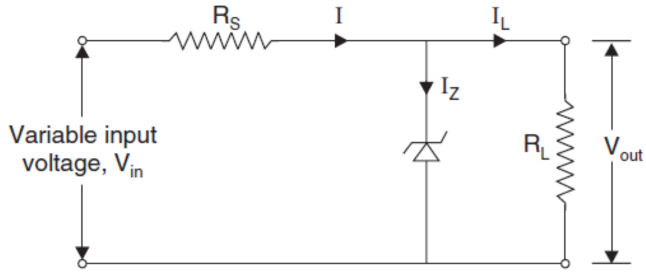


Fig. 24

Solution. Input voltage, $V_{in} = 50$ V

Output voltage, $V_{out} = 32$ V

Voltage drop in series resistor, $R_S = V_{in} - V_{out} = 50 - 32 = 18$ V

Current through series resistance, $I = \dfrac{V_{in} - V_{out}}{R} = \dfrac{18}{1800} = .01$ A or 10 mA

Load current, $I_L = \dfrac{V_{out}}{R_L} = \dfrac{32}{4000} = 0.008$ A or 8 mA

Current through Zener diode, $\mathbf{I_Z} = I - I_L = 10 - 8 = \mathbf{2\ mA.}$ **(Ans.)**

Example 5. *Determine the maximum and minimum values of Zener current if in the circuit shown in Fig. 24 the load resistance, R_L = 4000 Ω, series resistance = 8000 Ω, output voltage = 32 V and source voltage varies between 100 V and 128 V.*

Solution. Refer to Fig. 23. *Given :* R_L = 4000 Ω ; R = 8000 Ω ; V_{out} = 32 V ;

Load current, $I_L = \dfrac{V_{out}}{R_L} = \dfrac{32}{4000} = 0.008$ A or 8 mA

The Zener current will be maximum when input voltage is maximum *i.e.,* 128 V

Corresponding current through series resistance,

$$I = \frac{V_{in(max)} - V_{out}}{R_S} = \frac{128 - 32}{8000} = 0.012 \text{ A or } 12 \text{ mA}$$

Corresponding Zener current, $\mathbf{(I_Z)_{max.}} = I - I_L = 12 - 8 = \mathbf{4\ mA.}$ **(Ans.)**

The Zener current will be minimum when input voltage is minimum *i.e.,* 100 V.

Corresponding, current through series resistance,

$$I' = \frac{V_{in(min)} - V_{out}}{R_S} = \frac{100 - 32}{8000} = 0.0085 = 8.5 \text{ mA}$$

Corresponding Zener current, $\mathbf{(I_Z)_{min.}} = I' - I_L = 8.5 - 8 = \mathbf{0.5\ mA.}$ **(Ans.)**

Example 6. *In the simple Zener-diode based voltage regulator shown in Fig. 25, a 5.6 V, 0.25 W Zener diode is used. For reliable operation, the minimum I_Z should be 1 mA. The load R_L varies between 20 Ω and 50 Ω. Find the range of R_S for reliable and safe operation of the voltage regulator.*

Solution. (*i*) Let $R_S = 20\ \Omega$

$$I = \frac{5.6}{20} = 0.28 \text{ A}$$

$$R_S = \frac{10 - 5.6}{0.28 + 0.001} = 15.66\ \Omega \approx 16\ \Omega.$$

(*ii*) Let, $R_S = 50\ \Omega$

$$I = \frac{5.6}{50} = 0.112 \text{ A}$$

$$R_S = \frac{10 - 5.6}{0.112 + 0.001} = 38.93\ \Omega \approx 39\ \Omega.$$

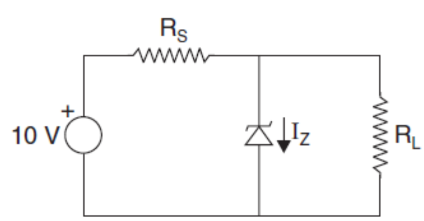
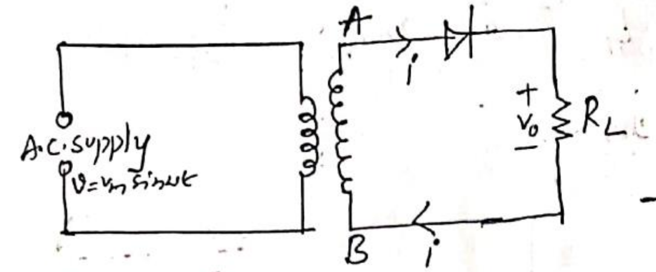
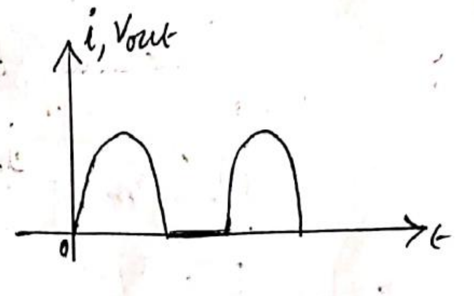


Fig. 25

∴ **R ranges from 16 Ω to 39 Ω. (Ans.)**

Half-wave rectifier:





Operation 1:- During the positive half-cycle of input a.c. voltage end A becomes positive w.r.t end B. This makes the diode forward biased and hence it conducts current.

Operation 2:- During the negative half-cycle, end A is negative w.r.t end B. Under this condition, the diode is reversed biased and it conducts no current.

→ Therefore, current flows through the diode during positive half-cycles of input a.c. voltage only, it is blocked during the -ve half-cycles. In this way, current flows through the Load R_L always in the same direction. Hence d.c. output is obtained across R_L.

(i) Average voltage (V_{avg})

$$V_{avg} = V_{dc} = \frac{1}{2\pi}\left[\int_0^{\pi} V_m \sin wt \, d(wt) + \int_{\pi}^{2\pi} 0 \, d(wt)\right]$$

$$= \frac{V_m}{2\pi}\int_0^{\pi} \sin wt \, d(wt) + 0$$

$$= \frac{V_m}{2\pi}\left[-\cos wt\right]_0^{\pi} = \frac{V_m}{2\pi}\left[-\cos\pi + \cos 0\right]$$

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

$$\boxed{\therefore V_{avg} = V_{dc} = \frac{V_m}{\pi}}$$

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

(ii) RMS Voltage :-

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} (V_m \sin wt)^2 \, d(wt)}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} V_m^2 \sin^2 wt \, d(wt)}$$

$$= V_m \sqrt{\frac{1}{2\pi}\int_0^{\pi} \sin^2 wt \, d(wt)}$$

$$= V_m \sqrt{\frac{1}{2\pi}\int_0^{\pi} \left(\frac{1-\cos 2wt}{2}\right) d(wt)}$$

$$= V_m \sqrt{\frac{1}{2\pi}\left(\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right)_0^{\pi}}$$

$$= V_m \sqrt{\frac{1}{2\pi}\left[\frac{\pi}{2} - 0\right]} = V_m \sqrt{\frac{1}{4}} = \frac{V_m}{2}$$

$$\boxed{\therefore V_{rms} = \frac{V_m}{2}}$$

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

(3) Ripple factor :- (Γ)

The ratio of rms value of ac components to dc components ~~to dc components~~ in the o/p is known as ripple factor

$$V_{rms} = \sqrt{V_{ac}^2 + V_{dc}^2}$$

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

$$\Gamma = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} = \sqrt{\frac{V_{rms}^2 - V_{dc}^2}{V_{dc}^2}}$$

$$\Gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}$$

substitute V_{rms} & V_{dc} values

$$\Gamma = \sqrt{\frac{\left(\frac{V_m}{2}\right)^2}{\left(\frac{V_m}{\pi}\right)^2} - 1} = \sqrt{\frac{\frac{V_m^2}{4}}{\frac{V_m^2}{\pi^2}} - 1} = \sqrt{\frac{\pi^2}{4} - 1} = 1.211$$

$$\boxed{\Gamma = 1.211}$$

From the expression; it is clear that the amount of ac present o/p is 121% of dc voltage. So half-wave rectifier is not practically used in converting ac to dc.

4-21

(4) Efficiency (η) :- The ratio of dc o/p to ac i/p power is known as the rectifier efficiency.

$$\eta = \frac{P_{dc}}{P_{ac}}$$

$$P_{dc} = I_{dc}^2 \cdot R_L = \left(\frac{I_m}{\pi}\right)^2 \cdot R_L$$

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

$$\therefore \eta = \frac{\left(\frac{I_m}{\pi}\right)^2 \cdot R_L}{\left(\frac{I_m}{2}\right)^2 \cdot (r_f + R_L)} = \frac{0.406\, R_L}{1 + \left(\frac{r_f}{R_L}\right)}$$

The efficiency will be max. if r_f is negligible as compared to R_L

$\therefore$ Max. rectifier efficiency = 40.6%.

(5) Peak Inverse voltage (PIV) :- It is defined as max. reverse voltage that a diode can withstand without destroying the junction. The peak inverse voltage across a diode is the peak of -ve half cycle.

$$\boxed{\therefore PIV = V_m}$$

(6) From Factor :-

$$F.F = \frac{\text{rms value}}{\text{avg. value}} = \frac{\frac{V_m}{2}}{\frac{V_m}{\pi}} = \frac{\pi}{2} = 1.57$$

(7) Peak Factor :-

$$P.F = \frac{\text{Peak value}}{\text{Rms value}} = \frac{V_m}{\frac{V_m}{2}} = 2$$

(1Q) A crystal diode having internal resistance $r_f = 20\,\Omega$ is used for half-wave rectification. If the applied voltage is $V = 50 \sin \omega t$ & load resistance $R_L = 800\,\Omega$ find (i) I_m, I_{dc}, I_{rms} (ii) a.c. power input and d.c. power output (iii) d.c. output voltage and (iv) efficiency of rectification.

Sol:- Given data

$r_f = 20\,\Omega$

$V = 50 \sin \omega t$

$\therefore V_m = 50$

$R_L = 800\,\Omega$

(i) $I_m = \dfrac{V_m}{r_f + R_L} = \dfrac{50}{20+800} = 0.061\,A$
$= 61\,mA$

$I_{dc} = I_m/\pi = 61/\pi = 19.4\,mA$

$I_{rms} = I_m/2 = 61/2 = 30.5\,mA$

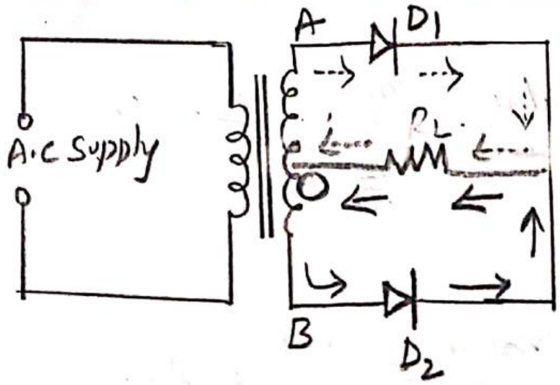
(ii) $P_{ac} = I_{rms}^2\,(r_f + R_L)$
$= (30.5 \times 10^{-3})^2 \times (20+800) = 0.763\,W$

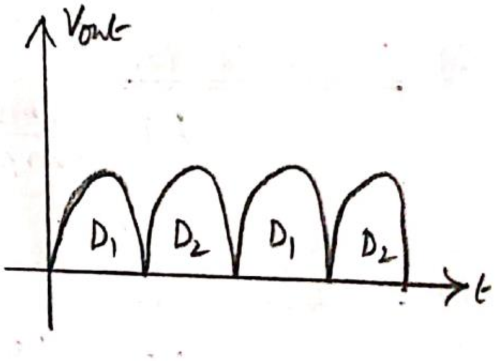
$P_{dc} = I_{dc}^2 \times R_L = (19.4 \times 10^{-3})^2 \times 800$
$= 0.301\,W$

(iii) d.c. output voltage $= I_{dc} \times R_L = 19.4\,mA \times 800\,\Omega = 15.52\,V$

(iv) Efficiency $= \dfrac{0.301}{0.763} \times 100 = 39.5\%$

Centre-Tap Full-Wave Rectifier





Operation(1):- During the positive halfcycle of secondary voltage, the end A of the secondary winding become positive & end B negative. This makes the diode D_1 forward biased & diode D_2 reverse biased. Therefore diode D_1 conducts while diode D_2 does not. The conventional current flow is through diode D_1, load resistor R_L

Operation 2 :- During the negative half-cycle, end A of the secondary becomes negative & end B positive. Therefore diode D_2 conducts while diode D_1 does not. The conventional current flow is through Diode D_2, Load R_L.

(i) Average value (V_{avg}) :-

The average voltage or dc voltage available across the load resistance is

$$V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_m \sin\omega t \, d\omega t$$

$$= \frac{V_m}{\pi}\left[-\cos\omega t\right]_0^{\pi} = \frac{V_m}{\pi}\left[-\cos\pi - (-\cos 0)\right]$$

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

$$\boxed{\therefore V_{avg} = V_{dc} = \frac{2V_m}{\pi}}$$

Similarly $\boxed{I_{dc} = I_{avg} = \frac{2I_m}{\pi}}$

(2) RMS value :-

$$V_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} V_m^2 \sin^2\omega t \, d(\omega t)}$$

$$= V_m \sqrt{\frac{1}{\pi}\left[\frac{1-\cos 2\omega t}{2}\right] d(\omega t)}$$

$$= V_m \sqrt{\frac{1}{\pi}\left[\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right]_0^{\pi}}$$

$$= V_m \sqrt{\frac{1}{\pi}\left[\frac{\pi}{2} - 0\right]} = V_m\sqrt{\frac{1}{2}} = \frac{V_m}{\sqrt{2}}$$

$$\boxed{\therefore V_{rms} = \frac{V_m}{\sqrt{2}}}$$

Similarly $\boxed{\therefore I_{rms} = \frac{I_m}{\sqrt{2}}}$

(3) Ripple Factor :- (Γ)

$$\Gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{\frac{V_m}{\sqrt{2}}}{\frac{2V_m}{\pi}}\right)^2 - 1} = \sqrt{\frac{\frac{V_m^2}{2}}{\frac{4V_m^2}{\pi^2}} - 1} = \sqrt{\frac{\pi^2}{8} - 1}$$

$$= 0.482$$

4-24

(4) Efficiency :-

$$\eta = \frac{P_{dc}}{P_{ac}}$$

$$P_{dc} = I_{dc}^2 \times R_L = \left(\frac{2I_m}{\pi}\right)^2 \cdot R_L \qquad \text{where } \boxed{I_m = \frac{V_m}{r_f + R_L}}$$

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

$$\therefore \eta = \frac{\left(\frac{2I_m}{\pi}\right)^2 \cdot R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)} = \frac{0.812 R_L}{r_f + R_L} = \frac{0.812}{1 + \left(\frac{r_f}{R_L}\right)}$$

The efficiency will be max. if r_f is negligible as compared to R_L

$$\boxed{\therefore \text{Max. efficiency} = 0.812 = 81.2\%}$$

(5) Peak inverse voltage (PIV):-

$$\boxed{PIV = 2V_m}$$

(6) Form factor:-

$$F.F = \frac{\text{RMS value}}{\text{Avg. value}} = 1.11$$

(7) Peak factor:-

$$P.F = \frac{\text{Peak value}}{\text{RMS value}} = \frac{V_m}{\frac{V_m}{\sqrt{2}}} = \sqrt{2} = 1.41$$

problems 4-26

(1Q) A full-wave rectifier uses two diodes, the internal resistances of each is assumed constant at 20 Ω. The transformer rms secondary voltage from centre-tap to each end of secondary is 50V & load resistance is 980 Ω. Find (i) the mean load current (ii) the rms value of load current.

Sol Given data:-

$r_f = 20\,\Omega$

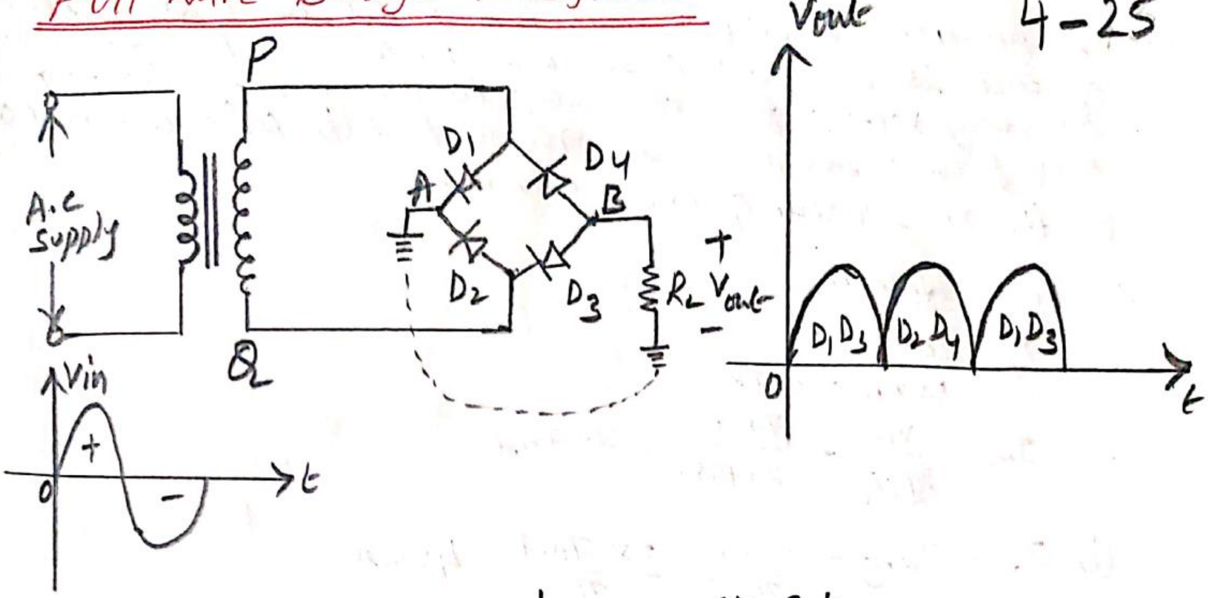
$V_m = 50 \times \sqrt{2} = 70.7V$

$$I_m = \frac{V_m}{r_f + R_L} = \frac{70.7}{20+980} = 70.7mA$$

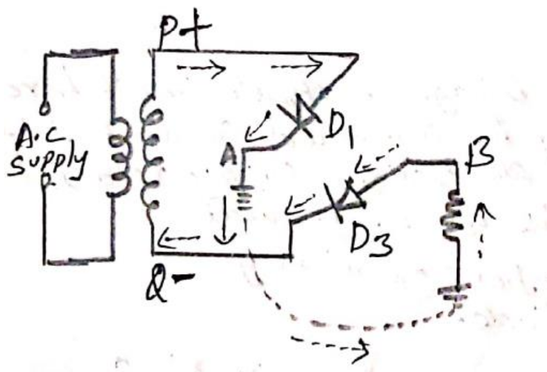
(i) $I_{dc} = I_{avg} = \frac{2I_m}{\pi} = \frac{2 \times 70.7}{\pi} = 45mA$

(ii) $I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{70.7}{\sqrt{2}} = 50mA$

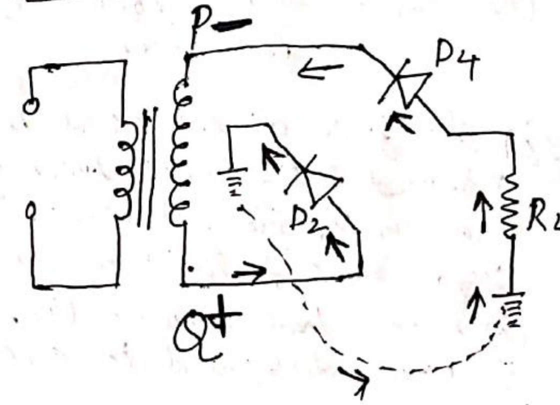
Full Wave Bridge Rectifier:



Operation 1:-



Operation 2:-



During +ve half-cycle secondary voltage, the end P of the secondary winding becomes positive and end Q negative. This makes diode D_1 & D_3 forward biased while diodes D_2 & D_4 are reverse biased. Therefore, only diodes D_1 & D_3 ~~forward biased while diode D_2~~ conduct.

During the −ve half-cycle of the secondary voltage, end P becomes negative & end Q positive. This makes diodes D_2 & D_4 forward biased while diodes D_1 & D_3 are reverse biased. Therefore, only diode D_2 & D_4 conduct.

Advantages

(i) The need for centre-tapped transformer is eliminated

(ii) The output is twice that of the centre-tap circuit for the same secondary voltage.

(2Q) The four diodes used in a bridge rectifier circuit have forward resistances which may be considered constant at 1- and an infinite resistance. The alternating supply voltage is 240 V r.m.s & resistive load is 48 Ω. Calculate

(i) mean load current (ii) rectifier efficiency

(iii) power dissipated in each diode.

Sol :- (i) Max. load current, $I_m = \frac{V_m}{2r_f + R_L} = \frac{\sqrt{2} \times 240}{2 \times 1 + 48} = 6.79$

$\therefore$ Mean load current, $I_{dc} = \frac{2 I_m}{\pi} = \frac{2 \times 6.79}{\pi} = 4.32$

(ii) RMS value of load current

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{6.79}{\sqrt{2}} = 4.8 \text{ A.}$$

5. Filter Circuits

5.1 Introduction

A power supply must provide ripple free source of power from an A.C. line. But the output of a rectifier circuit contains ripple components in addition to a D.C. term. It is necessary to include a filter between the rectifier and the loads in order to eliminate these ripple components. Ripple components are high frequency A.C. Signals in the D.C output of the rectifier. These are not desirable, so they must be filtered. So filter circuits are used.

Many types of passive filters are in use such as.

- Shunt capacitor filter
- Series inductor filter
- Chock input (LC) filter
- Pi(π) section filter or CLC filter or capacitor input filter .

5.2 Shunt capacitor filter

This type of filter consists of large value of capacitor connected across the load resistor R_l as shown in figure 5.1. This capacitor offers a low reactance to the a.c. components and very high impedance to d.c. so that the a.c. components in the rectifier output find low reactance path through capacitor and only a small part flows through R_L, producing small ripple at the output as shown in figure.

Here Xc ($=1/2\pi fC$, the impedance of capacitor) should be smaller than R_L. Because, current should pass through C and C should get charged. If C value is very small, Xc will be large and hence current flows through R_L only and no filtering action takes place.

The capacitor C gets charged when the diode (in the rectifier) is conducting and gets discharged (when the diode is not conducting) through RL. When the input voltage $v = Vm\ sin\ \omega t$ is greater than the capacitor voltage, C gets charged. When the input voltage is less than that of the capacitor voltage, C will discharge through R_L. The stored energy in the capacitor maintains the load voltage at a high value for a long period. The diode conducts only for a short interval of high current. The waveforms are as shown in figure 5.2. Capacitor opposes sudden fluctuations in voltage across it. So the ripple voltage is minimized.

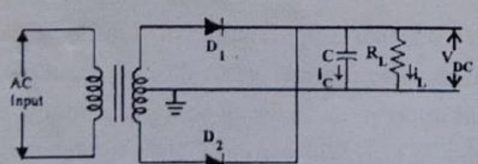


Fig 5.1 CT FWR with shunt Capacitor filter

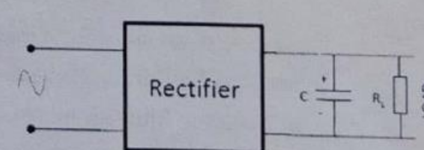


Fig 5.3 Rectifier with shunt Capacitor filter

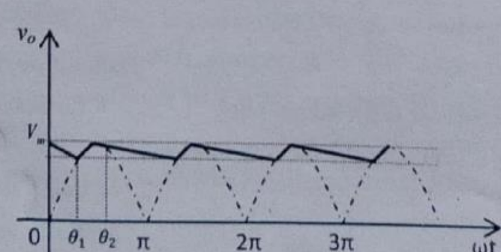


Fig 5.2 Filter output waveform

The discharging of the capacitor depends upon the time constant $C.R_L$. Hence the smoothness and the magnitude of output voltage depend upon the value of capacitor C and R_L. As the value of C increases the smoothness of the output also increases. But the maximum value of the capacitor is limited by the current rating of the diode. Also decrease in the value of R_L increases the load current and makes the time constant smaller. These types of filters are used in circuits with small load current like transistor radio receivers, calculators, etc. The ripple factor in capacitor filter is given b $\gamma = 1/4\sqrt{3}fCR_L$y.

Advantages

- Low cost
- Small size and weight
- Good characteristics
- Can be connected for both HW and FW rectifiers
- Improved d.c. output

Disadvantages

- Capacitor draws more current

5.3 Series inductor filter

The working of series inductor filter depends on the inherent property of the inductor to oppose any variation in current intend to take place. Fig 5.4 shows a series inductor filter connected at the output of a FWR. Here the reactance of the inductor is more for ac components and it offers more opposition to them. At the same time it provides no impedance for d.c. component. Therefore the inductor blocks a.c. components in the output of the rectifier and allows only d.c. component to flow through R_L.

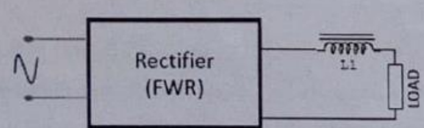


Fig 5.5 Rectifier with series inductor filter

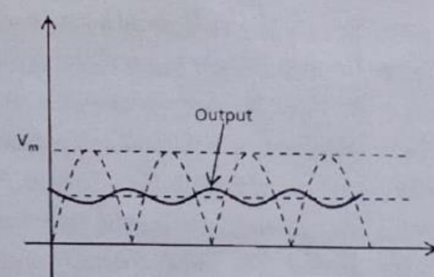


Fig 5.5 Filter output waveform

The action of an inductor depends upon the current through it and it requires current to flow at all time. Therefore filter circuits consisting inductors can only be used together with full wave rectifiers.

In inductor filter an increase in load current will improve the filtering action and results in reduced ripple. Series inductor filters are used in equipments of high load currents. The ripple factor in series inductor filter $\gamma = R_L/3\sqrt{2}\omega L$

Advantages

- Sudden changes in current is smoothen out
- Improved filtering action at high load currents

Disadvantages

- Reduced output voltage due to the drop across the inductor.
- Bulky and large in size
- Note suite for HWR

5.4 LC filter

It is a combination of inductor and capacitor filter. Here an inductor is connected in series and a capacitor is connected in parallel to the load as shown in fig 5.6. As discussed earlier, a series inductor filter will reduce the ripple, when increasing the load current. But in case of a capacitor filter it is reverse that when increasing current the ripple also increases. So a combination of these two filters would make ripple independent of load current. The ripple factor of a chock input filter is given by $\gamma = 1.194/LC$ **(by taking f=50Hz)**

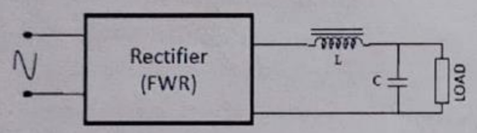


Fig 5.6 Rectifier with LC filter

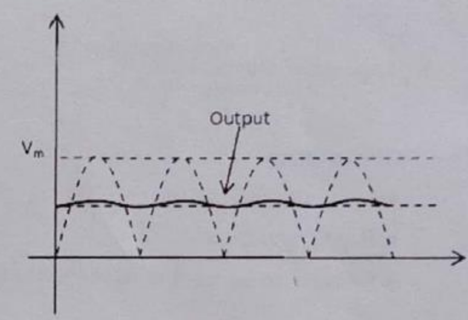


Fig 5.7 output waveform of Rectifier with LC filter

Since the d.c. resistance of the inductor is very low it allows d.c. current to flow easily through it. The capacitor appears open for d.c. and so all d.c. component passes through it. The capacitor appears open for d.c. and so all d.c components passes through the load resistor R_L.

5.4.1 Bleeder resistor

For optimum functioning, the inductor requires a minimum current to flow through, at all time. When the current falls below this rat, the output will increase sharply and hence the regulation become poor. To keep up the circuit current above this minimum value, a resistor is permanently connected across the filtering capacitor and is called **bleeder resistor**. This resistor always draws a minimum current even if the external load is removed. It also provides a path for the capacitor to discharge when power supply is turned off.

Advantages

- Reduced ripples at the output
- Action is independent of load current

Disadvantages

- Low output voltage
- Bulky and large in size
- Not suit to connect with HWR.

5.5 π – filter (Capacitor input filter) or CLC filter

This filter is basically a capacitor filter followed by an LC filter as shown in fig 5.8. Since its shape (C-L-C) is like the letter π it is called π – filter. It is also called capacitor input filter because the rectifier feeds directly into the capacitor C_1. Here the first capacitor C_1 offers a low reactance to a.c. component of rectifier output but provide more reactance to d.c components. Therefore most of the a.c. components will bypass through C_1 and the d.c. component flows through chock L. The chock offers very high reactance to the a.c. component. Thus it blocks a.c. components while pass the d.c. The capacitor C_2 bypasses any other a.c. component appears across the load and we get study d.c. output as shown below. The ripple factor in a π-section filter is given by $\gamma = \sqrt{2}\, X_{C1} X_{C2} / X_L R_L$

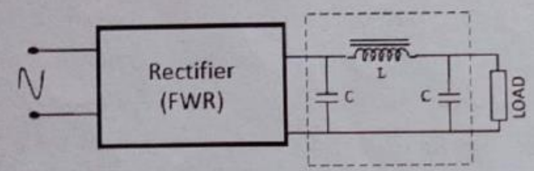


Fig 5.8 Rectifier with CLC filter

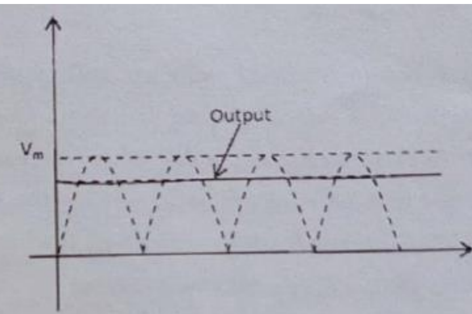


Fig 5.9 output waveform of Rectifier with CLC filter

Advantages

- More output voltage
- Ripple less output
- Suitable to be used with both HWR and FWR

Disadvantages

- Large in size and weight
- High cost

UNIT V

BIPOLAR JUNCTION TRANSISTOR AND JFET

5.1 INTRODUCTION

- The transistor was invented in 1947 by John Bardeen, Walter Brattain and William Shockley at Bell Laboratory in America. A transistor is a semiconductor device, commonly used as an Amplifier or an electrically Controlled Switch.

- There are two types of transistors:

1) Unipolar Junction Transistor
2) Bipolar Junction Transistor

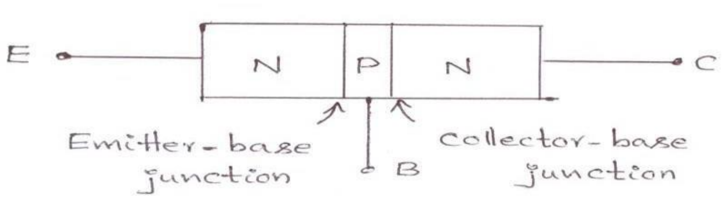
- In Unipolar transistor, the current conduction is only due to one type of carriers i.e., majority charge carriers. The current conduction in bipolar transistor is because of both the types of charge carriers i.e., holes and electrons. Hence it is called as Bipolar Junction Transistor and it is referred to as BJT.

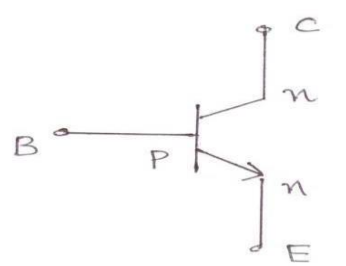
- BJT is a semiconductor device in which one type of semiconductor material is sand witched between two opposite types of semiconductor i.e., an n-type semiconductor is sandwiched between two p-type semiconductors or a p-type semiconductor is sandwiched between two n-type semiconductor.

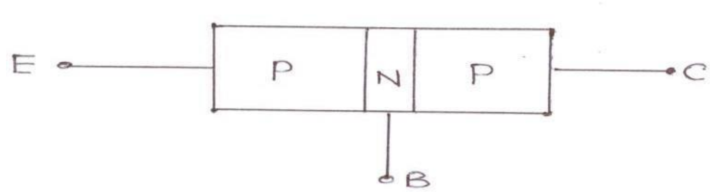
- Hence the BJTs are of two types.They are:

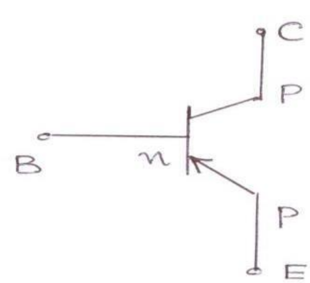
1) n-p-n Transistor
2) p-n-p Transistor

The two types of BJTs are shown in the figure below.









- The arrow head represents the conventional current direction from p to n. Transistor has three terminals.

1) Emitter 2) Base 3) Collector

- Transistor has two p-n junctions. They are:
1) Emitter-Base Junction
2) Collector-Base Junction

Emitter: Emitter is heavily doped because it is to emit the charge carriers.

Base: The charge carriers emitted by the emitter should reach collector passing through the base. Hence base should be very thin and to avoid recombination, and to provide more collector current base is lightly doped.
Collector: Collector has to collect the most of charge carriers emitted by the emitter. Hence the area of cross section of collector is more compared to emitter and it is moderately doped.

Transistor can be operated in three regions.
1) Active region.
2) Saturation region.
3) Cut-Off region.

Active Region: For the transistor to operate in active region base to emitter junction is forward biased and collector to base junction is reverse biased.

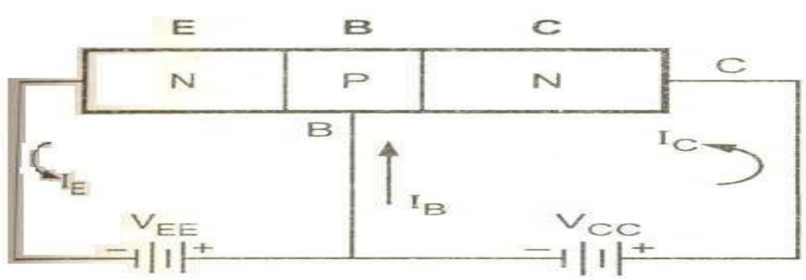
Saturation Region: Transistor to be operated in saturation region if both the junctions i.e., collector to base junction and base to emitter junction are forward biased.

Cut-Off Region: For the transistor to operate in cut-off region both the junctions i.e., base to emitter junction and collector to base junction are reverse biased.

Transistor can be used as
1) Amplifier 2) Switch
For the transistor to act as an amplifier, it should be operated in active region. For the transistor to act as a switch, it should be operated in saturation region for ON state, and cut-off region for OFF state.

5.2 TRANSISTOR OPERATION:

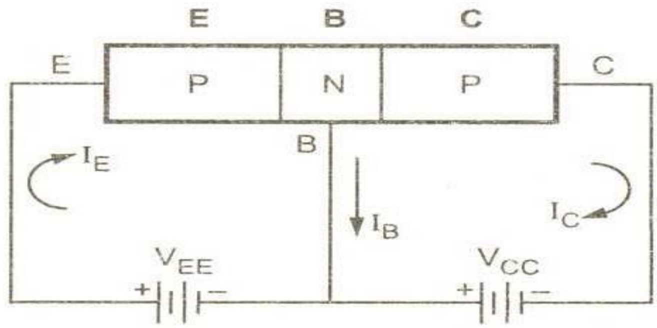
Working of a N-P-N Transistor:



The n-p-n transistor with base to emitter junction forward biased and collector base junction reverse biased is as shown in figure.
As the base to emitter junction is forward biased the majority carriers emitted by the n type emitter i.e., electrons have a tendency to flow towards the base which constitutes the emitter Current I_E. As the base is p-type there is chance of recombination of electrons emitted by the emitter with the holes in the p-type base. But as the base is very thin and lightly doped only few electrons emitted by the n-type emitter less than 5% combines with the holes in the p-type base, the remaining more than 95% electrons emitted by the n-type emitter cross over into the collector region constitute the collector current.

The current distributions are as shown in fig $\mathbf{I_E = I_B + I_C}$

Working of a P-N-P Transistor:



The p-n-p transistor with base to emitter junction is forward biased and collector to base junction reverse biased is as show in figure. As the base to emitter junction is forward biased the majority carriers emitted by the type emitter i.e., holes have a tendency to flow towards the base which constitutes the emitter current IE. As the base is n-type there is a chance of recombination of holes emitted by the emitter with the electrons in the n-type base. But as the base us very thin and lightly doped only few electrons less than 5% combine with the holes emitted by the p-type emitter, theremaining 95% charge carriers cross over into the collector region to constitute the collector current. The current distributions are shown in figure.

$$\mathbf{I_E = I_B + I_C}$$

5.1 TRANSISTOR CIRCUIT CONFIGURATIONS:

Following are the three types of transistor circuit configurations:

1) Common-Base (CB)

2) Common-Emitter (CE)

3) Common-Collector (CC)

Here the term 'Common' is used to denote the transistor lead which is common to the input and output circuits. The common terminal is generally grounded.It should be remembered that regardless the circuit configuration, the emitter is always forward-biased while the collector is always reverse-biased.

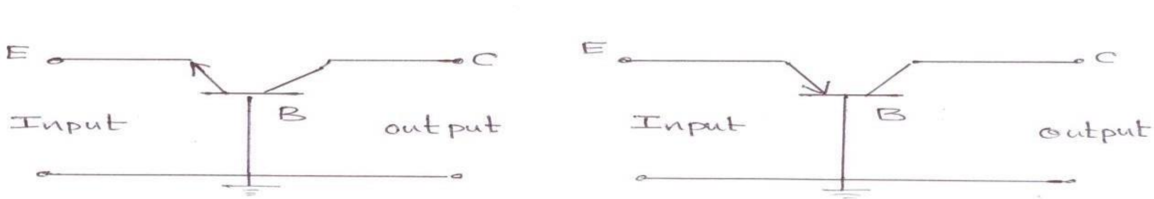


Fig. Common – Base Configuration

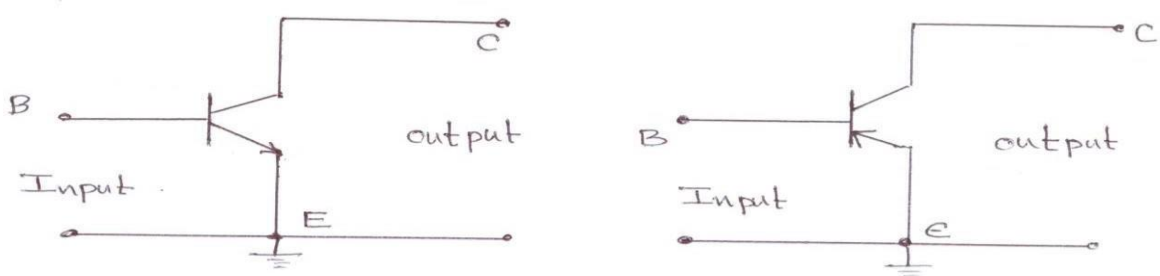


Fig. Common – Emitter Configuration

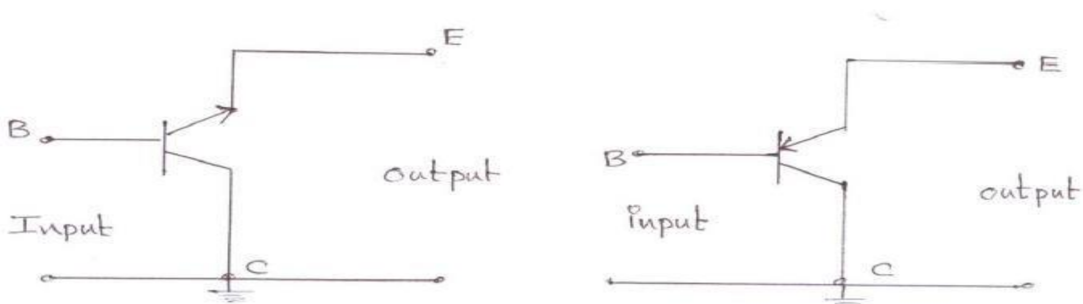


Fig. Common – Collector Configuration

5.1.1 Common – Base (CB) Configurations:

In this configuration, the input signal is applied between emitter and base while the output is taken from collector and base. As base is common to input and output circuits, hence the name common-base configuration. Figure show the common-base P-N-P transistor circuit.

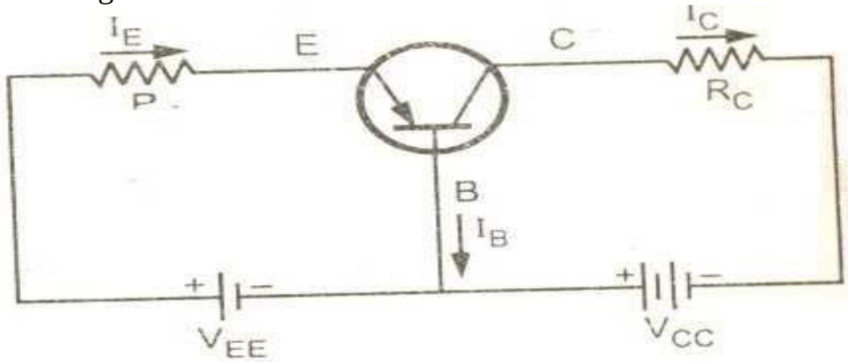


Fig. Common – Base PNP transistor amplifier.

Current Amplification Factor (α) **:**

When no signal is applied, then the ratio of the collector current to the emitter current is called dc alpha (α_{dc}) of a transistor.

$$\alpha_{dc} = \frac{\Delta I_C}{\Delta I_E}$$

(Negative sign signifies that I_E flows into transistor while I_C flows out of it). ‘ α’ of a transistor is a measure of the quality of a transistor. Higher is the value of ‘α ’, better is the transistor in the sense that collector current approaches the emitter current. By considering only magnitudes of the currents, $I_C = \boldsymbol{\alpha} I_E$ and hence $I_B = I_E - I_C$

Therefore,

$$I_B = I_E - \boldsymbol{\alpha} I_E = I_E(1- \boldsymbol{\alpha})$$

For all practical purposes, $\alpha_{dc} = \alpha_{ac} = \alpha$ and practical values in commercial transistors range from 0.9 to 0.99.

Total Collector Current:

The total collector current consists of the following two parts

i) I_E current due to majority carriers

ii) I_{CBO} current due to minority carriers

Total collector current $I_C = \alpha I_E + I_{CBO}$

The collector current can also be expressed as $I_C = \alpha (I_B+I_C) + I_{CBO}$ (Q $I_E = I_B + I_C$)

$$\Rightarrow I_C(1-\alpha) = \alpha I_B + I_{CBO}$$

$$\Rightarrow I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \left(\frac{1}{1-\alpha}\right) I_{CBO}$$

5.1.2 COMMON-EMITTER (CE) CONFIGURATION:

In this configuration, the input signal is applied between base and emitter and the output is taken from collector and emitter. As emitter is common to input and output circuits, hence the name common emitter configuration.

Figure shows the Common-Emitter P-N-P transistor circuit.

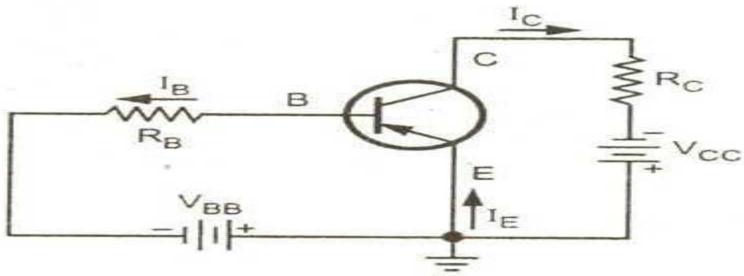


Fig. Common-Emitter PNP transistor amplifier.

Current Amplification Factor (β):

When no signal is applied, then the ratio of collector current to the base current is called dc beta (β_{dc}) of a transistor.

$$\beta_{dc} = \beta = \frac{I_C}{I_B} \quad \text{...........(1)}$$

When signal is applied, the ratio of change in collector current to the change in base current is defined as base current amplification factor. Thus,

$$\beta_{dc} = \beta = \frac{\Delta I_C}{\Delta I_B} \quad \text{...........(2)}$$

From equation (1), $I_C = \beta I_B$

Almost in all transistors, the base current is less than 5% of the emitter current. Due to this fact, 'β' ranges from 20 to 500. Hence this configuration is frequently used when appreciable current gain as well as voltage gain is required.

Total Collector Current:

The Total collector current $I_C = \beta\, I_B + I_{CEO}$ ....(3)

Where I_{CEO} is the leakage current.

But, we have, $I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \left(\frac{1}{1-\alpha}\right) I_{CBO}$ ....(4)

Comparing equations (3) and (4), we get

$$\beta = \frac{\alpha}{1-\alpha} \text{ and } I_{CEO} = \frac{1}{1-\alpha} I_{CBO} \quad \text{...........(5)}$$

Relation between α and β:

We know that $\alpha = \frac{I_C}{I_E}$ and $\beta = \frac{I_C}{I_B}$

$I_E = I_B + I_C$ (or) $I_B = I_E - I_C$

Now
$$\beta = \frac{I_C}{I_E - I_C} = \frac{\frac{I_C}{I_E}}{1 - \frac{I_C}{I_E}} = \frac{\alpha}{1-\alpha} \quad \text{................ (6)}$$

$$\Rightarrow \beta(1-\alpha) = \alpha \text{ (or) } \beta = \alpha(1+\beta)$$

$$\Rightarrow \alpha = \frac{\beta}{1+\beta} \quad \text{................ (7)}$$

It can be seen that $1 - \alpha = \frac{1}{1+\beta}$ .... (8)

5.1.3 COMMON – COLLECTOR (CC) CONFIGURATION:

In this configuration, the input signal is applied between base and collector and the output is taken from the emitter. As collector is common to input and output circuits, hence the name common collector configuration. Figure shows the common collector PNP transistor circuit.

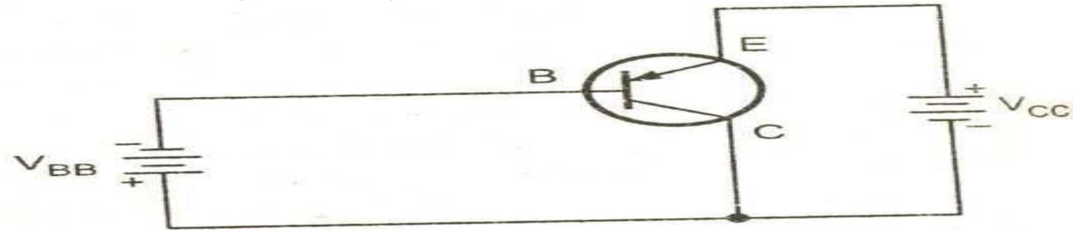


Fig. Common Collector PNP transistor amplifier.

Current Amplification Factor (γ):

When no signal is applied, then the ratio of emitter current to the base current is called as dc gamma (γ_{dc}) of the transistor.

$$\gamma_{dc} = \gamma = \frac{I_E}{I_B} \qquad \text{................ (1)}$$

5.4 CHARACTERISTICS OF COMMON-BASE CIRCUIT:

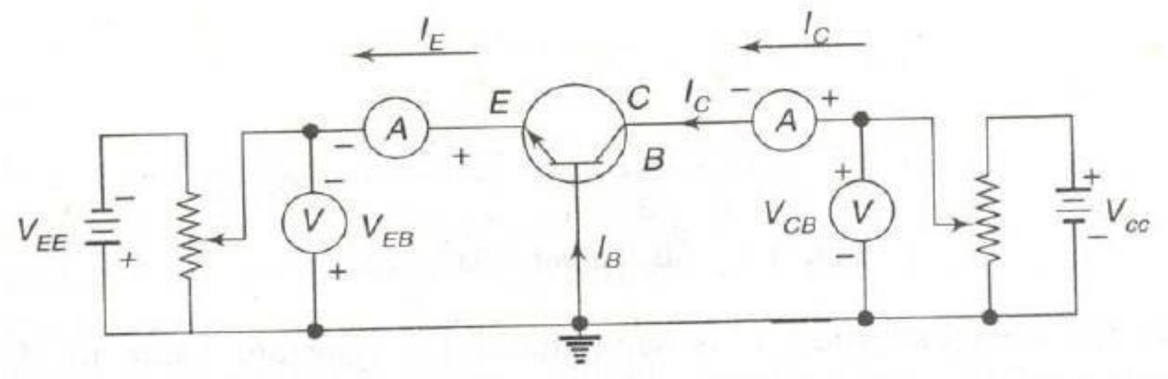


Fig. Circuit to determine CB static characteristics.

Input Characteristics:

To determine the input characteristics, the collector-base voltage V_{CB} is kept constant at zero volts and the emitter current I_E is increased from zero in suitable equal steps by increasing V_{EB}. This is repeated for higher fixed values of V_{CB}. A curve is drawn between emitter current IE and emitter- base voltage V_{EB} at constant collector-base voltage V_{CB}.

The input characteristics thus obtained are shown in figure below.

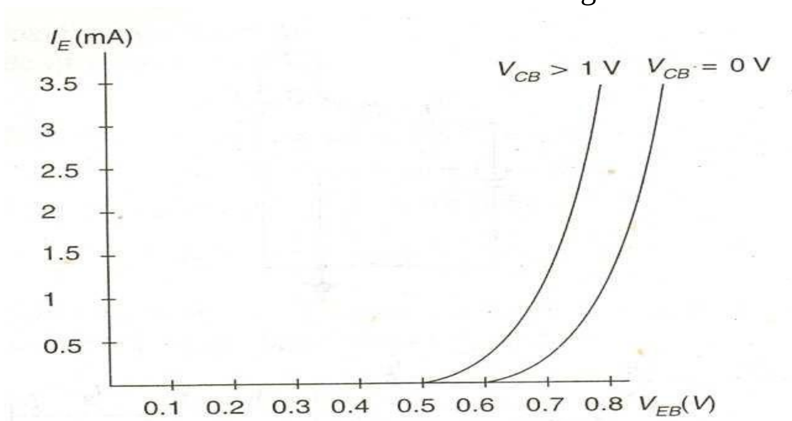


Fig. CB Input Characteristics.

Output Characteristics:

To determine the output characteristics, the emitter current I_E is kept constant at a suitable value by adjusting the emitter-base voltage V_{EB}. Then V_{CB} is increased in suitable equal steps and the collector current I_C is noted for each value of I_E. Now the curves of I_C versus V_{CB} are plotted for constant values of I_E and the output characteristics thus obtained is shown in figure below.

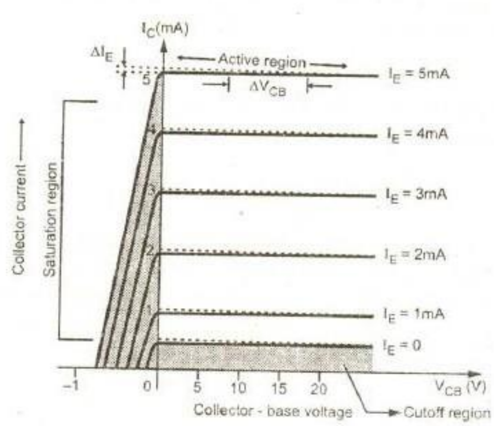


Fig. CB Output Characteristics

From the characteristics, it is seen that for a constant value of I_E, I_C is independent of V_{CB} and the curves are parallel to the axis of V_{CB}. Further, I_C flows even when V_{CB} is equal to zero. As the emitter-base junction is forward biased, the majority carriers, i.e., electrons, from the emitter are injected into the base region. Due to the action of the internal potential barrier at the reverse biased collector-base junction, they flow to the collector region and give rise to I_C even when V_{CB} is equal to zero.

It is the slope of CB output characteristics I_C versus V_{CB}.

5.5CHARACTERISTICS OF COMMON-EMITTER CIRCUIT:

The circuit diagram for determining the static characteristic curves of the an N-P-N transistor in the common emitter configuration is shown in figure below.

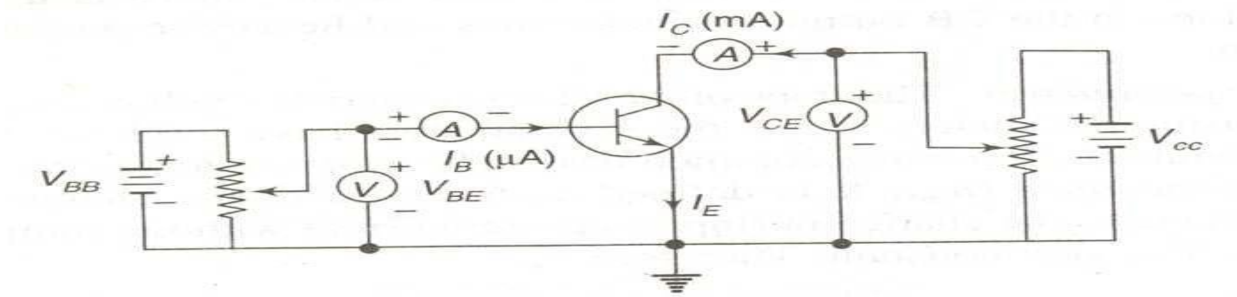


Fig. Circuit to determine CE Static characteristics.

Input Characteristics:

To determine the input characteristics, the collector to emitter voltage is kept constant at zero volts and base current is increased from zero in equal steps by increasing V_{BE} in the circuit. The value of V_{BE} is noted for each setting of I_B. This procedure is repeated for higher fixed values of V_{CE}, and the curves of I_B versus V_{BE} are drawn.
The input characteristics thus obtained are shown in figure below.

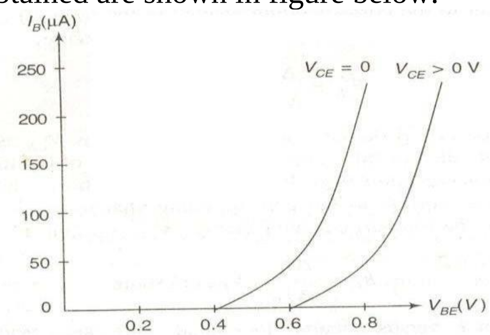


Fig. CE Input Characteristics.

When V_{CE}=0 , the emitter-base junction is forward biased and he junction behaves as a forward biased diode. When V_{CE} is increased, the width of the depletion region at the reverse biased collector-base junction will increase. Hence he effective width of the base will decrease. This effect causes a decrease in the base current I_B. Hence, to get the same value of I_B as that for V_{CE}=0, V_{BE} Should be increased. Therefore, the curve shifts to the right as V_{CE} increases.

Output Characteristics:

To determine the output characteristics, the base current I_B is kept constant at a suitable value by adjusting base-emitter voltage, V_{BE}. The magnitude of collector-emitter voltage V_{CE} is increased in suitable equal steps from zero and the collector current I_C is noted for each setting of V_{CE}. Now the curves of I_C versus V_{CE} are plotted for different constant values of I_B. The output characteristics thus obtained are shown in figure below.

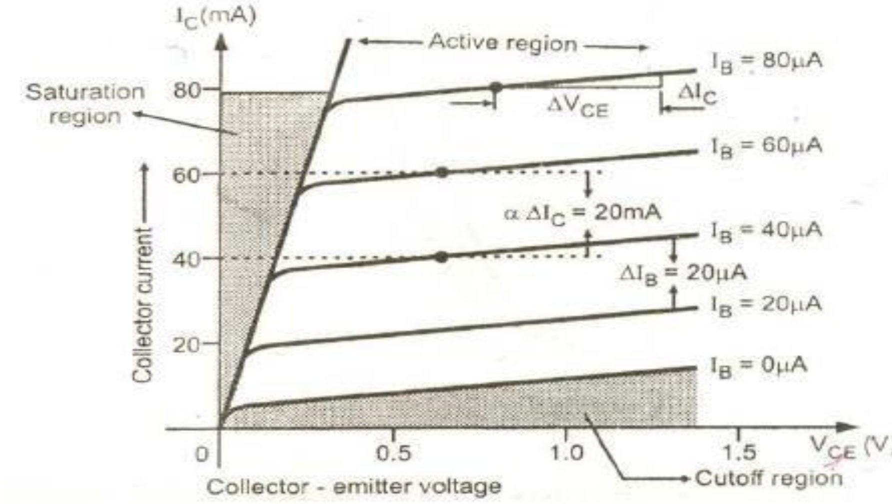


Fig. CE Output characteristics

The output characteristics of common emitter configuration consist of three regions: Active, Saturation and Cut-off regions.

Active Region:

The region where the curves are approximately horizontal is the "Active" region of the CE configuration. In the active region, the collector junction is reverse biased. As V_{CE} is increased, reverse bias increase. This causes depletion region to spread more in base than in collector, reducing the changes of recombination in the base. This increase the value of a dc . This Early effect causes collector current to rise more sharply with increasing V_{CE} in the active region of output characteristics of CE transistor.

Saturation Region:

If V_{CE} is reduced to a small value such as 0.2V, then collector-base junction becomes forward biased, since the emitter-base junction is already forward biased by 0.7V. The input junction in CE configuration is base to emitter junction, which is always forward biased to operate transistor in active region. Thus input characteristics of CE configuration are similar to forward characteristics of p-n junction diode. When both the junctions are forwards
biased, the transistor operates in the saturation region, which is indicated on the output characteristics. The saturation value of V_{CE}, designated V_{CE}(Sat) , usually ranges between 0.1V to 0.3V.

Cut-Off Region:

When the input base current is made equal to zero, the collector current is the reverse leakage current ICEO. Accordingly, in order to cut off the transistor, it is not enough to reduce IB=0. Instead, it is necessary to reverse bias the emitter junction slightly. We shall define cut off as the condition where the collector current is equal to the reverse saturation current ICO and the emitter current is zero.

5.5 Characteristics of common collector circuit:

The circuit diagram for determining the static characteristics of an N-P-N transistor in the common collector configuration is shown in fig. below.

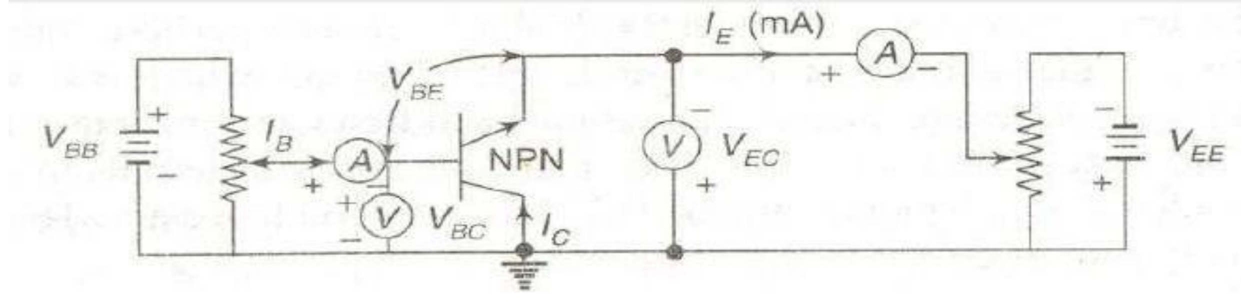


Fig. Circuit to determine CC static characteristics.

Input Characteristics:

To determine the input characteristic, V_{EC} is kept at a suitable fixed value. The base collector voltage V_{BC} is increased in equal steps and the corresponding increase in I_B is noted. This is repeated for different fixed values of V_{EC}. Plots of V_{BC} versus I_B for different values of V_{EC} shown in figure are the input characteristics.

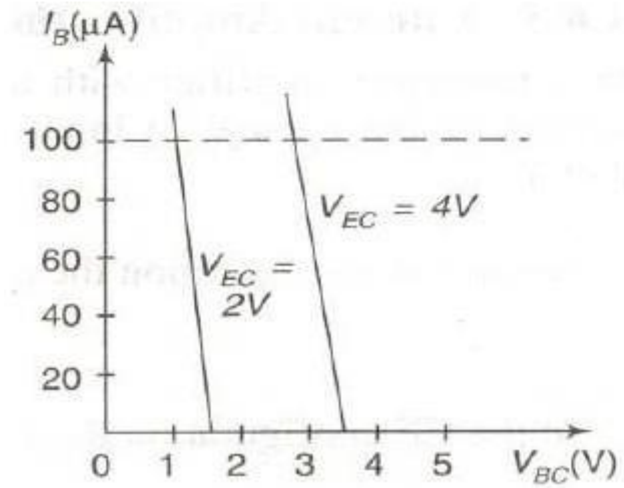


Fig. CC Input Characteristics.

Output Characteristics:

The output characteristics shown in figure below are the same as those of the common emitter configuration.

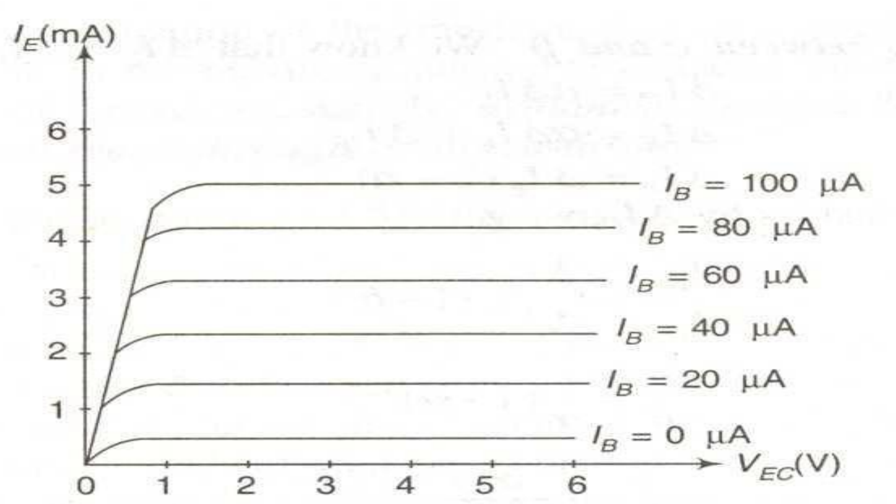
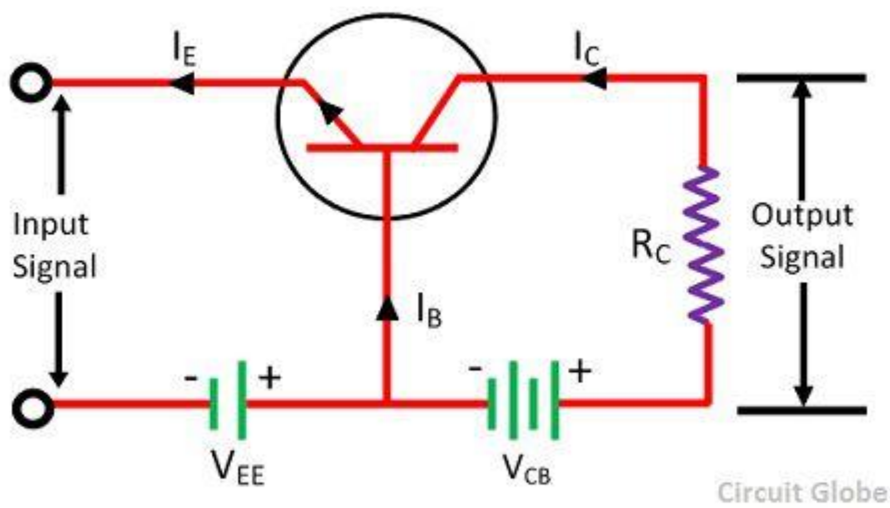


Fig. CC output characteristics.

Transistor as an Amplifier :

The transistor raises the strength of a weak signal and hence acts an amplifier. The transistor amplifier circuit is shown in the figure below. The transistor has three terminals namely emitter, base and collector. The emitter and base of the transistor are connected in forward biased and the collector base region is in reverse bias. The forward bias means the P-region of the transistor is connected to the positive terminal of the supply and the negative region is connected to the N-terminal and in reverse bias just opposite of it has occurred.



The input signal or weak signal is applied across the emitter base and the output is obtained to the load resistor R_C which is connected in the collector circuit. The DC voltage V_{EE} is applied to the input circuit along with the input signal to achieve the amplification. The DC voltage V_{EE} keeps the emitter-base junction under the forward biased condition regardless of the polarity of the input signal and is known as a bias voltage.

In the collector circuit, a load resistor R_C of high value is connected. When collector current flows through such a high resistance, it produces a large voltage drop across it. Thus, a weak signal (0.1V) applied to the input circuit appears in the amplified form (10V) in the collector circuit.

FIELD EFFECT TRANSISTOR

INTRODUCTION

1. The Field effect transistor is abbreviated as FET , it is an another semiconductor device like a BJT which can be used as an amplifier or switch.
2. The Field effect transistor is a voltage operated device. Whereas Bipolar junction transistor is a current controlled device. Unlike BJT a FET requires virtually no input current.
3. This gives it an extremely high input resistance , which is its most important advantage over a bipolar transistor.
4. FET is also a three terminal device, labeled as source, drain and gate.
5. The source can be viewed as BJT's emitter, the drain as collector, and the gate as the counter part of the base.
6. The material that connects the source to drain is referred to as the channel.
7. FET operation depends only on the flow of majority carriers ,therefore they are called uni polar devices. BJT operation depends on both minority and majority carriers.
8. As FET has conduction through only majority carriers it is less noisy than BJT.
9. FETs are much easier to fabricate and are particularly suitable for ICs because they occupy less space than BJTs.
10. FET amplifiers have low gain bandwidth product due to the junction capacitive effects and produce more signal distortion except for small signal operation.
11. The performance of FET is relatively unaffected by ambient temperature changes. As it has a negative temperature coefficient at high current levels, it prevents the FET from thermal breakdown. The BJT has a positive temperature coefficient at high current levels which leads to thermal breakdown.

CLASSIFICATION OF FET:

There are two major categories of field effect transistors:

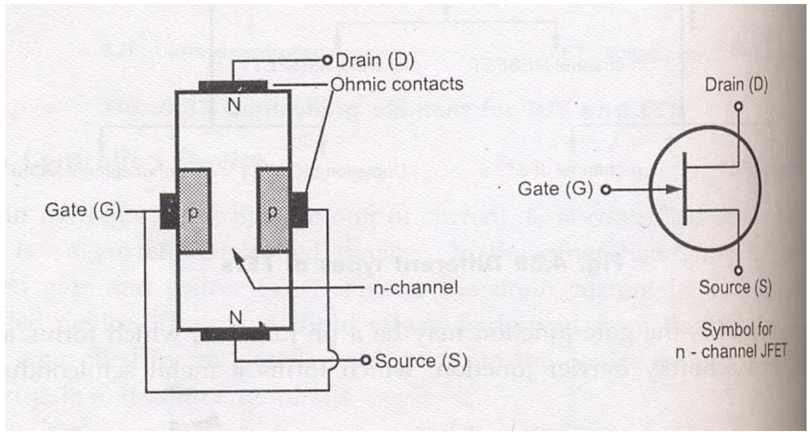
1. Junction Field Effect Transistors
2. MOSFETs

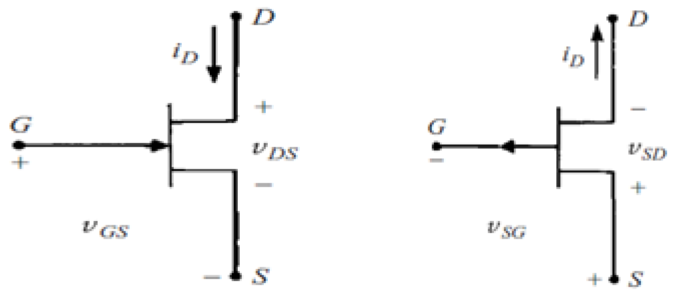
1. Junction Field Effect Transistors

- Junction Field Effect Transistors are further sub divided in to P- channel and N-channel devices.
- When the channel is of N-type the JFET is referred to as an N-channel JFET ,when the channel is of P-type the JFET is referred to as P-channel JFET.

CONSTRUCTION OF N-CHANNEL JFET

A piece of N- type material, referred to as channel has two smaller pieces of P-type materialattached to its sides, forming PN junctions. The channel ends are designated as the drain and source . And the two pieces of P-type material are connected together and their terminal is called the gate. Since this channel is in the N-type bar, the FET is known as N-channel JFET.





N-channel FET P-channel FET

The schematic symbols for the P-channel and N-channel JFETs are shown in the figure

OPERATION OF N-CHANNEL JFET:-

The overall operation of the JFET is based on varying the width of the channel to control the drain current.

A piece of N type material referred to as the channel, has two smaller pieces of P type material attached to its sites, farming PN –Junctions. The channel's ends are designated the drain and the source. And the two pieces of P type material are connected together and their terminal is called the gate. With the gate terminal not connected and the potential applied positive at the drain negative at the source a drain current I_D flows.

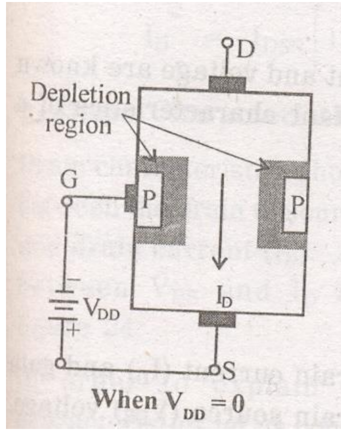
When the gate is biased negative with respective to the source the PN junctions are reverse biased and depletion regions are formed. The channel is more lightly doped than the P type gate blocks, so the depletion regions penetrate deeply into the channel. Since depletion region is a region depleted of charge carriers it behaves as an Insulator. The result is that the channel is narrowed. Its resistance is increased and I_D is reduced. When the negative gate bias voltage is further increased, the depletion regions meet at the center and Id is cut off completely.

There are two ways to control the channel width

1. By varying the value of V_{GS}
2. And by Varying the value of V_{DS} holding V_{GS} constant

1 By varying the value of V_{GS} :-

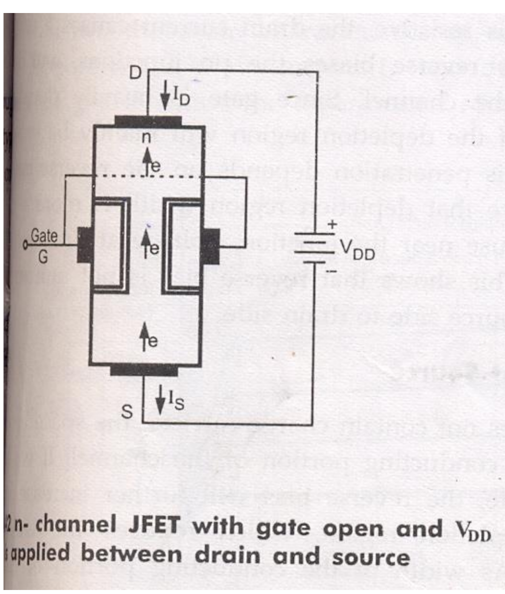
We can vary the width of the channel and in turn vary the amount of drain current. This can be done by varying the value of V_{GS}. This point is illustrated in the fig below. Here we are dealing with N channel FET. So channel is of N type and gate is of P type that constitutes a PN junction. This PN junction is always reverse biased in JFET operation .The reverse bias is applied by a battery voltage V_{GS} connected between the gate and the source terminal i.e positive terminal of the battery is connected to the source and negative terminal to gate.



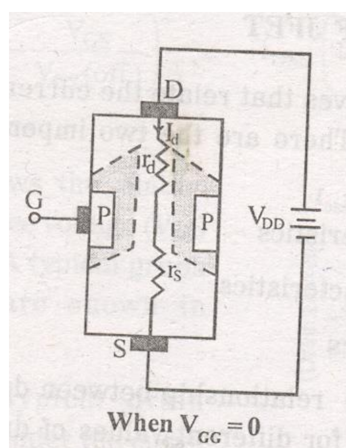
1) When a PN junction is reverse biased the electrons and holes diffuse across junction by leaving immobile ions on the N and P sides , the region containing these immobile ions is known as depletion regions.
2) If both P and N regions are heavily doped then the depletion region extends symmetrically on both sides.
3) But in N channel FET P region is heavily doped than N type thus depletion region extends more in N region than P region.
4) So when no V_{DS} is applied the depletion region is symmetrical and the conductivity becomes Zero. Since there are no mobile carriers in the junction.
5) As the reverse bias voltage is increases the thickness of the depletion region also increases. i.e. the effective channel width decreases .
6) By varying the value of V_{GS} we can vary the width of the channel.

2 Varying the value of V_{DS} holding V_{GS} constant :-

1) When no voltage is applied to the gate i.e. V_{GS} =0 , V_{DS} is applied between source and drain the electrons will flow from source to drain through the channel constituting drain current I_D .
2) With V_{GS} = 0 for I_D = 0 the channel between the gate junctions is entirely open .In response to a small applied voltage V_{DS} , the entire bar acts as a simple semi conductor resistor and the current I_D increases linearly with V_{DS} .
3) The channel resistances are represented as R_D and R_S as shown in the fig.



n- channel JFET with gate open and V_{DD} applied between drain and source



4) This increasing drain current I_D produces a voltage drop across rd which reverse biases the gate to source junction,(R_D> R_S) .Thus the depletion region is formed which is not symmetrical .
5) The depletion region i.e. developed penetrates deeper in to the channel near drain and less towards source because V R_D >> V R_S. So reverse bias is higher near drain than at source.
6) As a result growing depletion region reduces the effective width of the channel. Eventually a voltage V_{DS} is reached at which the channel is pinched off. This is the voltage where the current Id begins to level off and approach a constant value.
7) So, by varying the value of V_{DS} we can vary the width of the channel holding V_{GS} constant.

When both V_{GS} and V_{DS} is applied:-

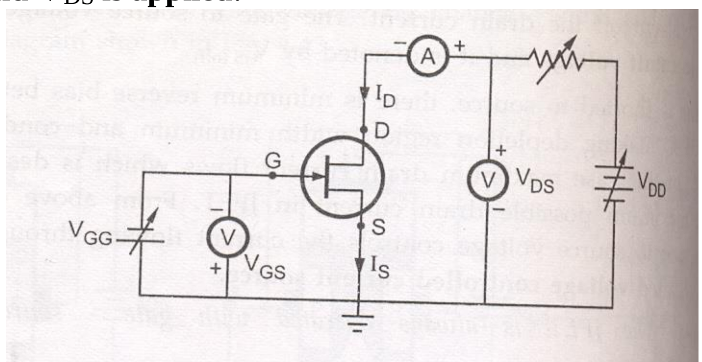
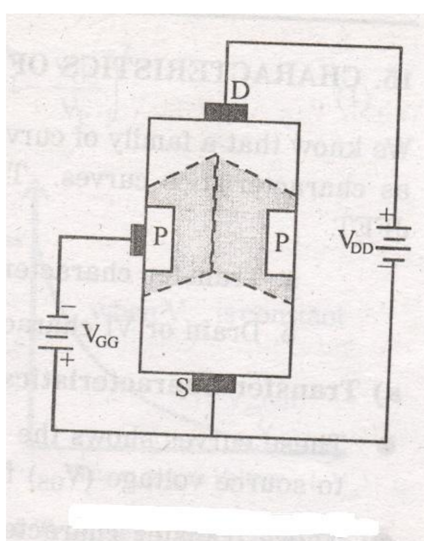


Fig. 4.45 Experimental setup to plot JFET characteristics

It is of course in principle not possible for the channel to close Completely and there by reduce the current Id to Zero for, if such indeed, could be the case the gate voltage V_{GS} is applied in the direction to provide additional reverse bias

1) When voltage is applied between the drain and source with a battery V_{DD}, the electrons flow from source to drain through the narrow channel existing between the depletion regions. This constitutes the drain current I_D, its conventional direction is from drain to source.
2) The value of drain current is maximum when no external voltage is applied between gate and source and is designated by I_{DSS}.



3) When V_{GS} is increased beyond Zero the depletion regions are widened. This reduces the effective width of the channel and therefore controls the flow of drain current through the channel.
4) When V_{GS} is further increased a stage is reached at which to depletion regions touch each other that means the entire channel is closed with depletion region. This reduces the drain current to Zero.

CHARACTERISTICS OF N-CHANNEL JFET :-

The family of curves that shows the relation between current and voltage are known as characteristic curves.

There are two important characteristics of a JFET.

1) Drain or VI Characteristics
2) Transfer characteristics

1. Drain Characteristics:

Drain characteristics shows the relation between the drain to source voltage V_{DS} and drain current Id. In order to explain typical drain characteristics let us consider the curve with $V_{GS} = 0$ V.

1) When V_{DS} is applied and it is increasing the drain current I_D also increases linearly up to knee point.
2) This shows that FET behaves like an ordinary resistor.This region is called as ohmic region.
3) I_D increases with increase in drain to source voltage. Here the drain current is increased slowly as compared to ohmic region.

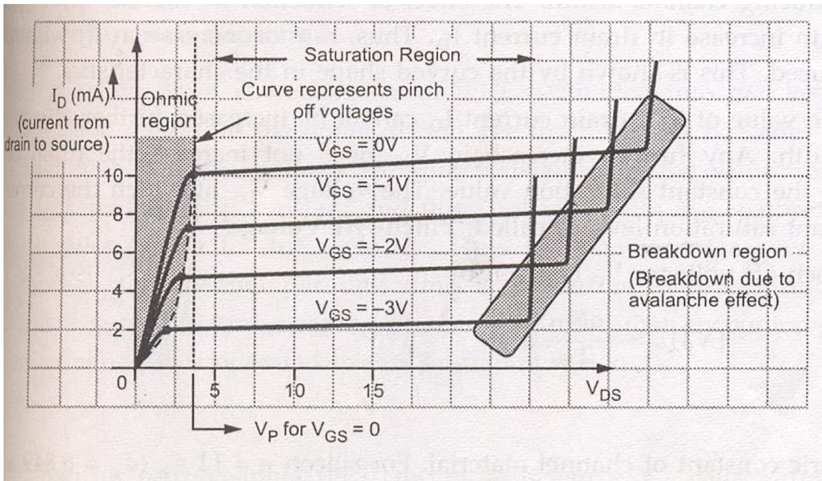


Fig. 4.44 Drain V-I characteristics of n-channel JFET

4) It is because of the fact that there is an increase in V_{DS} .This in turn increases the reverse bias voltage across the gate source junction .As a result of this depletion region grows in size thereby reducing the effective width of the channel.

5) All the drain to source voltage corresponding to point the channel width is reduced to a minimum value and is known as pinch off.

6) The drain to source voltage at which channel pinch off occurs is called pinch off voltage(V_P).

PINCH OFF Region:

1) This is the region shown by the curve as saturation region.
2) It is also called as saturation region or constant current region. Because of the channel is occupied with depletion region , the depletion region is more towards the drain and less towards the source, so the channel is limited, with this only limited number of carriers are only allowed to cross this channel from source drain causing a current that is constant in this region. To use FET as an amplifier it is operated in this saturation region.
3) In this drain current remains constant at its maximum value I_{DSS}.

4) The drain current in the pinch off region depends upon the gate to source voltage and is given by the relation

$$I_D = I_{DSS} [1- V_{GS} / V_P]^2$$

This is known as shokley's relation.

BREAKDOWN REGION:

1) The region is shown by the curve .In this region, the drain current increases rapidly as the drain to source voltage is increased.
2) It is because of the gate to source junction due to avalanche effect.
3) The avalanche break down occurs at progressively lower value of V_{DS} because the reverse bias gate voltage adds to the drain voltage thereby increasing effective voltage across the gate junction

   This causes

   1. The maximum saturation drain current is smaller
   2. The ohmic region portion decreased.
4) It is important to note that the maximum voltage V_{DS} which can be applied to FET is the lowest voltage which causes available break down.

2. TRANSFER CHARACTERISTICS:

These curves shows the relationship between drain current I_D and gate to source voltage V_{GS} for different values of V_{DS}

1) First adjust the drain to source voltage to some suitable value , then increase the gate to source voltage in small suitable value.
2) Plot the graph between gate to source voltage along the horizontal axis and current ID on the vertical axis. We shall obtain a curve like this.

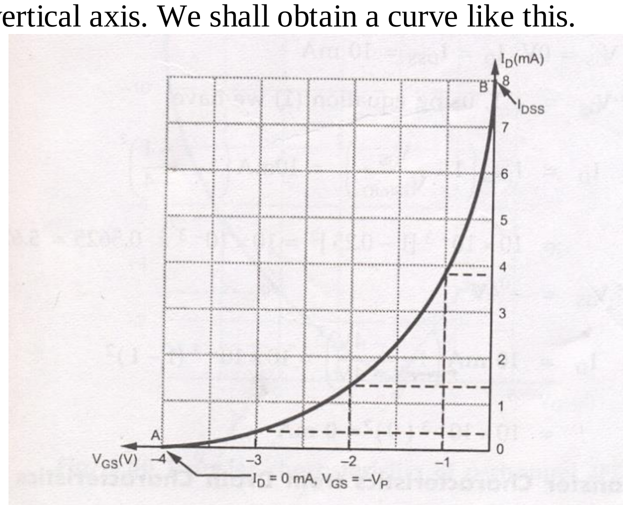


Fig. 4.48 Transfer characteristics of n-channel JFET

3) As we know that if V_{GS} is more negative curves drain current to reduce . where V_{GS} is made sufficiently negative, I_D is reduced to zero. This is caused by the widening of the depletion region to a point where it is completely closes the channel. The value of V_{GS} at the cutoff point is designed as $V_{GS\ off}$
4) The upper end of the curve as shown by the drain current value is equal to I_{DSS} that is when $V_{GS} = 0$ the drain current is maximum.
5) While the lower end is indicated by a voltage equal to $V_{GS\ off}$
6) If V_{GS} continuously increasing , the channel width is reduced , then $I_D = 0$
7) It may be noted that curve is part of the parabola; it may be expressed as

$$I_D = I_{DSS} [1- V_{GS} / V_{GS\ off}]^2$$

DIFFERENCE BETWEEN V_P AND $V_{GS\ off}$:

1) V_P is the value of V_{GS} that causes the JFET to become constant current component, It is measured at $V_{GS} = 0V$ and has a constant drain current of $I_D = I_{DSS}$.

.Where $V_{GS\ off}$ is the value of V_{GS} that reduces I_D to approximately zero.

<u>Why the gate to source junction of a JFET be always reverse biased ?</u>

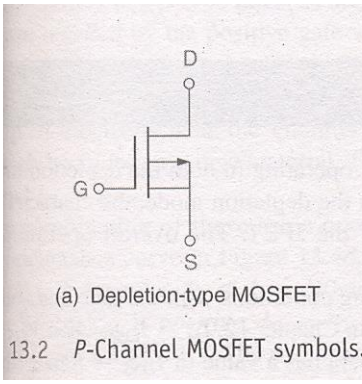
The gate to source junction of a JFET is never allowed to become forward biased because the gate material is not designed to handle any significant amount of current. If the junction is allowed to become forward biased, current is generated through the gate material. This current may destroy the component.

There is one more important characteristic of JFET reverse biasing i.e. J FET 's have extremely high characteristic gate input impedance. This impedance is typically in the high mega ohm range. With the advantage of extremely high input impedance it draws no current from the source. The high input impedance of the JFET has led to its extensive use in integrated circuits. The low current requirements of the component makes it perfect for use in ICs. Where thousands of transistors must be etched on to a single piece of silicon. The low current draw helps the IC to remain relatively cool, thus allowing more components to be placed in a smaller physical area.

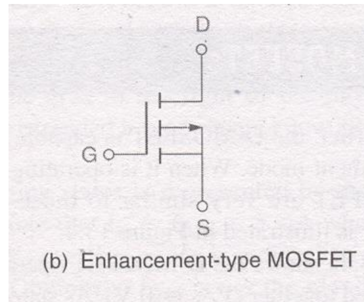
MOSFET:

- We now turn our attention to the Insulated Gate FET or Metal Oxide Semi Conductor FET which is having the greater commercial importance than the junction FET.
- Most MOSFETS however are triodes, with the substrate internally connected to the source.

The circuit symbols used by several manufacturers are indicated in the Fig below.



(a) Depletion type MOSFET

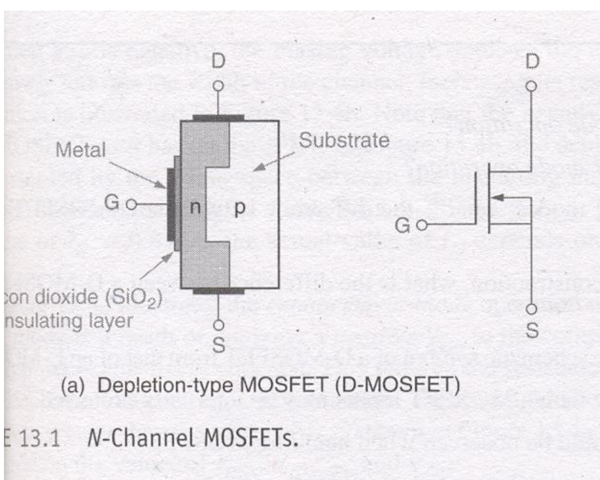


(b) Enhancement type MOSFET

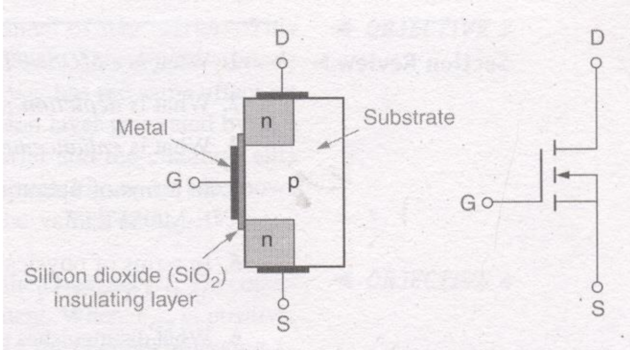
Both of them are P- channel

- Here are two basic types of MOSFETS

  (1) Depletion type (2) Enhancement type MOSFET.
- D-MOSFETS can be operated in both the depletion mode and the enhancement mode.
- E MOSFETS are restricted to operate in enhancement mode. The primary difference between them is their physical construction.
- The construction difference between the two is shown in the fig given below.



As we can see the D MOSFET have physical channel between the source and drain terminals(Shaded area)



(b) Enhancement-type MOSFET (E-MOSFET)

The E MOSFET on the other hand has no such channel physically. It depends on the gate voltage to form a channel between the source and the drain terminals.

Both MOSFETS have an insulating layer between the gate and the rest of the component. This insulating layer is made up of SIO_2 a glass like insulating material. The gate material is made up of metal conductor .Thus going from gate to substrate, we can have metal oxide semi conductor which is where the term MOSFET comes from.

Since the gate is insulated from the rest of the component, the MOSFET is sometimes referred to as an insulated gate FET or IGFET.

The foundation of the MOSFET is called the substrate. This material is represented in the schematic symbol by the center line that is connected to the source.

In the symbol for the MOSFET, the arrow is placed on the substrate. As with JFET an arrow pointing in represents an N-channel device, while an arrow pointing out represents p-channel device.

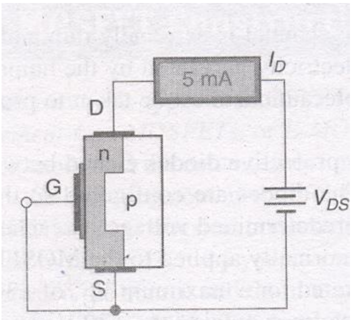
CONSTRUCTION OF AN N-CHANNEL MOSFET :

The N- channel MOSFET consists of a lightly doped p type substance into which two heavily doped n+ regions are diffused as shown in the Fig. These n+ sections , which will act as source and drain.

A thin layer of insulation silicon dioxide (SIO_2) is grown over the surface of the structure, and holes are cut into oxide layer, allowing contact with the source and drain. Then the gate metal area is overlaid on the oxide, covering the entire channel region.Metal contacts are made to drain and source and the contact to the metal over the channel area is the gate terminal.The metal area of the gate, in conjunction with the insulating dielectric oxide layer and the semiconductor channel, forms a parallel plate capacitor. The insulating layer of Sio2 Is the reason why this device is called the insulated gate field effect transistor. This layer results in an extremely high input resistance (10 10 to 10power 15ohms) for MOSFET.

DEPLETION MOSFET

The basic structure of D –MOSFET is shown in the fig. An N-channel is diffused between source and drain with the device an appreciable drain current I_{DSS} flows foe zero gate to source voltage, V_{GS}=0.



(a) $I_D = I_{DSS}$ when $V_{GS} = 0$ V

Depletion mode operation:-

1) The above fig shows the D-MOSFET operating conditions with gate and source terminals shorted together(V_{GS}=0V)

2) At this stage I_D= I_{DSS} where V_{GS} =0V, with this voltage V_{DS}, an appreciable drain current I_{DSS} flows.

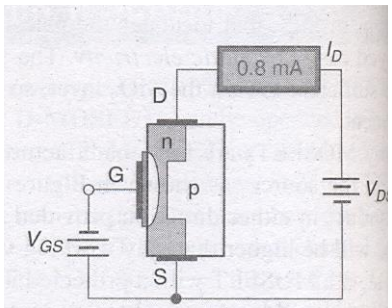
3) If the gate to source voltage is made negative i.e. V_{GS} is negative .Positive charges are induced in the channel through the SIO_2 of the gate capacitor.

4) Since the current in a FET is due to majority carriers(electrons for an N-type material) , the induced positive charges make the channel less conductive and the drain current drops as V_{GS} is made more negative.

5) The re distribution of charge in the channel causes an effective depletion of majority carriers , which accounts for the designation depletion MOSFET.

6) That means biasing voltage V_{GS} depletes the channel of free carriers This effectively reduces the width of the channel , increasing its resistance.

7) Note that negative V_{GS} has the same effect on the MOSFET as it has on the JFET.



(b) $I_D < I_{DSS}$ when V_{GS} is negative

8) As shown in the fig above, the depletion layer generated by V_{GS} (represented by the white space between the insulating material and the channel) cuts into the channel, reducing its width. As a result , I_D< I_{DSS} .The actual value of I_D depends on the value of I_{DSS}, V_{GSOFF} and V_{GS}

Enhancement mode operation of the D-MOSFET:-

1) This operating mode is a result of applying a positive gate to source voltage V_{GS} to the device.

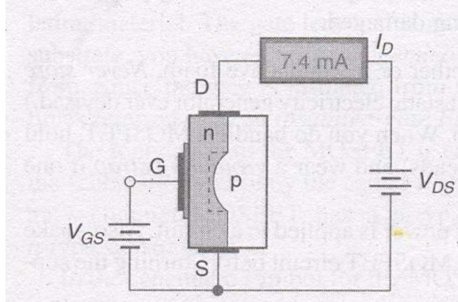
2) When V_{GS} is positive the channel is effectively widened. This reduces the resistance of the channel allowing I_D to exceed the value of I_{DSS}

3) When V_{GS} is given positive the majority carriers in the p-type are holes. The holes in the P type substrate are repelled by the +ve gate voltage.

4) At the same time, the conduction band electrons (minority carriers) in the P type material are attracted towards the channel by the +gate voltage.

5) With the build up of electrons near the channel , the area to the right of the physical channel effectively becomes an N type material.

6) The extended n type channel now allows more current, I_D > I_{DSS}



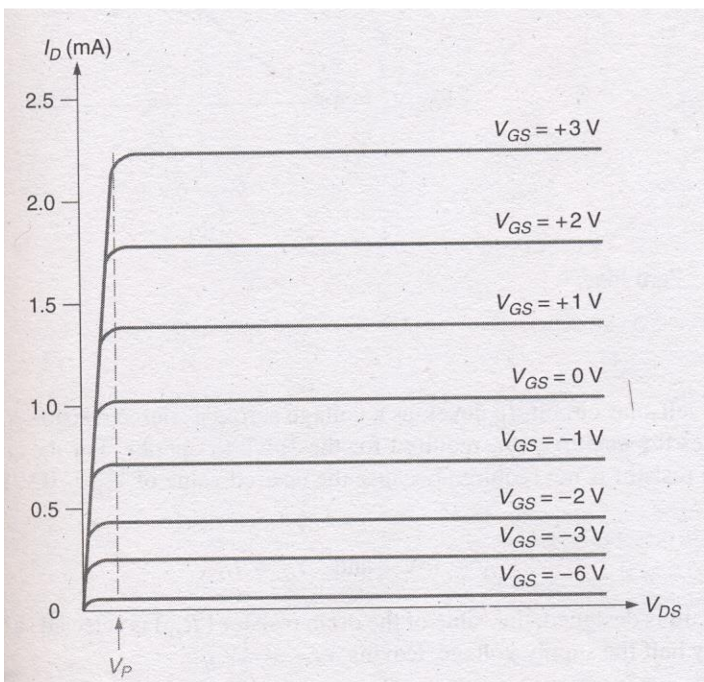
(c) $I_D > I_{DSS}$ when V_{GS} is positive

FIGURE 13.4 D-MOSFET operation.

<u>Characteristics of Depletion MOSFET:-</u>

The fig. shows the drain characteristics for the N channel depletion type MOSFET

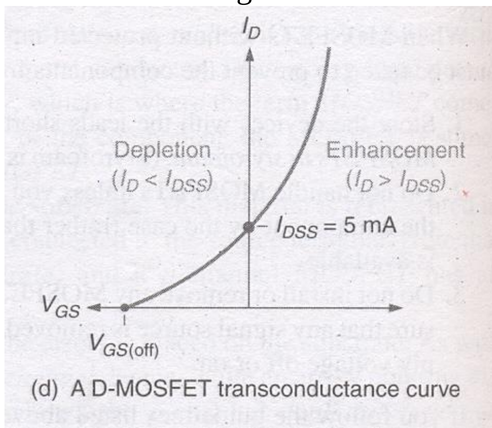
1) The curves are plotted for both V_{GS} positive and V_{GS} negative voltages
2) When V_{GS} =0 and negative the MOSFET operates in depletion mode when V_{GS} is positive ,the MOSFET operates in the enhancement mode.
3) The difference between JFET and D MOSFET is that JFET does not operate for positive values of V_{GS}.
4) When V_{DS}=0, there is no conduction takes place between source to drain, if V_{GS} <0 and V_{DS} >0 then Id increases linearly.
5) But as V_{GS},0 induces positive charges holes in the channel, and controls the channel width. Thus the conduction between source to drain is maintained as constant, i.e. I_D is constant.
6) If V_{GS} >0 the gate induces more electrons in channel side, it is added with the free electrons generated by source. again the potential applied to gate determines the channel width and maintains constant current flow through it as shown in Fig



6 MOSFET drain curves.

TRANSFER CHARACTERISTICS:-

The combination of 3 operating states i.e. V_{GS} =0V, V_{GS} < 0V, V_{GS} > 0V is represented by the D MOSFET transconductance curve shown in Fig.



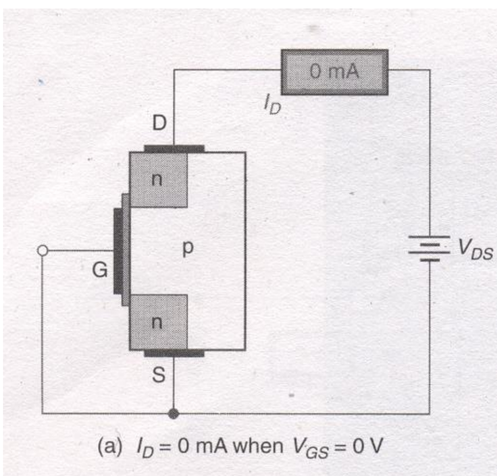
1) Here in this curve it may be noted that the region AB of the characteristics similar to that of JFET.

2) This curve extends for the positive values of V_{GS}
3) Note that I_D= I_{DSS} for V_{GS} =0V when V_{GS} is negative, I_D< I_{DSS} when V_{GS} = V_{GS} (off) , I_D is reduced to approximately 0mA.Where V_{GS} is positive I_D > I_{DSS}.So obviously Idss is not the maximum possible value of I_D for a MOSFET.

4) The curves are similar to JFET so thet the D MOSFET have the same transconductance equation.

E-MOSFETS

The E MOSFET is capable of operating only in the enhancement mode.The gate potential must be positive w.r.t to source.



1) when the value of V_{GS} =0V, there is no channel connecting the source and drain materials.

2) As aresult , there can be no significant amount of drain current.

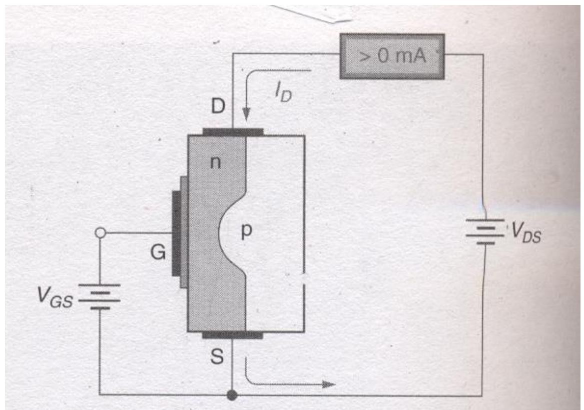
3) When V_{GS} =0, the Vdd supply tries to force free electrons from source to drain but the presence of p-region does not permit the electrons to pass through it. Thus there is no drain current at V_{GS} =0,

4) If V_{GS} is positive, it induces a negative charge in the p type substrate just adjacent to the SIO_2 layer.

5) As the holes are repelled by the positive gate voltage, the minority carrier electrons attracted toward this voltage. This forms an effective N type bridge between source and drain providing a path for drain current.

6) This +ve gate voltage forma a channel between the source and drain.

7) This produces a thin layer of N type channel in the P type substarate.This layer of free electrons is called N type inversion layer.



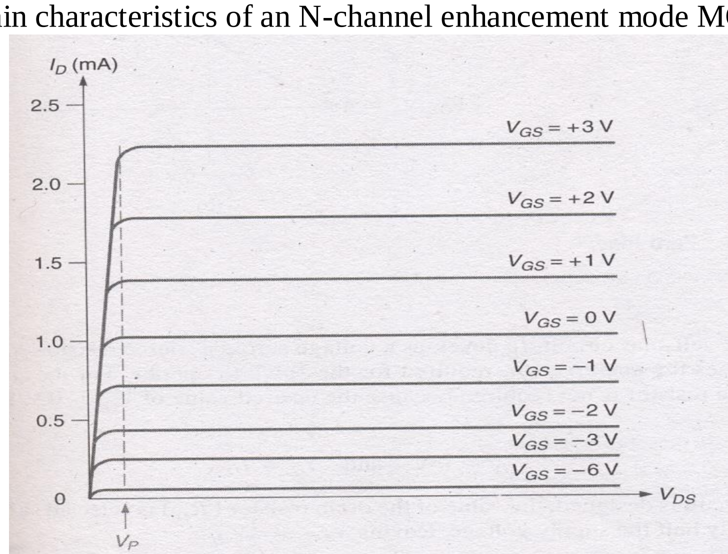
(b) $I_D > 0$ mA when V_{GS} is sufficient to form a channel.

8) The minimum V_{GS} which produces this inversion layer is called threshold voltage and is designated by V_{GS}(th).This is the point at which the device turns on is called the threshold voltage V_{GS}(th)
9) When the voltage V_{GS} is < V_{GS}(th) no current flows from drain to source.

10) How ever when the voltage V_{GS} > V_{GS}(th) the inversion layer connects the drain to source and we get significant values of current.

CHARACTERISTICS OF E MOSFET:
1. DRAIN CHARACTERISTICS:

The volt ampere drain characteristics of an N-channel enhancement mode MOSFET are given in.



6 MOSFET drain curves.

2. TRANSFER CHARACTERISTICS:

1) The current I_{DSS} at $V_{GS} \leq 0$ is very small beinf of the order of a few nano amps.
2) As V_{GS} is made +ve , the current I_D increases slowly at forst, and then much more rapidly with an increase in V_{GS}.
3) The standard transconductance formula will not work for the E MOSFET.
4) To determine the value of I_D at a given value of VGs we must use the following relation

$$I_D = K[V_{GS} - V_{GS\,(Th)}]^2$$

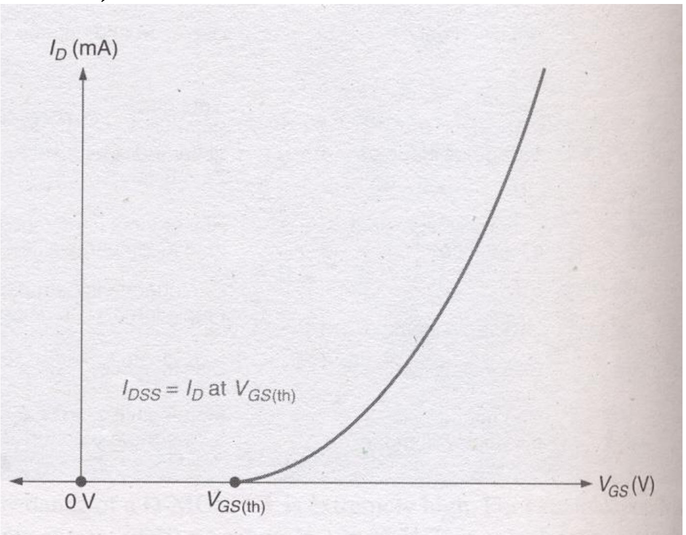
Where K is constant for the MOSFET . found as

$$K = \frac{Id(on)}{[vgs(on) - Vgs(Th)]2}$$

From the data specification sheets, the 2N7000 has the following ratings.

$I_D(on)$= 75mA(minimum).

And V_{GS} (th)=0.8(minimum)



E-MOSFET transconductance curve.

APPLICATION OF MOSFET

One of the primary contributions to electronics made by MOSFETs can be found in the area of digital (computer electronics). The signals in digital circuits are made up of rapidly switching dc levels. This signal is called as a rectangular wave ,made up of two dc levels (or logic levels). These logic levels are 0V and +5V.

A group of circuits with similar circuitry and operating characteristics is referred to as a logic family. All the circuits in a given logic family respond to the same logic levels, have similar speed and power-handling capabilities , and can be directly connected together. One such logic family is complementary MOS (or CMOS) logic. This logic family is made up entirely of MOSFETs.

COMPARISON OF MOSFET WITH JFET

a. In enhancement and depletion types of MOSFET, the transverse electric field induced across an insulating layer deposited on the semiconductor material controls the conductivity of the channel.

b. In the JFET the transverse electric field across the reverse biased PN junction controls the conductivity of the channel.

c. The gate leakage current in a MOSFET is of the order of 10^{-12}A. Hence the input resistance of a MOSFET is very high in the order of 10^{10} to 10^{15} Ω. The gate leakage current of a JFET is of the order of 10^{-9}A., and its input resistance is of the order of 10^{8}Ω.

d. The output characteristics of the JFET are flatter than those of the MOSFET, and hence the drain resistance of a JFET (0.1 to 1MΩ) is much higher than that of a MOSFET (1 to 50kΩ).

e. JFETs are operated only in the depletion mode. The depletion type MOSFET may be operated in both depletion and enhancement mode.

f. Comparing to JFET, MOSFETs are easier to fabricate.

g. Special digital CMOS circuits are available which involve near zero power dissipation and very low voltage and current requirements. This makes them suitable for portable systems.