LECTURE NOTES

ON

BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

ACADEMIC YEAR 2021-22

I B.Tech.–II SEMESTER(R20)

P MANJUSHA,Assistant Professor

DEPARTMENT OF HUMANITIES AND BASIC SCIENCES

V S M COLLEGE OF ENGINEERING
RAMCHANDRAPURAM
E.G DISTRICT
533255

VSM COLLEGE OF ENGINEERING

RAMACHANDRAPRUM-533255

DEPARTMENT OF MECHANICAL ENGINEERING

Course Title	Year-Sem	Branch	Contact Periods/Week	Sections
BASIC ELECTRICAL AND ELECTRONICS ENGINEERING	1-2	**MECHANICAL ENGINEERING**	6	-

COURSE OUTCOMES: Students are able to

1. Analyse various electrical networks.
2. Understand operation of DC generators ,3-point starter and DC machine testing by Swinburne's Test and Brake test.
3. Analyse performance of single-phase transformer and acquire proper knowledge and working of 3-phase alternator and 3-phase induction motors
4. Analyse operation of half wave, full wave bridge rectifiers and OP-AMPs.
5. Understanding operations of CE amplifier and basic concept of feedback amplifier.

Unit/ item No.	Outcomes		Topic	Number of periods	Total periods	Book Reference	Delivery Method
1	**CO1:** Analyse various electrical networks		**Transmission Line Parameters**		10	T1, T2, R2	Chalk & Talk, PPT, Active Learning & Tutorial
		1.1	Basic definitions – types of network elements	1			
		1.2	Ohm's Law	1			
		1.3	Kirchhoff's Laws	1			
		1.4	inductive networks	1			
		1.5	capacitive networks	1			
		1.6	series – parallel circuits	2			
		1.7	star- delta and delta-star transformations.	2			
		1.8	Numerical Problems	1			
2	**CO2:** Understand operation of DC generators ,3-point starter and DC machine testing by		**Performance of Short and Medium Length Transmission Lines**				
		2.1	Principle of operation of DC generator types of DC machines three point starter	1			
		2.2	EMF equation	2			
		2.3	torque equation characteristics of DC motors – applications	2			

	Swinburne’s Test and Brake test.	2.4	speed control methods of DC motor t	2	10	T1, T2, R4	Chalk & Talk, PPT, Active Learnin g & Tutorial
		2.5	Swinburne’s Test	1			
		2.6	Brake test on DC shunt motor	1			
		2.7	Numerical Problems	1			
3	**CO3** Analyse performance of single-phase transformer and acquire proper knowledge and working of 3-phase alternator and 3-phase induction motors		**Performance of Long Transmission Lines**		12	T1 T2, R4	Chalk & Talk, PPT, Active Learnin g & Tutorial
		3.1	Principle of operation and construction of single phase transformers	1			
		3.2	EMF equation – Losses	1			
		3.3	OC & SC tests – efficiency and regulation.	1			
		3.4	Numerical Problems	2			
		3.5	principle of operation and construction of alternators	2			
		3.6	types of alternators Regulation of alternator by synchronous impedance method	1			
		3.7	principle of operation of synchronous motor	1			
		3.8	principle of operation of 3-Phase induction motor	1			
		3.9	slip-torque characteristics – efficiency – applications- Numerical Problems.	2			
4	**CO4:** Analyse operation of half wave, full wave bridge rectifiers and OP-AMPs		**Power System Transients**		8	T1, T2, R3	Chalk & Talk, PPT, Active Learnin g & Tutorial
		4.1	PN junction diodes Characteristics of operation amplifiers (OP-AMP)	2			
		4.2	diode applications (half wave and bridge rectifiers).	2			
		4.3	application of OP-AMPs (inverting, non-inverting, integrator and differentiator)	2			
		4.4	Numerical Problems.	2			
5	**CO5:** Understanding operations of CE amplifier and basic concept of feedback amplifier.		**Various Factors Governing the Performance of Transmission line**		8	T1, T2, R1	Chalk & Talk, PPT, Active Learnin g & Tutorial
		5.1	PNP and NPN junction transistor, transistor as an amplifier.	2			
		5.2	frequency response of CE amplifier	2			
		5.3	Basic concepts of feedback amplifier	1			

		5.4	Numerical problems	1			
	TOTAL			**48**			

LIST OF TEXT BOOKS AND AUTHORS

Text Books:

1. Electrical Technology by Surinder Pal Bali, Pearson Publications.
2. Electronic Devices and Circuits by R.L. Boylestad and Louis Nashelsky, 9th edition, PEI/PHI 2006.

Reference Books:

1. Electrical Circuit Theory and Technology by John Bird, Routledge Taylor &Francis Group
2. Basic Electrical Engineering by M.S.Naidu and S.Kamakshiah, TMH Publications
3. Fundamentals of Electrical Engineering by Rajendra Prasad, PHI Publications,2nd edition
4. Basic Electrical Engineering by Nagsarkar, Sukhija, Oxford Publications,2nd edition
5. Industrial Electronics by G.K. Mittal, PHI

Faculty Member　　　　Head of the Department　　　　PRINCIPAL

VSM COLLEGE OF ENGINEERING

RAMACHANDRAPURAM

I Year-II Semester **BASIC ELECTRICAL AND ELECTRONICS ENGINEERING**

Unit - I
Electrical Circuits
Basic definitions – types of network elements – Ohm's Law – Kirchhoff's Laws – inductive networks – capacitive networks – series – parallel circuits – star-delta and delta-star transformations.-Numerical Problems.
Unit - II
DC Machines
Principle of operation of DC generator – EMF equation – types of DC machines – torque equation characteristics of DC motors – applications – three point starter – speed control methods of DC motor – Swinburne's Test-Brake test on DC shunt motor-Numerical problems.
Unit - III
AC Machines:
Transformers
Principle of operation and construction of single phase transformers – EMF equation – Losses – OC &SC tests – efficiency and regulation-Numerical Problems.
AC Rotating Machines
Principle of operation and construction of alternators – types of alternators Regulation of alternator by synchronous impedance method – principle of operation of synchronous motor – principle of operation of3-Phase induction motor – slip-torque characteristics – efficiency – applications- Numerical Problems.
Unit IV
Rectifiers & Linear ICs
PN junction diodes – diode applications (half wave and bridge rectifiers). Characteristics of operation amplifiers (OP-AMP) – application of OP-AMPs (inverting, non-inverting, integrator and differentiator)- Numerical Problems.
Unit V Transistors
PNP and NPN junction transistor, transistor as an amplifier– frequency response of CE amplifier – Basicconcepts of feedback amplifier-Numerical problems

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1. Electrical Technology by Surinder Pal Bali, Pearson Publications.
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Unit-1

Introduction

Charge: The basic quantity in an electric circuit is the electric charge.

Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).

Addition or deficiency of electrons causes charge (q)

The charge on an electron is negative and equal in magnitude to 1.602×10^{-19} C

In 1 C of charge, there are $1/(1.602 \times 10^{-19}) = 6.24 \times 10^{18}$ electrons.

Solved Problem: What quantity of charge is carried by 6.24×10^{21} electrons?

The charge on an electron is 1.602×10^{-19} Coulombs

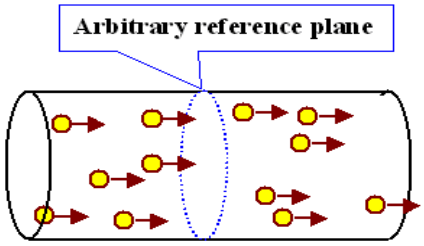
$$1e^{-} = 1.602 \times 10^{-19}\ C$$

$$1C = \frac{1}{1.602 \times 10^{-19}}\ electrons$$

$$= 6.24 \times 10^{18}\ electrons$$

$$\frac{6.24 \times 10^{21}}{6.24 \times 10^{18}} = 10^{3} = 1000\,C$$

Electric Current: The flow of electric charges.



Electric Current is the time rate of change of charge, measured in ampere (A).

$$I = \frac{Q}{t}\quad or\quad i = \frac{dq}{dt}$$

1 ampere= 1 coulomb/ second

Current must be designated with both a direction and a magnitude

Solved Problem: If a current of 5A flows for 2 minutes, find the quantity of charge transferred.

Solution: Quantity of electricity Q= It coulombs

I =5A

t =2×60=120 sec

Hence Q=5×120=600 C

Voltage: To move the electron in a conductor in a particular direction requires some work or energy transfer performed by an external electro motive force (emf). Voltage also known as voltage or potential difference.

Voltage (or potential difference) is the energy required to move a unit charge through an element , measured in volts (V).

The voltage between two point a and b in electric circuit is the energy (work) needed to move 1 C of charge from a to b :

$$v_{ab} = \frac{dw}{dq} \quad or \quad V = \frac{W}{Q}$$

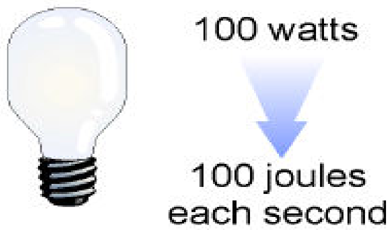
Where w =energy (J), q = charge (C)

1 volt = 1 joule/coulomb = 1 newton meter/ coulomb

Power and Energy : Power is the time rate of expending or absorbing energy, measured in watts . It is the rate at which energy is used.

Energy is the capacity to do work (to push electrons through a material)

$$p = \frac{dw}{dt} \quad p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = v\,i \quad P = V\,I$$



Where w =energy (J), t = time (s)

Since energy is measured in joules, power is measured in joules per second.

One joule per second is equal to one watt.

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

Solved Problem: A source e.m.f. of 5V supplies a current of 3A for 10 minutes. How much energy is provided in this time?

Solution: Energy = Power × time and Power = Voltage × Current.

Hence Energy = V I t

= 5×3×(10×60) = 9000Ws or J = 9kJ

Solved Problem: An electric heater consumes 1.8 MJ when connected to a 250 V supply for 30 minutes. Find the power rating of the heater and the current taken from the supply.

Solution: Energy = Power × time , hence

Power = Energy/time

= (1.8×10^6) J/(30 × 60) s

=1000 J/s=1000W

i.e. Power rating of heater=1kW

Power P=VI, thus I = P/V = 1000/250 = 4A

Hence the current taken from the supply is 4A

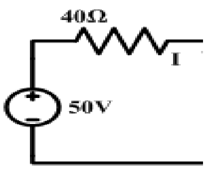
Concepts of Circuit/Network

An electric network : is defined as an interconnection of two or more electrical elements.

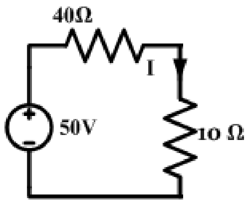
Circuit :A network that contains at least one closed path is known as circuit

All circuits can be called as networks

But all networks are not circuits



Network

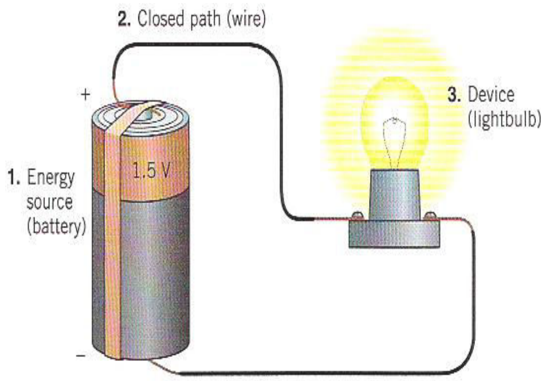


Circuit

All electric circuits have three main parts

1. A source of energy
2. A closed path
3. A device which uses the energy

If Any part of the circuit is open the device will not work!



Classification of Network Elements

- Active & Passive elements
- Bilateral & Unilateral elements
- Linear & Non linear elements

Active & Passive elements

Passive Elements: The elements that absorbs or stores energy is called passive element. These are not capable of generating energy

Examples: Resistor (R), Capacitor (C) , Inductor (L) , Transformer

Active Elements: The elements that supply energy to the circuit is called active element.

These are capable of generating energy

Examples: Voltage and Current sources, Generators,

Bilateral & Unilateral elements

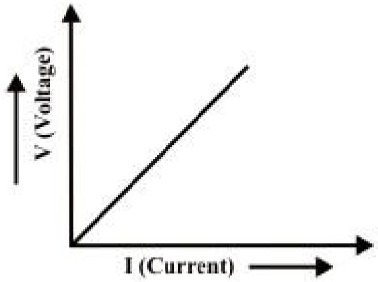
Bilateral Elements: Conduction of current in both directions in an element with same magnitude is termed as bilateral element.

Examples: Resistance; Inductance; Capacitance

Unilateral Elements: Conduction of current in one direction in an element is termed as unilateral element

Examples: Diode, Transistor**.**

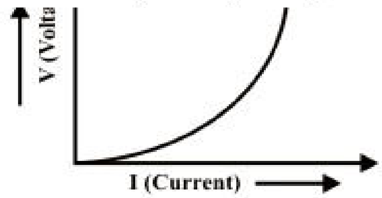
Linear & Non linear elements



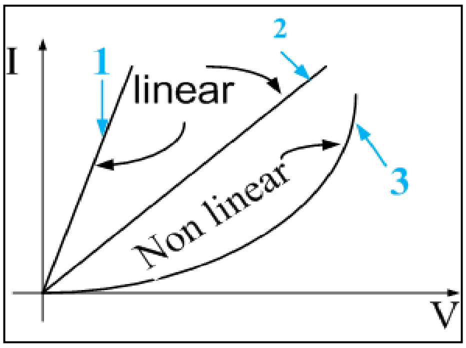
Linear Element: The elements that obeys ohm's law and homogeneity principle is called Linear element.

Examples: Resistor (R), Capacitor (C), Inductor (L)

Non-Linear Element: The elements that does not obey ohm's law and homogeneity principle is called Non-Linear element.



Examples: Semiconductors, Diode, Transistor



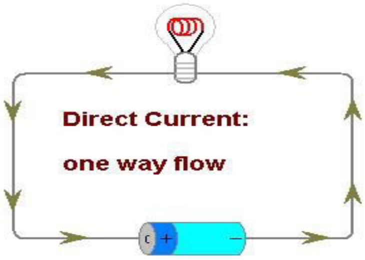
Linear elements are the elements that shows a linear relation ship between voltage and current as shown in curve 1 & 2

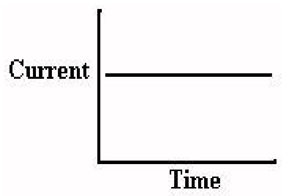
Non linear elements are the elements that doesnt show a linear relation ship between voltage and current as shown in curve 3

Direct and Alternating Current (DC &AC)

DC = Direct Current - current flows in one direction

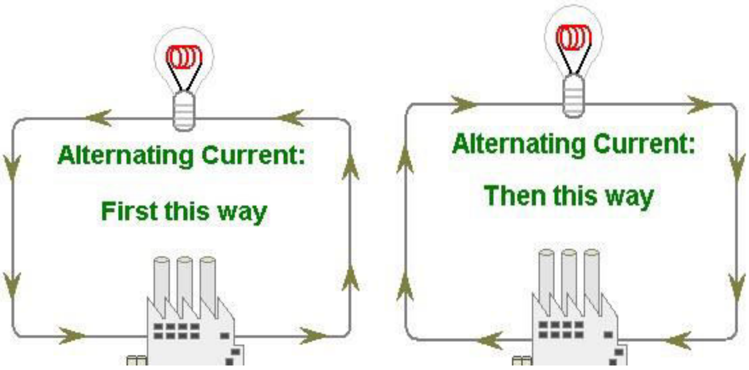
Example: Battery

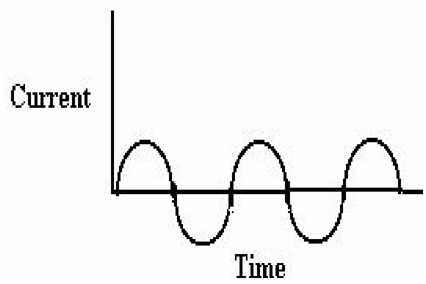


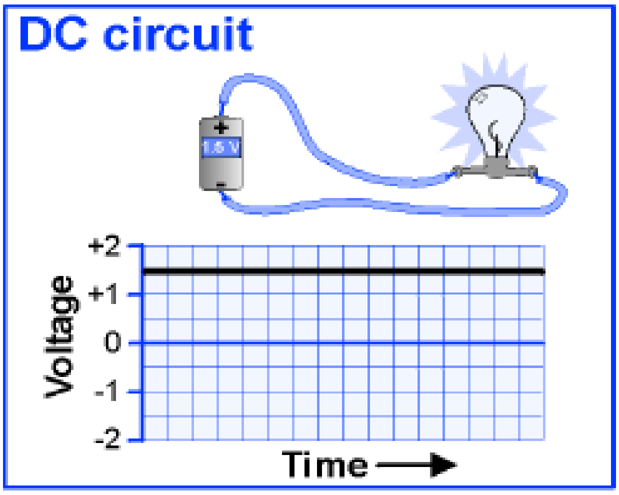


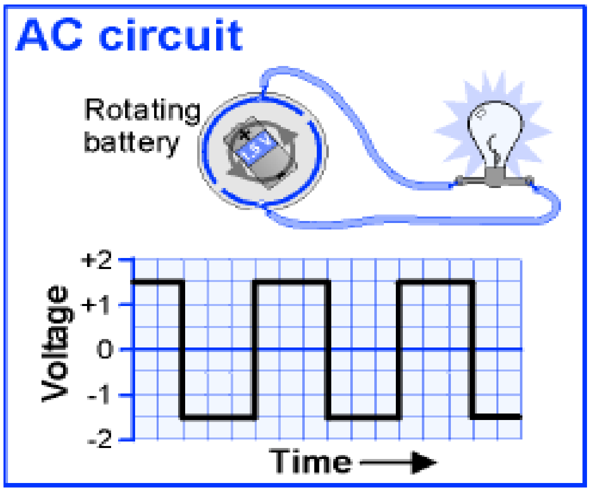
AC = Alternating Current- current reverses direction many times per second.

Example: Wall outlet (progress energy)









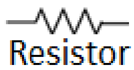
Passive Elements:

The passive elements are three

1. Resistance   2. Inductance   3. Capacitance

1. Resistance:

Definition: The tendency for a material to oppose the flow of electrons



Due to resistances electrical energy changes into thermal energy and light

Example: light bulb filament

Resistance is measured in Ohms (Ω)

Resistor : An object that has a given resistance is known as resistor

Ohm's law:

It defines the relationship between voltage, current, and resistance in an electric circuit

Electric Current in a conductor is direct proportional to the voltage applied to it at constant temeperature.

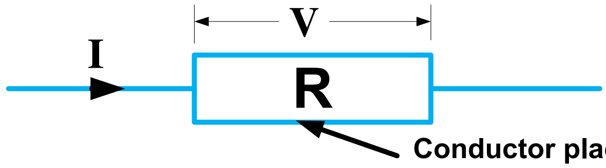
The proportionality constant is inverse of resistance of conductor

According to definition

$$I \alpha V$$

$$I = \frac{1}{R} V$$

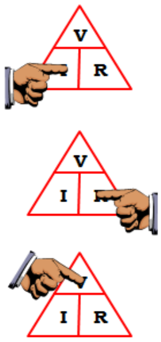
$$V = I R$$



Where, V = Voltage across the conductor in volts

I = Current flowing through the conductor in Ampere

R = Proportionality constant (resistance in ohms)



$$I = \frac{V}{R} \text{ (amperes, A)}$$

$$R = \frac{V}{I} \text{ (ohms, }\Omega)$$

$$V = IR \text{ (volts, V)}$$

The resistance (R) is defined as the ratio of the voltage V applied across a piece of material to the current I through the material.

<u>Factors affecting the Resistance:</u>

1. Length of the material:

The Resistance "R" is directly proportional with its length: ***" l "*** $R \propto l$

As length of the wire increases, resistance also increases.

2. Cross Sectional area of the material:

The Resistance "R" is inversely proportional with its Cross Sectional Area: ***" a "***

$$R \propto \frac{1}{a}$$

As Cross Sectional Area of the wire increases, resistance also decreases.

3. Nature of the material:

The Resistance "R" is dependent on the Nature of the material

i.e specific resistivity or specific resistance ρ

- In Conductors, No of free electrons are very high so resistance of the conductor is very less.
- In Insulators and Semi conductors, No of free electrons are less so resistance of the conductor is very high.

4. Temperature of the conductor:

The Resistance "R" is dependent on the Temperature of the conductor.

$$R_2 = R_2 (1 + \alpha \ \Delta t)$$

Where 'α' is the temperature coefficient of resistance

- For Conductors 'α' = **+ve, as** temperature increases, resistance also increases.
- For Insulators and Semi conductors 'α' = **-ve, as** temperature increases, resistance decreases.

So neglecting the effect of temperature we can write

$$\mathbf{R} \propto \mathbf{l} \Rightarrow \mathbf{R} \propto \frac{\mathbf{1}}{\mathbf{a}} \Rightarrow \mathbf{R} = \rho \frac{\mathbf{l}}{\mathbf{a}}$$

Where l = length of the conductor,
a = area of cross section, and
ρ = specific resistance or resistivity of the material this factor will change for each material

Thus, when the current is carried by the resistor,

1. The voltage is dropped across it and is given by V=IR
2. Also the heat dissipation occurs $P = I^2R$.

Therefore, the resistance is an heat dissipation element and never stores the energy

Inductance:


Inductor

Definition: The flux linkages per ampere current.

$$L = \frac{N\varphi}{i} \text{ where } L = \text{inductance in Henry, } N\phi = \text{Flux linkages in Wb - T, } i = \text{current in Ampere}$$

When the inductor is carrying an alternating current with di/dt, then an voltage is induced across it. The magnitude of the voltage induced is directly proportional to the rate of change of current

$$\text{i.e, } V\alpha \frac{di}{dt} \Rightarrow \text{therefore, the voltage is } V = L\frac{di}{dt}$$

The current in the inductor is obtained from the above defined voltage equation

$$\frac{di}{dt} = \frac{V}{L} \Rightarrow di = \frac{V}{L}dt \Rightarrow \int_0^t di = \frac{1}{L}\int_0^t Vdt \Rightarrow i(t) = \frac{1}{L}\int_0^t Vdt + i(0)$$

The power consumed by the inductor is $p = vi = Li\frac{di}{dt}$

The energy stored in the inductor is $W = \int_0^t pdt = \int_0^t Li\frac{di}{dt}dt = \int_0^t Lidi = \frac{1}{2}Li^2$

Salient points:

1. Inductor behaves as a short circuit element for dc supply

2. Inductor doesn't allows the sudden changes in the current

3. Inductor stores the energy even if the voltage across it is zero and stores the energy in the form of magnetic field

4. Inductor is an energy storing element and never dissipates the energy, whereas the practical inductor dissipates the energy due to its internal resistance.

<u>Capacitance:</u>

Definition: The Charge per unit Voltage.

$$\mathrm{C} = \frac{\mathrm{Q}}{\mathrm{V}} \text{ where C = capacitance in Farad, } Q = \text{Charge in Coloumb, V = voltage in Volt}$$

When the capacitor is applied an alternating voltage with dv/dt, then the current in it is given by

$$\mathrm{i} = \frac{\mathrm{dq}}{\mathrm{dt}} \Rightarrow i = \mathrm{C}\frac{\mathrm{dv}}{\mathrm{dt}}$$

The voltage across the capacitor is obtained from the above defined current equation

$$\frac{dv}{dt} = \frac{i}{C} \Rightarrow dv = \frac{i}{C}dt \Rightarrow \int_0^t dv = \frac{1}{C}\int_0^t idt \Rightarrow v(t) = \frac{1}{C}\int_0^t idt + v(0)$$

The power consumed by the capacitor is $p = vi = Cv\frac{dv}{dt}$

The energy stored in the capacitor is $W = \int_0^t pdt = \int_0^t Cv\frac{dv}{dt}dt = \int_0^t Cvdv = \frac{1}{2}Cv^2$

Salient points:

1. Capacitor behaves as a open circuit element for dc supply

2. Capacitor doesn't allows the sudden changes in the voltage

3. Capacitor stores the energy even if the current in it is zero and stores the energy in the form of electrostatic field

4. Capacitor is an energy storing element and never dissipates the energy, whereas the practical capacitor dissipates the energy due to its internal resistance.

Solved Problem: A coil consists of 2000 turns of copper wire having a cross-sectional area of 0.8 mm^2. The mean length per turn is 80 cm and the resistivity of copper is 0.02 μΩ-m. Find the resistance of the coil

Solution: Length of the coil, *l =0.8 x 2000 =1600 m*
Area of Cross section *a =0.8 mm²=0.8 x 10⁻⁶m²*
Resistivity ρ = 0.02 μΩ-m

$$R = \rho \frac{l}{a} = 0.02 \times 10^{-6} \times \frac{1600}{0.8} = 40 \ \Omega$$

Solved Problem: A rectangular carbon block has dimensions 1.0cm x1.0cm x 50 cm. Resistivity of carbon at 20°C is 3.5 X 10^{-5} Ω -m.

(i) What is the resistance measured between the two square ends?
(ii) What is the resistance measured between two opposing rectangular faces

Solution:

(i) Length of the block, ***l =0.5 m*** Area of Cross section ***a = 1x1 = 1 cm² =10⁻⁴m²***
Resistivity ρ = 3.5 x 10^{-5} Ω-m

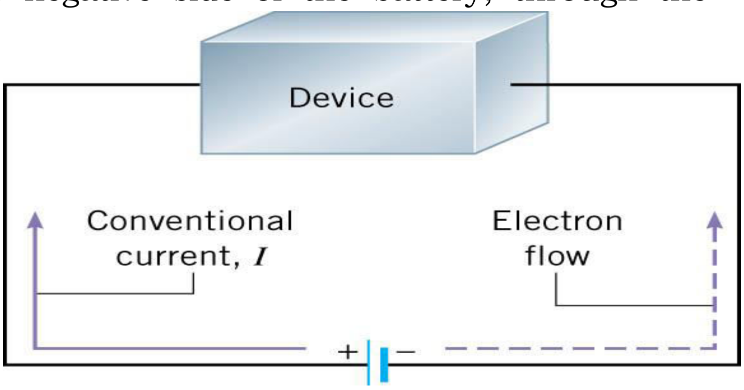
$$R = \rho \frac{l}{a} = 3.5 \times 10^{-5} \times \frac{0.5}{10^{-4}} = 0.175 \ \Omega$$

(ii) Length of the block, ***l =1 cm*** Area of Cross section ***a = 1x50 = 50cm² =5x10⁻³m²***
Resistivity ρ = 3.5 x 10^{-5} Ω-m

$$R = \rho \frac{l}{a} = 3.5 \times 10^{-5} \times \frac{10^{-2}}{5 \times 10^{-3}} = 7 \times 10^{-5} \ \Omega$$

Current Flow

The electrons flow out of the negative side of the battery, through the circuit, and back to the positive side of the battery.



Conventional Current assumes that current flows out of the positive side of the battery, through the circuit, and back to the negative side of the battery.

Conventional current is the hypothetical flow of positive charges that would have the same effect in the circuit as the movement of negative charges that actually does occur.

Solved Problem: The flashlight uses two 1.5 V batteries to provide a current of 0.4 A in the filament. Determine the resistance of the glowing filament.

Solution: $$R = \frac{V}{I} = \frac{3.0\text{ V}}{0.4\text{ A}} = 7.5\,\Omega$$

Solved Problem: An electric iron draws 2 A at 120 V. Find its resistance.

Solution: From Ohm's law, Resistance $R = \frac{V}{I} = \frac{120\text{ V}}{2\text{A}} = 60\,\Omega$

Solved Problem: The essential component of a toaster is an electrical element (a resistor) that converts electrical energy to heat energy. How much current is drawn by a toaster with resistance 15 Ohms at 110 V?

Solution: From Ohm's law, Current $I = \frac{V}{R} = \frac{110\text{ V}}{15\,\Omega} = 7.333\text{ A}$

Solved Problem: Determine the p.d. which must be applied to a 2k resistor in order that a current of 10mA may flow.

Solution:

$$R = 2\ k\Omega = 2\times10^{3}\ \Omega$$

$$I = 10\ mA = 10\times10^{-3}\ A = 0.01\,A$$

From Ohm's law, $V = R\,I = (0.01)(2000) = 20V$

Solved Problem: A 100V battery is connected across a resistor and causes a current of 5mA to flow. Determine the resistance of the resistor. If the voltage is now reduced to 25V, what will be the new value of the current flowing?

Solution:

Resistance $R = \frac{V}{I} = \frac{100}{5\times10^{-3}} = 20\,k\Omega$

Current when voltage is reduced to 25V, $I = \frac{V}{R} = \frac{25}{20\times10^{3}} = 1.25\,mA$

Other useful formulas :

$$V = R\,I \quad \& \quad P = V\,I$$

$$Power\ \ P = (R\,I)\,I = I^2 R$$

$$I = \frac{V}{R} \quad \& \quad P = V\,I$$

$$Power \quad P = V\left(\frac{V}{R}\right) = \frac{V^2}{R}$$

Solved Problem: Calculate the power dissipated when a current of 4mA flows through a resistance of 5 k

Solution: Power $P = I^2R = (4\times10{-}3)^2(5\times10^3)$

$= 16\times10^{-6} \times 5\times10^3 = 80\times10^{-3}$

$= 0.08$W or 80mW

Alternatively, since $I = 4\times10^{-3}$ and $R = 5\times10^3$

then from Ohm's law, voltage $V = I R = 4\times10^{-3} \times 5\times10^{-3} = 20V$

Hence, power $P = V \times I = 20\times4\times10^{-3} = 80mW$

Solved Problem: An electric heater consumes 3.6 MJ when connected to a 250V supply for 40 minutes. Find the power rating of the heater and the current taken from the supply.

Solution

$$\text{Power} = \frac{\text{energy}}{\text{time}} = \frac{3.6\times10^6}{40\times60}\frac{\text{J}}{\text{s}}\ (\text{or W}) = 1500\,\text{W}$$

i.e. Power rating of heater $=$ **1.5 kW**

$$\text{Power } P = VI, \text{ thus } I = \frac{P}{V} = \frac{1500}{250} = 6\,\text{A}$$

Hence the current taken from the supply is **6 A**

Active Elements:

The most important active elements are voltage or current sources that generally deliver power to the circuit.

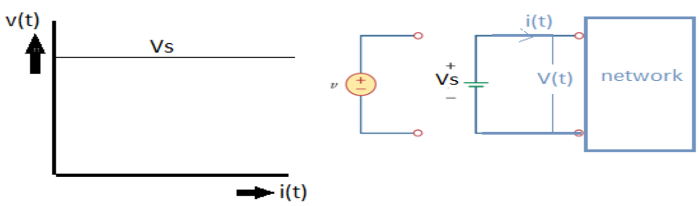
Active elements (Sources) are classified as

- Independent Sources
- Dependent Sources

Independent source: is an active element that provides a specified voltage or current that is completely independent of other circuit elements

Ideal Voltage source:

The ideal voltage source delivers Vs as v(t) for all the values of i(t) Therefore, $v(t) = V_s$ for all values of i(t) and its V-I characteristics are shown in below fig.



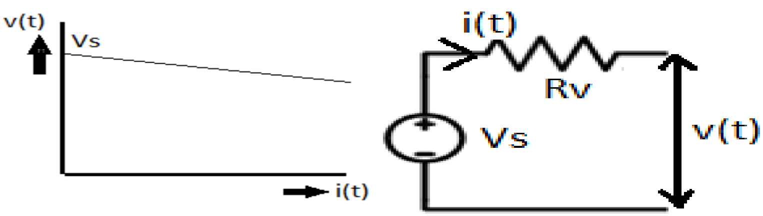
Ideal Voltage Source and V-I Characteristics

Practical Voltage source:

The Practical voltage source delivers v(t) and i(t) from the generated V_s against its internal resistance R_v

$v(t) = V_s$ for $i(t) = 0$

$v(t) = V_s - i(t)R_v$ for $i(t) > 0$

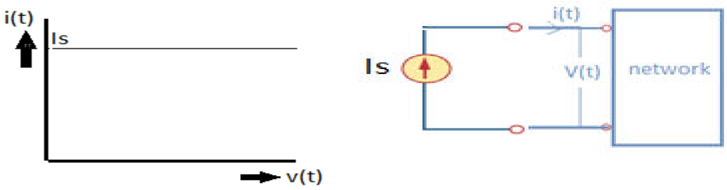


Practical Voltage Source and its V-I Characteristics

Ideal Current source:

The ideal current source delivers Is as i(t) for all the values of v(t)

Therefore, $i(t) = I_s$ for all values of v(t) and its V-I characteristics are shown in the adjacent figure



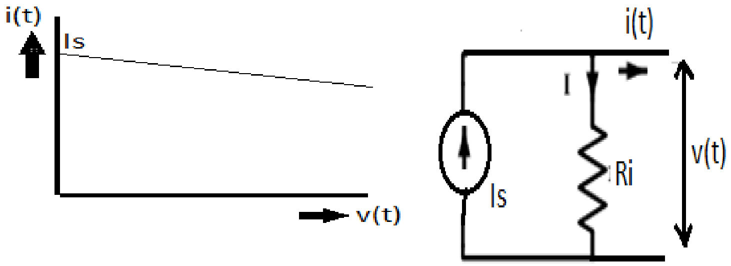
Ideal Current Source and V-I Characteristics

Practical Current source:

The Practical current source delivers i(t) and v(t) from the generated I_s against its internal resistance R_i

$i(t) = I_s$ for $v(t) = 0$ and

$$i(t) = I_s - \frac{v(t)}{R_i} \text{ for } v(t) > 0$$

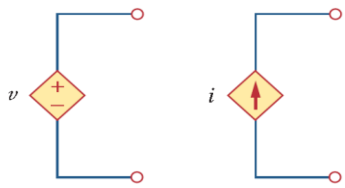


Practical Current Source and V-I Characteristics

- ***The internal resistance of an ideal voltage source is zero***
- ***The internal resistance of an ideal current source is infinity***

Dependent (controlled) source : is an active element that provides a specified voltage or current controlled by another voltage or current.

Dependent sources are usually designated by diamond-shaped symbols

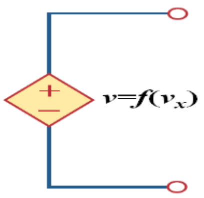


Dependent voltage Source ***Dependent Current source***

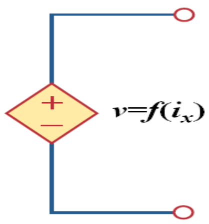
The control of the dependent source is achieved by a voltage or current of some other element in the circuit

There are four possible types:

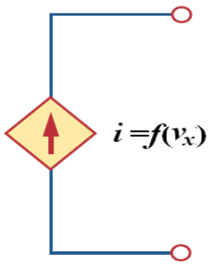
1. A voltage-controlled voltage source (VCVS)
2. A current-controlled voltage source (CCVS)
3. A voltage-controlled current source (VCCS)
4. A current-controlled current source (CCCS)

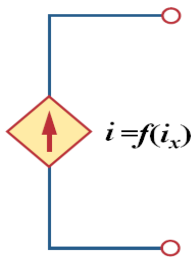


Voltage-controlled voltage source



current-controlled voltage source





Voltage-controlled current source current-controlled current source

Kirchhoff Laws:

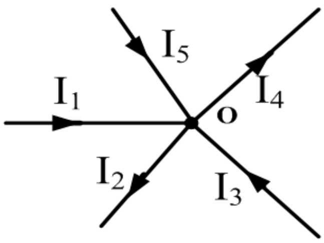
Gustav Kirchhoff (1824-1887), an eminent Germen physicist did a considerable amount of work on the principle of governing behavior of electric circuits. He gave his finding in a set of two laws which together called Kirchhoff's laws. These two laws are

1. Kirchhoff's Current Law (KCL) 2. Kirchhoff's Voltage Law (KVL)

<u>Kirchhoff's Current Law (KCL)</u>

Kirchhoff's Current Law states that the algebraic sum of the current meeting at a node (junction) is equal to zero

i.e., $\sum I = 0$



This law is illustrated below.

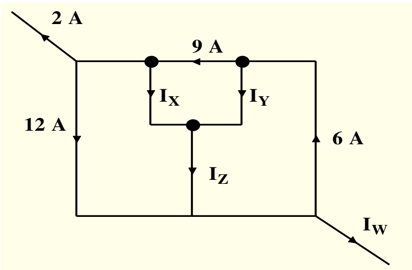
Five branches are connected to node O which carries currents I_1, I_2, I_3, I_4 and I_5 as shown in figure (1). Consider current entering (I_1, I_3 & I_5) to the node as positive and current leaving (I_2 & I_4) from the node as negative.

From above diagram $-I_1 - I_2 + I_3 + I_4 + I_5 = 0$ or $I_1 + I_2 = I_3 + I_4 + I_5$

i. e., Incoming currents = Outgoing currents, Hence Kirchhoff's first law can be stated as:

In an electric circuit the sum of currents flowing towards any junction is equal to the sum of the currents flowing away from the junction

Solved Problem: Find the currents I_W, I_X, I_Y, I_Z



Solution: $I_W = -2$ A $I_X = -5$ A

$I_Y = -3$ A $I_Z = -8$ A

Kirchhoff's Voltage Law (KVL)

Kirchhoff's voltage law tells us how to handle voltages in an electric circuit.

Kirchhoff's voltage law states that the algebraic sum of the voltages around any closed path is equal to zero

Or

The algebraic sum of the voltage drops is zero.

Or

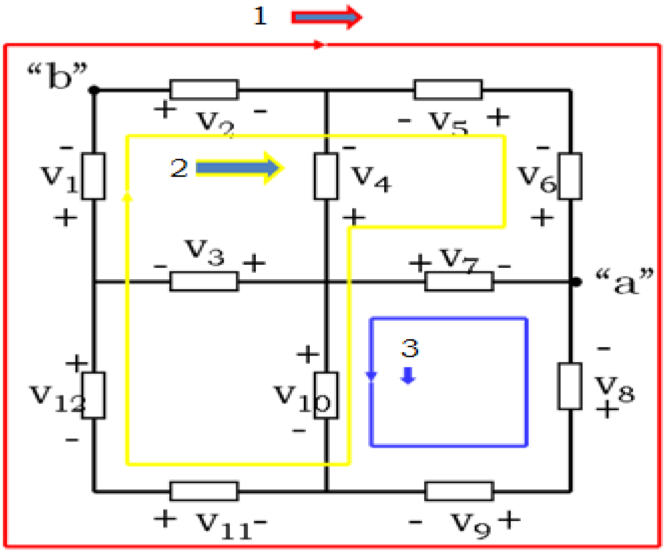
The algebraic sum of the voltage rises is zero.

Or

The algebraic sum of the voltage drops equals the algebraic sum of the voltage rises.

Solved Problem: In the following network there are a number of closed paths. Apply KVL.

Solution:



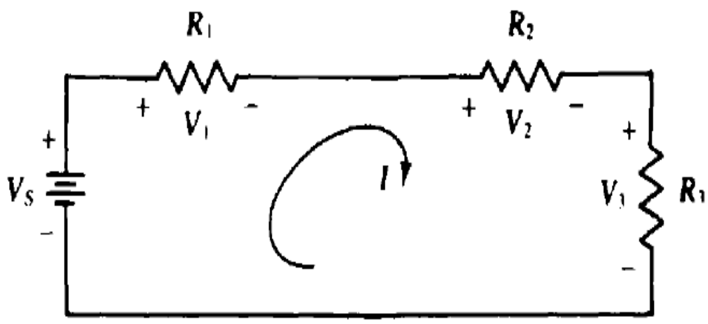
Path,1 : starting at "b" $-v_2 + v_5 + v_6 + v_8 - v_9 + v_{11} + v_{12} - v_1 = 0$

Path,2 : starting at "b" $-v_2 + v_5 + v_6 + v_7 - v_{10} + v_{11} + v_{12} - v_1 = 0$

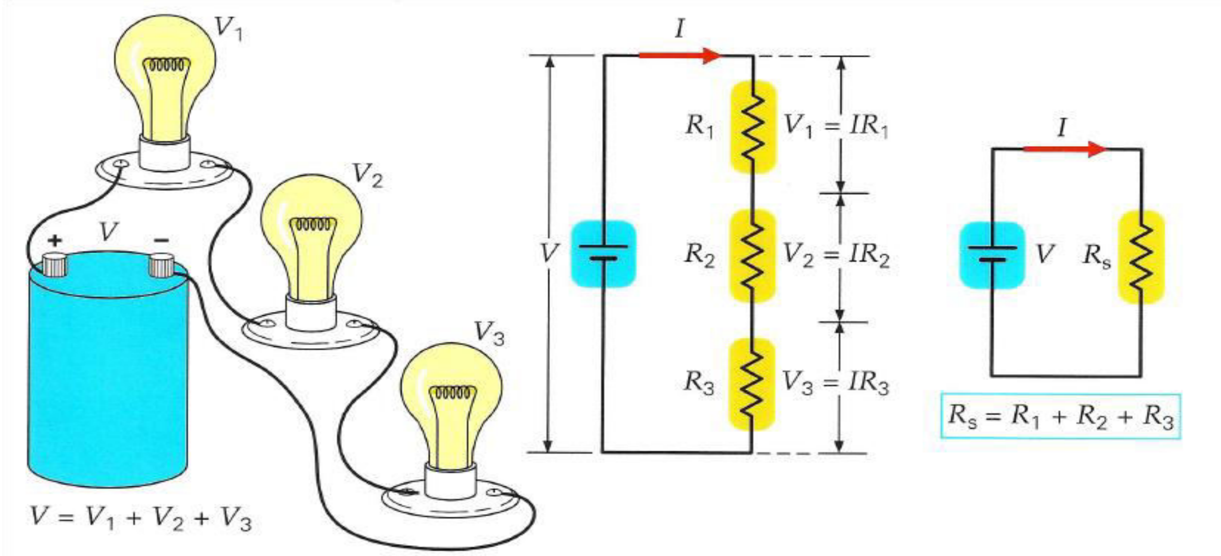
Path 3 : starting at "a" $v_7 - v_{10} + v_9 - v_8 = 0$

Series and Parallel Circuits:

In a series circuit



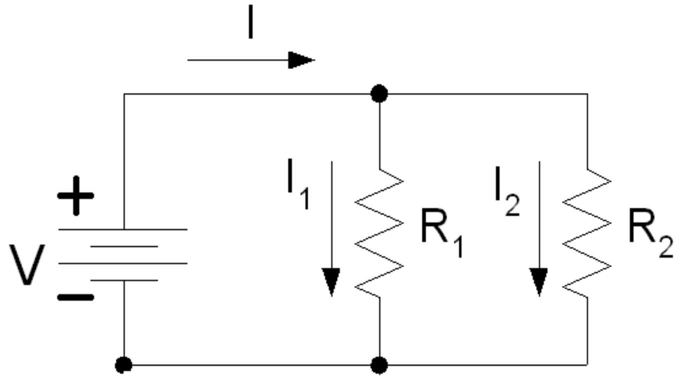
- ✓ The current I is the same in all parts of the circuit
- ✓ The sum of the voltages V_1, V_2 and V_3 is equal to the total applied voltage, $V_s = V_1 + V_2 + V_3$



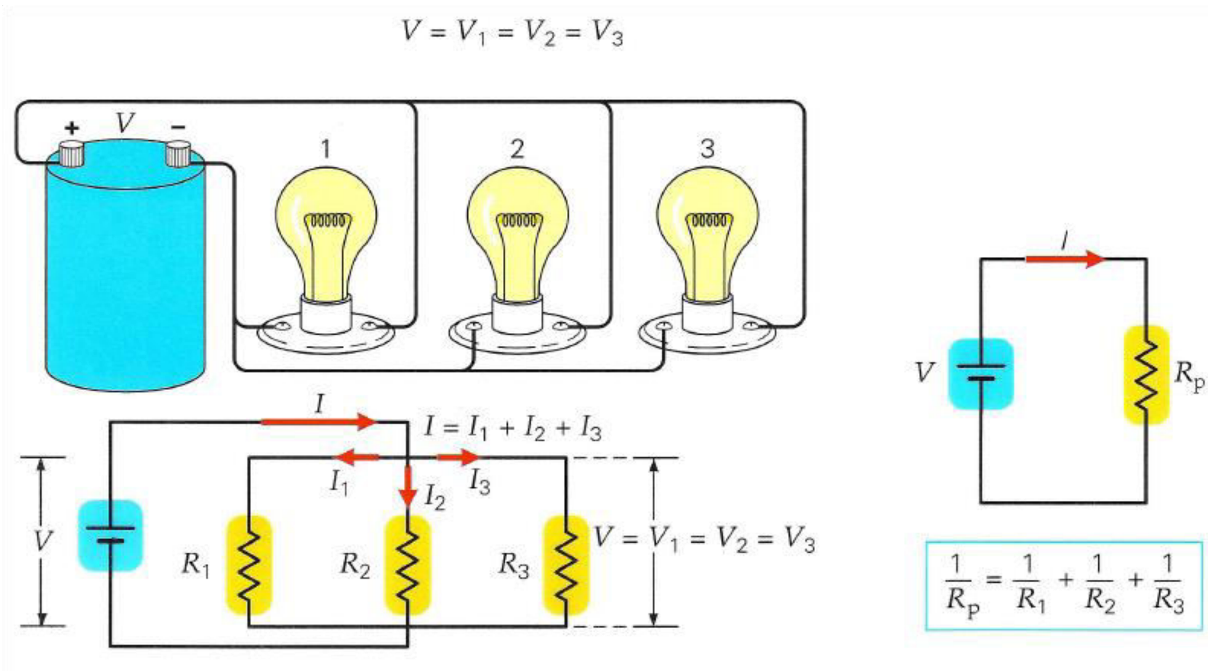
This R_s , is the total resistance of the series connected resistors. Also called as equivalent resistance, with symbol R_{eq}

For N Series Resistors $$R_{eq} = R_s = R_1 + R_2 + \cdots\cdots + R_N$$

In a parallel circuit:



- ✓ The sum of the currents I_1 and I_2 is equal to the total circuit current, I, i.e. $I = I_1 + I_2$ and
- ✓ The source Voltage, V volts, is the same across each of the resistors.



The equivalent resistance for any number of resistors in parallel (i.e. they have the same voltage across each resistor)

For N Parallel Resistors

$$R_{eq} = R_p = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} \ldots\ldots + \frac{1}{R_N}}$$

For Two Parallel Resistors

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

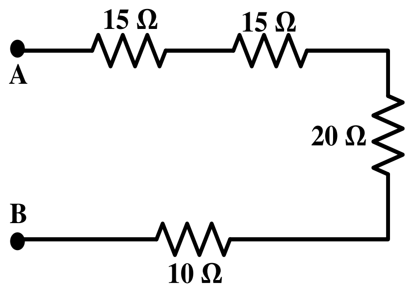
Solved Problem: Find out the equivalent resistance between the nodes A &B in the given diagrams.

Solution:

In a series circuit equivalent resistance is equal to sum of the individual resistances.

$R_{eq} = R_1 + R_2 + R_3 + R_4$

$R_{eq} = 15+15+20+10 = 60\ \Omega$



Equivalent resistance between A& B $= R_{AB} = 60\ \Omega$

Solved Problem: Find out the equivalent resistance between the nodes A &B in the given diagrams.

Solution:

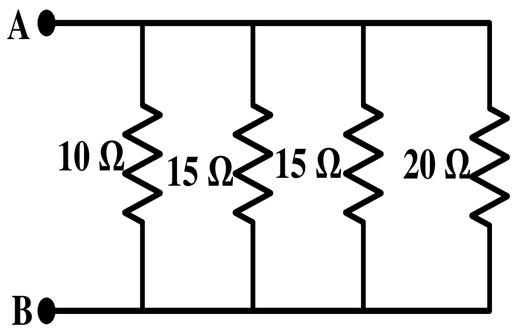
In a series circuit equivalent resistance is equal to sum of the individual resistances.

$R_{eq} = R_1 + R_2 + R_3 + R_4$

$R_{eq} = 15+15+20+10 = 60\ \Omega$

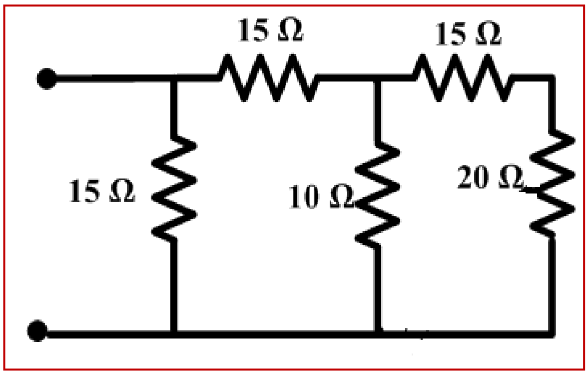
$$\frac{1}{R_{eq}} = \frac{1}{10} + \frac{1}{15} + \frac{1}{15} + \frac{1}{20}$$

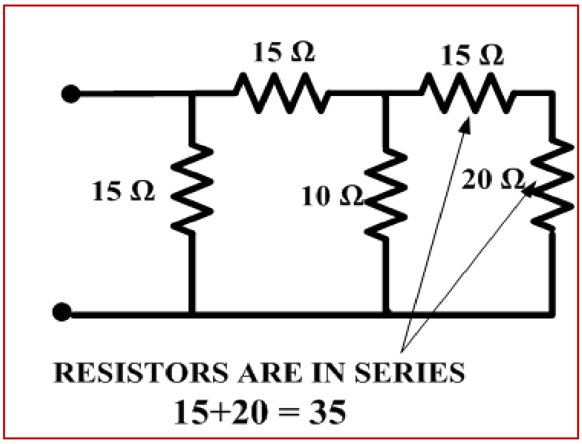
$R_{eq} = 3.52\ \Omega$

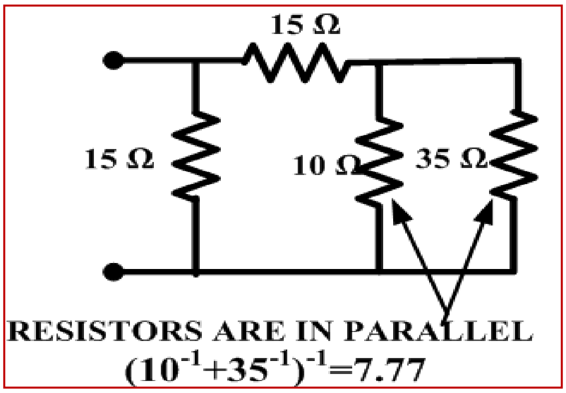


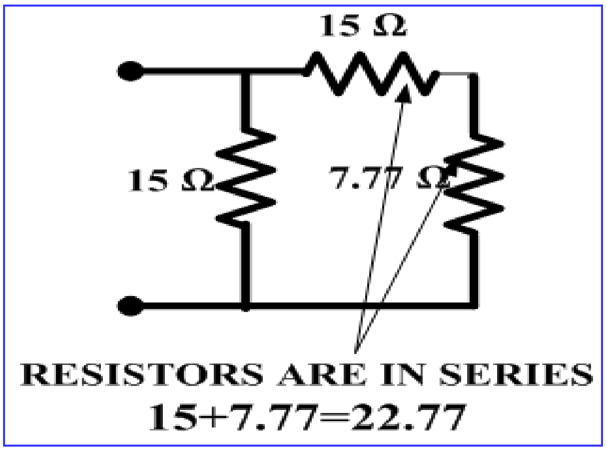
Solved Problem: Find out the equivalent resistance between the nodes

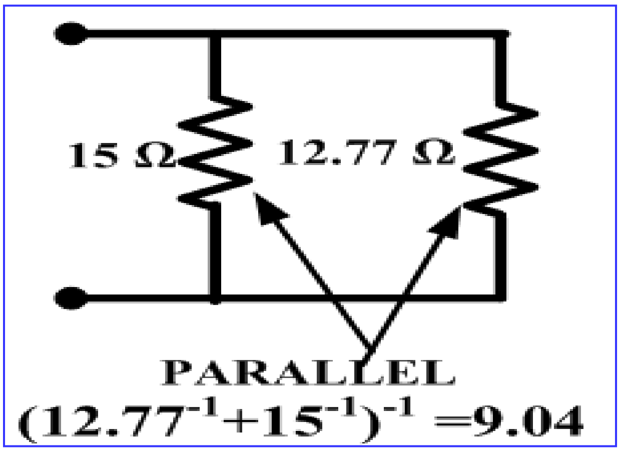
Solution:







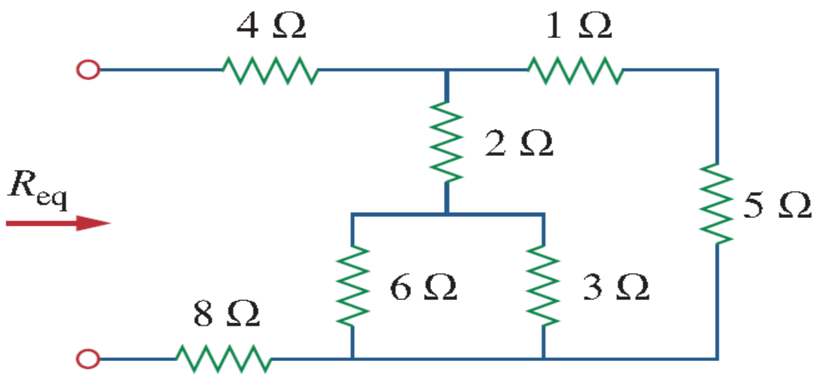


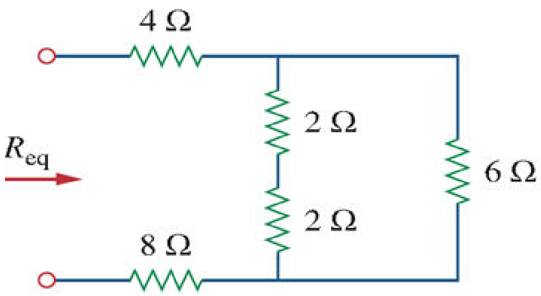


Equivalent resistance between A& B $=R_{AB}=$ 9.044 Ω

Solved Problem: Find out the equivalent resistance between the nodes

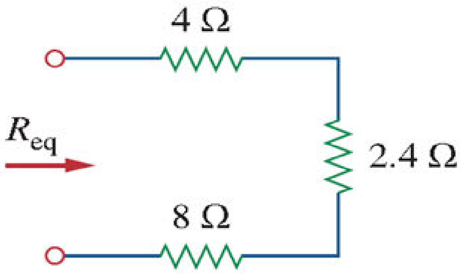
Solution:





$$6\,\Omega \parallel 3\Omega = \frac{6 \times 3}{6 + 3} = 2\,\Omega$$

$$1\,\Omega + 5\,\Omega = 6\,\Omega$$



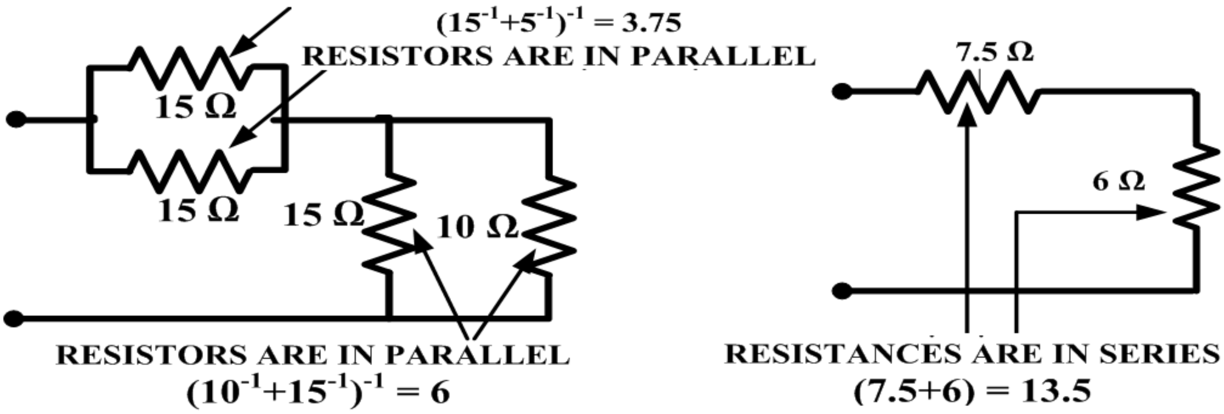
$$2\,\Omega + 2\,\Omega = 4\,\Omega$$

$$4\,\Omega \parallel 6\,\Omega = \frac{4 \times 6}{4 + 6} = 2.4\,\Omega$$

$$R_{eq} = 4\,\Omega + 2.4\,\Omega + 8\,\Omega = 14.4\,\Omega$$

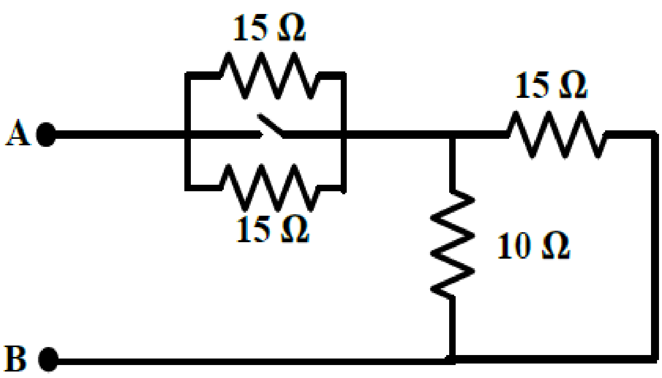
Solved Problem: Find out the equivalent resistance between the nodes

Solution:



Equivalent resistance between A& B =R_{AB}= 13.5 Ω

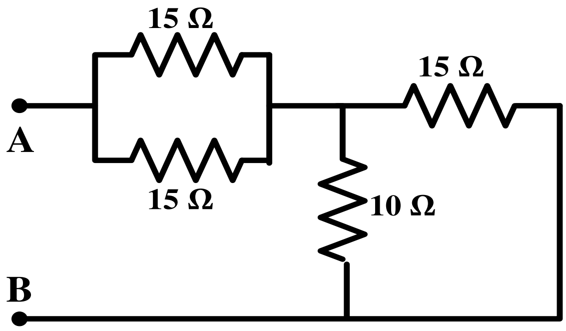
Solved Problem: Find out the equivalent resistance between the nodes A &B in the given diagrams **before and after closing switch**.



Solution:

Before closing switch.

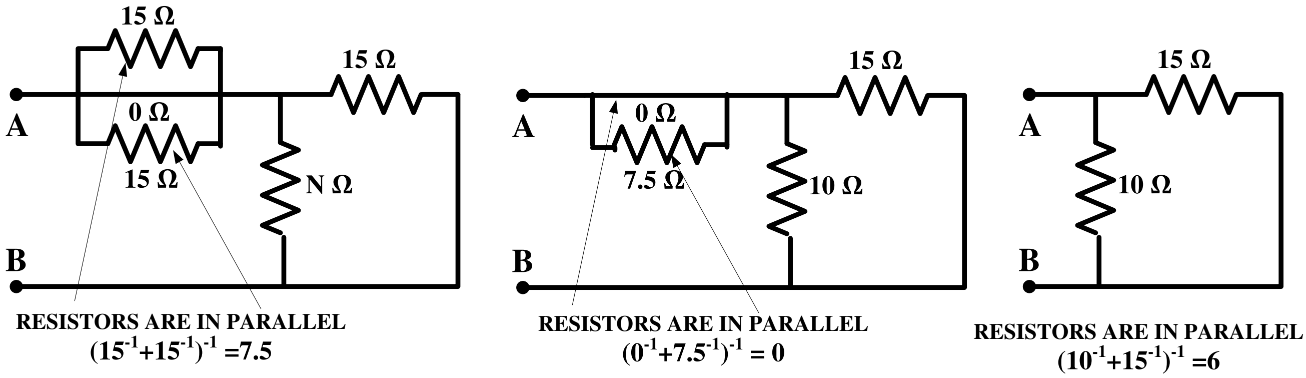
When switch is opened current flowing through switch is zero.



Equivalent resistance between A& B $=R_{AB}=13.5\ \Omega$

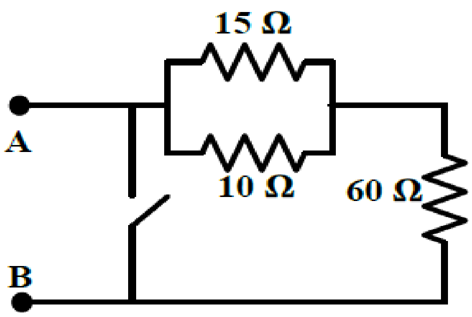
After closing switch.

When switch is closed ideal switch offers zero resistance so there is no effect of parallel resistors



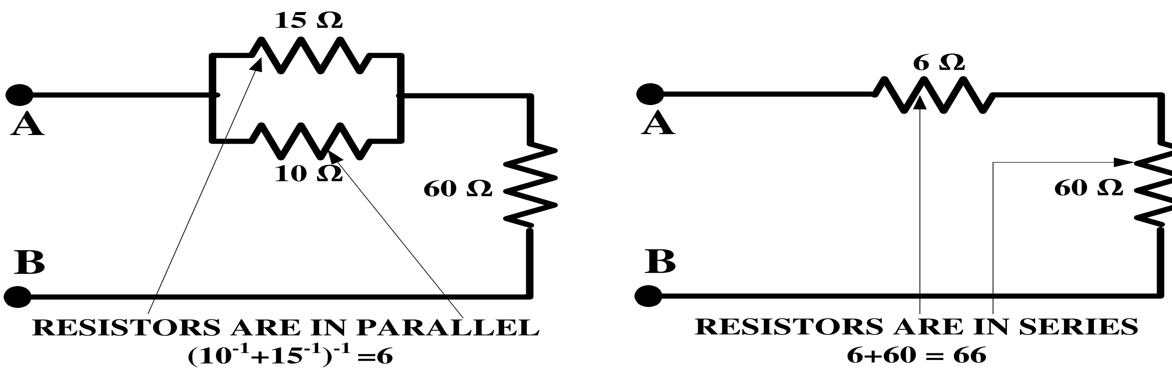
Equivalent resistance between A& B $=R_{AB}=6\ \Omega$

Solved Problem: Find out the equivalent resistance between the nodes A &B in the given diagrams **before and after closing switch**.



Solution: Before closing switch.

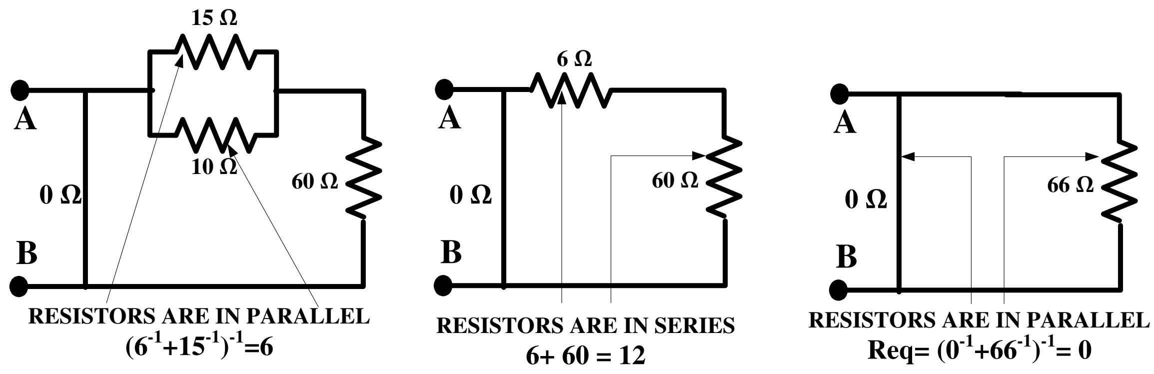
When switch is opened current flowing through switch is zero.



Equivalent resistance between A& B $=R_{AB}=66\ \Omega$

After closing switch.

When switch is closed ideal switch offers zero resistance so there is no effect of parallel resistors



Equivalent resistance between A& B =R_{AB}= 0 Ω

<u>The voltage division Rule:</u>

In general, for any number of series resistors with a total resistance of R_s and with a voltageof V across the series combination, the voltage Vx across one of the resistors Rx , is $V_X = \frac{R_X}{R_s} V$

If N resistors in series , then equivalent resistance is

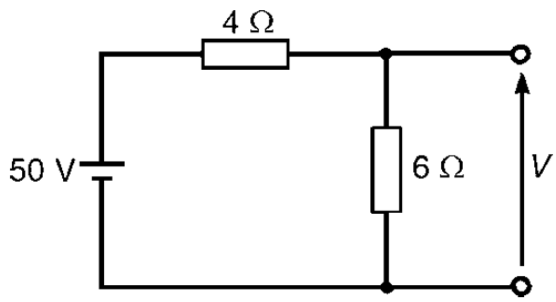
$$R_s = R_1 + R_2 + \cdots + R_N$$

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

Voltage across X^{th} branch is $V_X = \frac{R_X}{R_s} V$

Solved Problem : Find voltage across 6Ω

Solution:



$$V_X = \frac{R_X}{R_T} V_s$$

$$V_{6\Omega} = \frac{6}{6+4} 50 = 30V$$

Current Division Rule :

In general, for any number of parallel resistors with a total resistance of Rp and with a voltage of V across the parallel combination, the Current Ix in the xth resistors Rj , is: $I_X = \frac{R_p}{R_X} I$

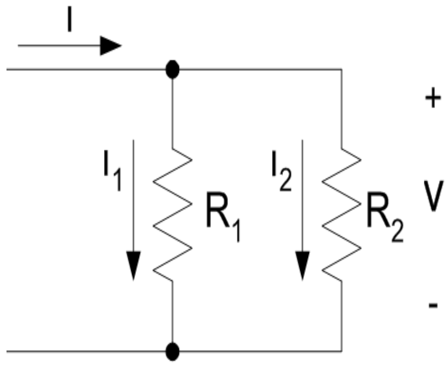
If N resistors in parallel equivalent resistance is

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} \cdots + \frac{1}{R_N}$$

$$V = R_p I$$

Current in jth branch is $I_X = \frac{V}{R_X} = \frac{R_p}{R_X} I$

In case of two resisters in parallel



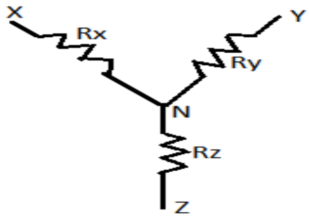
$$V = R_p I = \frac{R_1 R_2}{R_1 + R_2} I$$

$$I_1 = \frac{V}{R_1} = \frac{R_2}{R_1 + R_2} I$$

$$I_2 = \frac{V}{R_2} = \frac{R_1}{R_1 + R_2} I$$

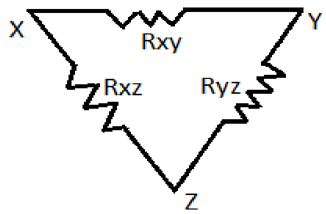
<u>Star or Wie Connection(Y):</u>

The star connection is formed with three resistors and one terminal of the three resistors is connected to the common point called star point and the remaining three terminals (open nodes) is shown in the figure.



<u>Delta Connection (Δ):</u>

The Delta connection is formed with three resistors in a closed loop forming the three nodes



<u>Star – Delta Transformation:</u>

The star to delta and delta to star transformation is possible based on the assumption that the equivalent resistance between any two terminals of the connections before and after the transformation must be same.

i.e, $R_{X\&Y \text{ in satr (Y)}} = R_{X\&Y \text{ in delta}(\Delta)}$

$R_{Y\&Z \text{ in satr (Y)}} = R_{Y\&Z \text{ in delta}(\Delta)}$

$R_{X\&Z \text{ in satr (Y)}} = R_{X\&Z \text{ in delta}(\Delta)}$

Therefore in Star connection,

$R_{X\&Y \text{ in satr (Y)}} = R_x + R_y$ ... (1)

$R_{Y\&Z \text{ in satr (Y)}} = R_y + R_z$ ... (2)

$R_{X\&Z \text{ in satr (Y)}} = R_x + R_z$ ... (3)

Similarly in Delta connection,

$$R_{X\&Y \text{ in delta } (\Delta)} = \frac{R_{xy}(R_{yz} + R_{xz})}{R_{xy} + R_{yz} + R_{xz}} \quad \text{... (4)}$$

$$R_{Y\&Z \text{ in delta } (\Delta)} = \frac{R_{yz}(R_{xy} + R_{xz})}{R_{xy} + R_{yz} + R_{xz}} \quad \text{... (5)}$$

$$R_{X\&Z \text{ in delta } (\Delta)} = \frac{R_{xz}(R_{yz} + R_{xy})}{R_{xy} + R_{yz} + R_{xz}} \quad \text{... (6)}$$

Based on the assumption equate equations (1), (4); (2),(5) and (3),(6)

$$R_x + R_y = \frac{R_{xy}(R_{yz} + R_{xz})}{R_{xy} + R_{yz} + R_{xz}} \quad \text{... (7)}$$

$$R_y + R_z = \frac{R_{yz}(R_{xy} + R_{xz})}{R_{xy} + R_{yz} + R_{xz}} \quad \text{...(8)}$$

$$R_x + R_z = \frac{R_{xz}(R_{yz} + R_{xy})}{R_{xy} + R_{yz} + R_{xz}} \quad \text{... (9)}$$

Delta to star transformation:

Simplify the above three equations, the formulae for star connected resistances(R_x, R_y and R_z) are obtained in terms of the given delta connected resistances (R_{xy}, R_{yz} and R_{xz})

Subtract Equation (7) and equation (8) = equation (10)

$$R_x - R_z = \frac{R_{xy}R_{xz} - R_{yz}R_{xz}}{R_{xy} + R_{yz} + R_{xz}} \quad \text{...(10)}$$

On adding equations (10) and equation (9) = equation (11)

$$2R_x = \frac{R_{xy}R_{xz} - R_{yz}R_{xz} + R_{xy}R_{xz} + R_{yz}R_{xz}}{R_{xy} + R_{yz} + R_{xz}} = \frac{2R_{xy}R_{xz}}{R_{xy} + R_{yz} + R_{xz}}$$

Therefore

$$R_x = \frac{R_{xy}R_{xz}}{R_{xy} + R_{yz} + R_{xz}} \text{ ...(11)} \qquad R_y = \frac{R_{xy}R_{yz}}{R_{xy} + R_{yz} + R_{xz}} \text{ ...(12)} \qquad R_z = \frac{R_{xz}R_{yz}}{R_{xy} + R_{yz} + R_{xz}} \text{ ... (13)}$$

Thus equations 11, 12 and 13 are the formulas for converting the given delta connected resistors to star connected values.

Star to Delta transformation:

Multiply equations 11,12 and equations 12,13 and also equations 11,13.

$$R_xR_y + R_yR_z + R_xR_z = \frac{R_{xy}^2R_{yz}R_{xz} + R_{xy}R_{yz}^2R_{xz} + R_{xy}R_{yz}R_{xz}^2}{\left(R_{xy} + R_{yz} + R_{xz}\right)^2} = \frac{R_{xy}R_{yz}R_{xz}(R_{xy} + R_{yz} + R_{xz})}{\left(R_{xy} + R_{yz} + R_{xz}\right)^2}$$

$$= \frac{R_{xy}R_{yz}R_{xz}}{\left(R_{xy} + R_{yz} + R_{xz}\right)}$$

Also divide the above equation with R_z on both sides from eq.13

$$\frac{R_xR_y + R_yR_z + R_xR_z}{R_z} = \frac{R_{xy}R_{yz}R_{xz}}{\left(R_{xy} + R_{yz} + R_{xz}\right)} * \frac{\left(R_{xy} + R_{yz} + R_{xz}\right)}{R_{yz}R_{xz}} = R_{xy}$$

$R_{xy} = R_x + R_y + \frac{R_xR_y}{R_z}$ ....(14) Similarly $R_{yz} = R_y + R_z + \frac{R_yR_z}{R_x}$ ......(15) and

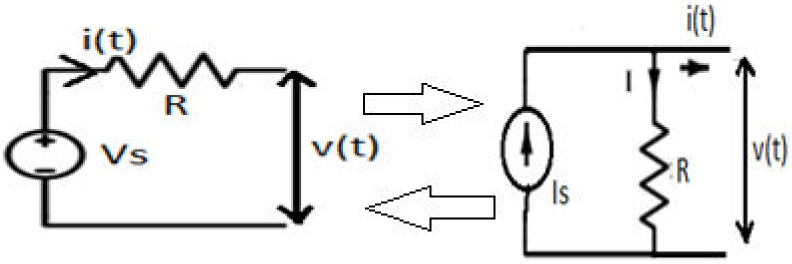
$R_{xz} = R_x + R_z + \frac{R_xR_z}{R_y}$ ....(16) .

Source transformation:

Using this transformation the voltage source can be transformed to current source and the current source to voltage source

This technique is applicable only for the practical sources

Let the voltage source shown in the below figure is to be converted to current source



KVL to the loop of voltage source is

$$v(t) = V_S - i(t)R$$

$$V_S = v(t) + i(t)\ R \quad ......(1)$$

$$\text{Similarly}\quad i(t) = I_S - \frac{v(t)}{R}$$

$$I_S = i(t) + \frac{v(t)}{R} \quad ......(2)$$

Multiply the eq.(2) on both sides with R, then

$$I_SR = i(t)\ R + \frac{v(t)}{R}R \Rightarrow I_SR = v(t) + i(t)\ R \quad .....(3)$$

Comparing the equations (1) and (3), the RHS sides are equal therefore, LHS sides should be same

i.e, $V_s = I_s R$

Thus, the rules for transformation are

1. Place the internal resistance in series for Voltage source, and in parallel for current source with same resistance value.
2. Voltage magnitude after transformation from current source is $V_s = I_s R$ volt and Current magnitude after transformation from voltage source is $I_s = V_s/R$

Summary: Important Formulas in unit – 1

Basic terms

$$I = \frac{Q}{t} \ or \ i = \frac{dq}{dt}$$ $$v_{ab} = \frac{dw}{dq} \ or \ V = \frac{W}{Q}$$ $$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi$$ $$W = Pt$$

V-I Relations in R,L and C

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

$$V = L\frac{di}{dt}$$ $$i(t) = \frac{1}{L}\int_0^t V dt + i(0)$$ $$p = Li\frac{di}{dt}$$ $$W = \frac{1}{2}Li^2$$

$$i = C\frac{dv}{dt}$$ $$v(t) = \frac{1}{C}\int_0^t i dt + v(0)$$ $$p = Cv\frac{dv}{dt}$$ $$W = \frac{1}{2}Cv^2$$

Series and Parallel

$$R_{eq} = R_s = R_1 + R_2 + \cdots\cdots + R_N$$

$$R_{eq} = R_p = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} \cdots\cdots\cdots + \frac{1}{R_N}}$$

Voltage and current division rules

$$V_X = \frac{R_X}{R_s} V$$

$$I_1 = \frac{V}{R_1} = \frac{R_2}{R_1 + R_2} I$$

$$I_2 = \frac{V}{R_2} = \frac{R_1}{R_1 + R_2} I$$

Star to delta And Delta to Star Transformation

Delta to star

$$R_x = \frac{R_{xy} R_{xz}}{R_{xy} + R_{yz} + R_{xz}}$$

$$R_y = \frac{R_{xy} R_{yz}}{R_{xy} + R_{yz} + R_{xz}}$$

$$R_z = \frac{R_{xz} R_{yz}}{R_{xy} + R_{yz} + R_{xz}}$$

Star to delta

$$R_{xy} = R_x + R_y + \frac{R_x R_y}{R_z}$$

$$R_{yz} = R_y + R_z + \frac{R_y R_z}{R_x}$$

$$R_{xz} = R_x + R_z + \frac{R_x R_z}{R_y}$$

Unit – 2

PRINCIPLE OF OPERATION OF DC GENERATOR

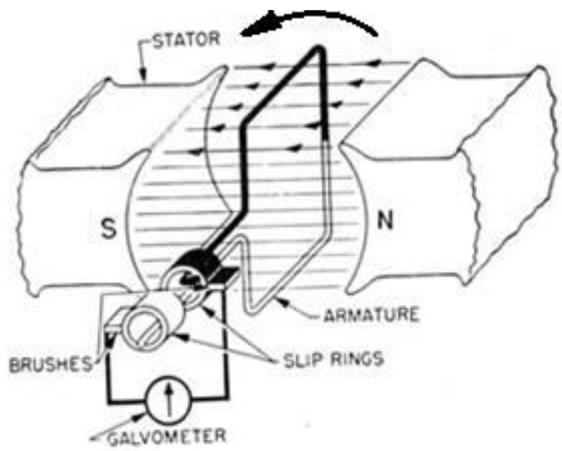
1. DC Generator is an electro mechanical energy conversion device used to ***convert mechanical energy to electrical energy.***
2. It works as per ***Faradays laws of electromagnetic induction*** which states that

> I Law: *"Whenever the conductor cuts the magnetic flux a dynamical emf is induced in the conductor"*
> II Law: *"The magnitude of the emf induced is directly proportional to the rate of change of flux linkages"*

3. ***Fleming's right hand rule*** is used to obtain the direction of the current in the coil of the DC Generator.

Simple loop dc generator:

The simple loop dc generator is assumed to have the following parts as shown in Fig (a)

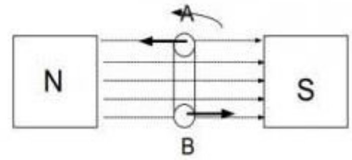


- Two permanent magnets (North pole and South pole) as stator
- A single turn rectangular coil named as Armature (placed on the shaft) as rotor
- Two Slip rings rotating along with the armature coil
- Two static carbon brushes mounted on the slip rings
- External load or galvanometer

The rectangular shaped armature coil is assumed to be rotated in anticlockwise with an angular velocity of ω rad/sec.

The working operation of the simple loop generator is explained over one complete rotation of the coil for 360^0 and is shown in the below figure at different positions of the coil.

At 0 degrees Position (1):

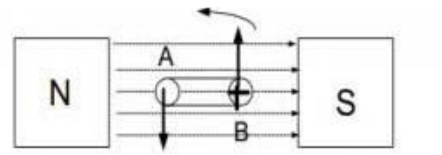


Position 1: (θ =0°)minimum $\frac{d\emptyset}{dt}$

1. This position is also known as the "Neutral Plane";
2. In this position the loop is parallel to the magnetic lines of flux
3. In this position there is maximum flux passing through the coil.
4. No EMF is induced in the coil because of no "Change in flux through the loop".

At 90 degrees Position (2):

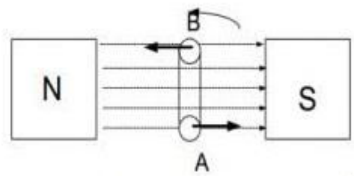
1. After the loop has been rotated 90 degrees clockwise through the magnetic field the flux linkage through it now becomes zero.
2. But the rate of change of flux through it was maximum,
3. This results in an induced EMF which climbs from zero to its peak value.



Position 2: (θ =90°) maximum $\frac{d\emptyset}{dt}$

At 180 degrees Position (3):

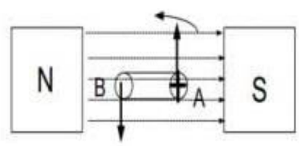
1. Once again the coil is rotated 90 degrees clockwise resulting in the completion of a 180 degrees cycle.
2. Here the loop is perpendicular to the magnetic lines of force
3. This means that there is maximum flux density through it resulting the EMF to falls back to zero.



Position 3: (θ =180°)minimum $\frac{d\emptyset}{dt}$

At 270 degrees Position (4):

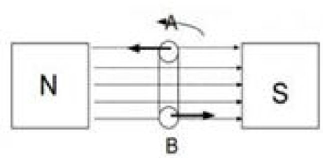
1. At 270 degrees the flux linkage through the loop is once again zero,
2. but the rate of change of flux is maximum.
3. In this position, the EMF induced goes up to its peak value, but this time it's in the reverse direction.



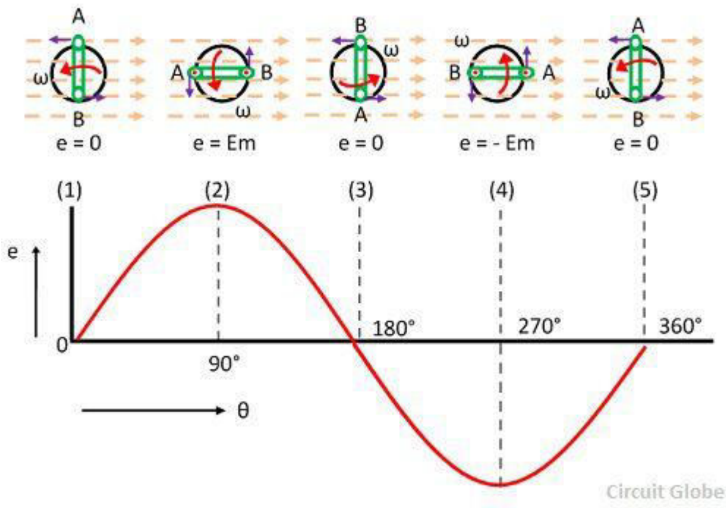
Position 4: (θ =270°) maximum $\frac{d\emptyset}{dt}$

At 360 degrees Position(5):

1. The loop is rotated through another 90 degrees such that it has completed a rotation of 360 degrees.
2. The flux linkage through it is maximum and the voltage decreases back to zero.

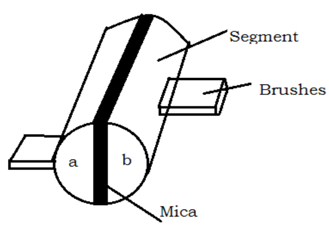


Position **5** : (θ =0°)minimum $\frac{d\emptyset}{dt}$



- Hence, it is observed that the nature of the emf induced in the armature coil is alternating quantity (i.e, positive voltage during first half cycle and negative voltage during second half cycle)
- Thus, to convert the induced alternating ac to dc nature the Commutator (or) split rings are used in the place of the slip rings of a simple loop generator.

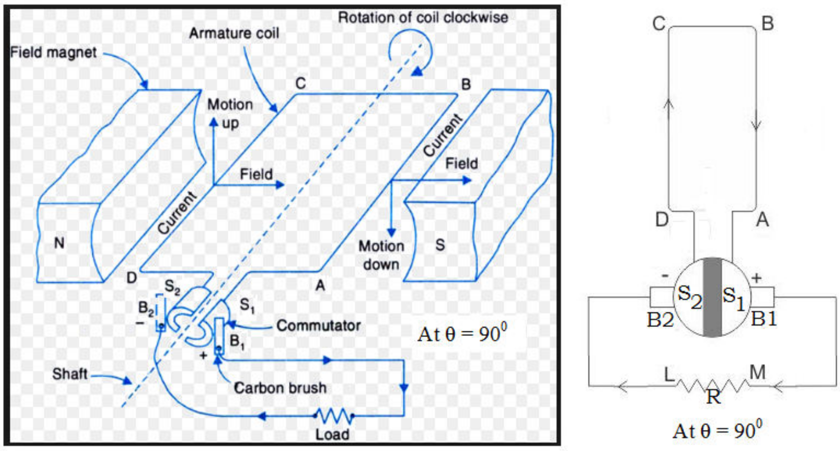
ACTION OF COMMUTATOR:



- The Commutator is a mechanical rectifier used to convert AC to DC
- Here, the split rings or Commutator segments (s_1 and s_2) are placed instead of slip rings
- The split rings or commutator are made out of conducting cylinder, which is cut into two halves or segments insulated from each other by a thin sheet of mica.
- Brushes B_1 and B_2 are mounted on two Commutator segments having + and - polarities

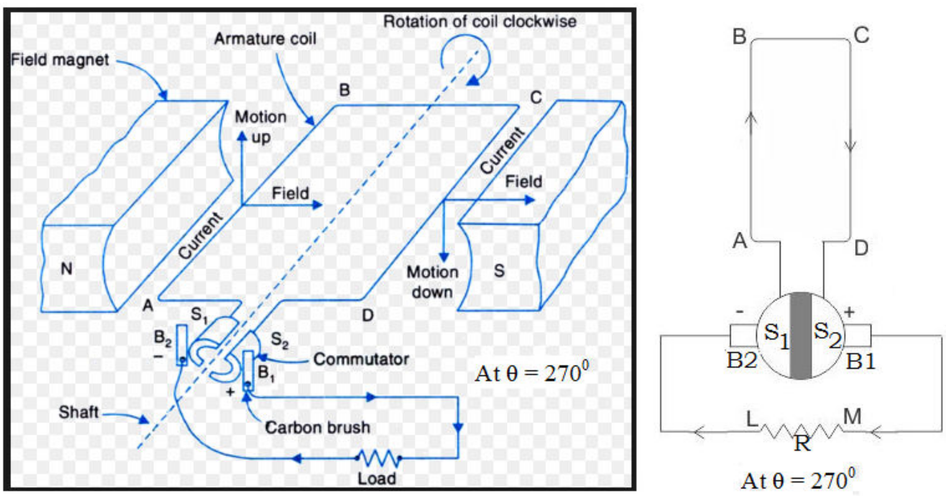
At $\theta = 90^0$ position :

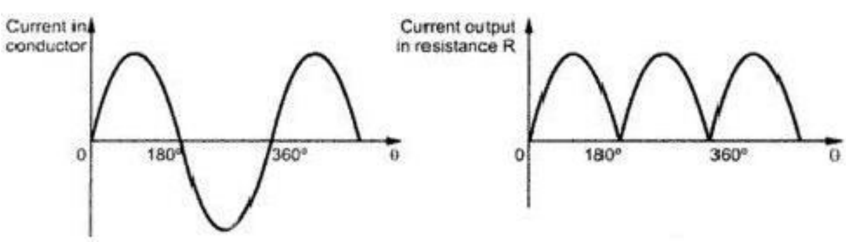
- Conductor AB is under South Pole and Conductor CD are under North Pole, with coil rotating in clock wise direction.
- Using Flemings right hand rule, the current in the conductor AB is from B-A and in conductor CD is from D-C
- Therefore the current flow is in the path of A – S_1 - B_1 – **M – L** - B_2 - S_2 – D – C – B - A



At θ = 270⁰position :

- Conductor AB is under North Pole and Conductor CD are under South Pole, with coil rotating in clock wise direction.
- Using Flemings right hand rule, the current in the conductor AB is from A-B and in conductor CD is from C-D
- Therefore the current flow is in the path of A – B – C - D- S_2- B_1 – **M – L** - B_2 – S_1- A



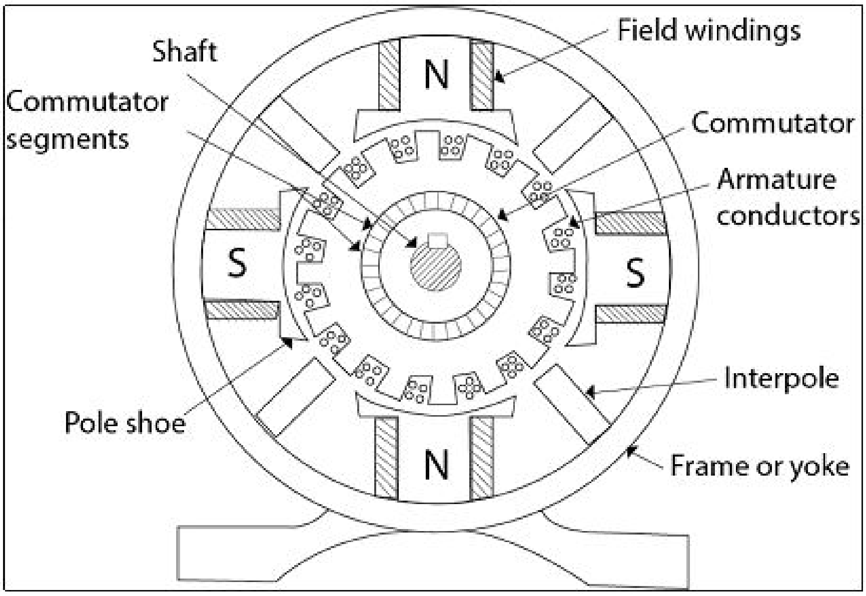


- Thus using the Commutator, the current in the load is unidirectional from M to L at all positions i.e current in coil is alternating and current in Resistance R is unidirectional (pulsating DC)

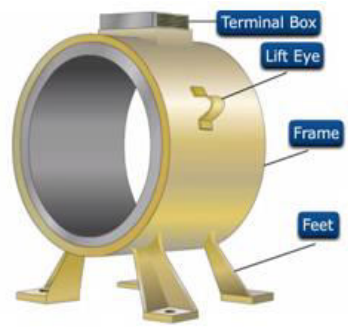
CONSTRUCTION OF DC GENERATOR

A DC generator has the following parts

1. Yoke (or) Magnetic frame
2. Pole core and pole shoe
3. Field winding (or) Pole coils
4. Armature Core
5. Armature winding
6. Commutator
7. Brushes
8. Bearing

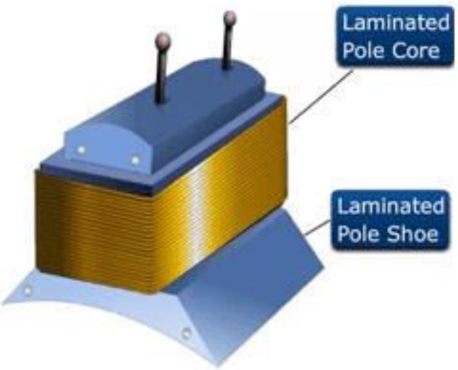


Yoke:



- Yoke or the outer frame of DC generator serves two purposes,
    1. It holds the magnetic pole cores of the generator and acts as cover of the generator.
    2. It carries the magnetic field flux.
- Yoke is made of cast iron for small rating generators, due to the cheaper in cost but heavier than steel.
- Yoke is made of lighter cast steel or rolled steel for larger rating generators , where weight of the machine is concerned.

Pole core and pole shoe



- The field magnets consist of pole cores and pole shoes.
- The pole core is fixed to the inner periphery of the yoke by means of bolts through the yoke and into the pole body.
- The pole core carries the field winding and there are two types of construction

    One: Solid pole core, where it is made of a single piece of cast iron or cast steel.

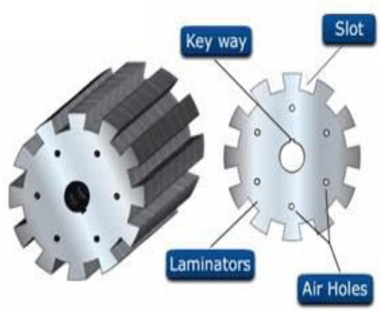
    Two: Laminated pole core, where it made of numbers of thin, limitations of annealed steel which are riveted together.
- The thickness of the lamination is in the range of 0.04" to 0.01".
- The ***pole shoes*** serve two purposes:

1. They spread out the flux in the air gap and also, being of larger cross-section, reduce the reluctance of the magnetic path
2. They support the exciting coils (or field coils)

Field winding (or) Pole coils

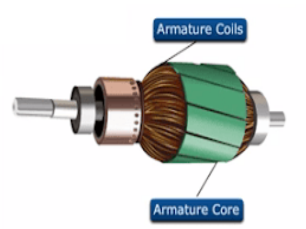
- The function of the field system is to produce uniform magnetic field within which the armature rotates.
- Field coils are mounted on the poles and carry the dc exciting current.
- The field coils are connected in such a way that adjacent poles have opposite polarity.
- The m.m.f. developed by the field coils produces a magnetic flux that passes through the pole pieces, the air gap, the armature and the frame.
- Practical d.c. machines have air gaps ranging from 0.5 mm to 1.5 mm.
- By reducing the length of air gap, we can reduce the size of field coils

Armature Core



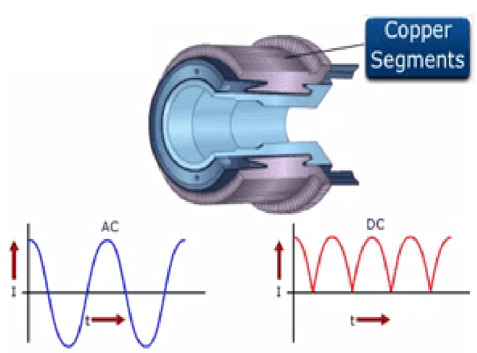
- The armature core consists of slotted soft-iron laminations (about 0.4 to 0.6 mm thick) that are stacked to form a cylindrical core as shown in adjacent figure.
- The purpose of laminating the core is to reduce the eddy current loss.
- Thinner the lamination, greater is the resistance offered to the induced e.m.f., smaller the current and hence lesser the I^2R loss in the core.
- The laminations are slotted to accommodate and provide mechanical security to the armature winding and to give shorter air gap for the flux to cross between the pole face and the armature "teeth".

Armature winding



- The slots of the armature core hold insulated conductors that are connected in a suitable manner. This is known as armature winding.
- This is the winding in which "working" emf is induced. The armature conductors are connected in series-parallel; the conductors being connected in series so as to increase the voltage and in parallel paths so as to increase the current.
- The armature winding of a D.C. machine is a closed-circuit winding; the conductors being connected in a symmetrical manner forming a closed loop or series of closed loops.
- There are two types of armature winding based on the connection to the Commutator they are (a) Lap winding and (b) Wave winding

Commutator

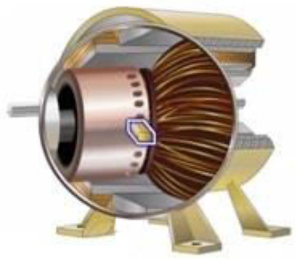


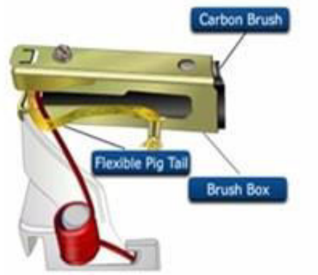
- A Commutator is a mechanical rectifier which converts the alternating voltage generated in the armature winding into direct voltage across the brushes
- The Commutator is made of copper segments insulated from each other by mica sheets and mounted on the shaft of the machine
- The armature conductors are soldered to the

Commutator segments in a suitable manner to give rise to the armature winding

Brushes

- The function of the brushes in DC generator is to collect current from Commutator segments.
- The brushes are made of carbon and rest on the Commutator.
- The brush pressure is adjusted by means of adjustable springs.





Bearing of DC Generator

- For small machine, ball bearing is used and for heavy duty DC generator, roller bearing is used.

The bearing must always be lubricated properly for smooth operation and long life of generator.

EMF EQUATION

Let,

E = Average emf induced in volts
Z = No. of armature conductors
N = Speed of the rotor in RPM
P = No. of the poles
A = No. of parallel paths
Φ = Flux per pole in Weber's

As per Faradays second Law,

- The magnitude of the induced emf (e) is directly proportional to the rate of change of flux linkages (ψ)

  $e \alpha \frac{d\Psi}{dt} = e \alpha N \frac{d\Phi}{dt} = e = k N \frac{d\Phi}{dt}$, In SI unit system k =1, $\therefore e = N \frac{d\Phi}{dt}$

- Emf per conductor is $e = \frac{d\Phi}{dt}$

Where,

- $d\Phi$ = total flux in the airgap that cuts the conductor for one revolution.

  As (P) No. of poles and each pole produces the Φ flux, then $d\Phi = P\Phi$

- dt = time taken by the conductor to cut the flux of $d\Phi$

  i.e The time taken for the armature coil to complete one rotation $dt = \frac{60}{N}$ sec

Thus,

$$e = \frac{P\phi}{\left(\frac{60}{N}\right)} = \frac{P\phi N}{60}$$

As there are (A) No. of parallel paths with 'Z' No. of conductors, then the emf per parallel path is given by

$$e = \frac{P\phi N}{60} * \left(\frac{Z}{A}\right) = \frac{\phi ZN}{60} * \frac{P}{A}$$

Therefore, average value of the emf induced is $\boxed{E = \frac{\phi ZN}{60} * \frac{P}{A}}$

The No. of parallel paths in the armature winding depends on the type of the armature windings

For Wave connected Armature (A=2)

$$E = \frac{\phi ZN}{60} * \frac{P}{2}$$

For Lap connected Armature (A=P)

$$E = \frac{\phi ZN}{60} * \frac{P}{P}$$

Differences between LAP and WAVE windings

Lap Winding	Wave Winding
The lap winding can be defined as a coil which can be lap back toward the succeeding coil.	The wave winding can be defined as the loop of the winding can form the signal shape.
The connection of the lap winding is, the armature coil end is connected to the nearby section on the commutators.	The connection of the wave winding is, the armature coil end is connected to commutator sections at some distance apart.
The numbers of the parallel paths are equal to the total of number poles.	The number of parallel paths is equal to two.
Another name of lap winding is **multiple winding** otherwise **Parallel Winding**	Another name of wave winding is **Series Winding** otherwise Two-circuit
The e.m.f of lap winding is Less	The e.m.f of wave winding is More
The no. of brushes in lap winding is Equivalent to the no. of parallel paths.	The no. of brushes in wave winding is Equivalent toTwo
The types of lap winding are **Simplex lap winding** & Duplex lap winding.	The types of wave winding are **Progressive & Retrogressive**
The efficiency of the lap winding is Less	The efficiency of the wave winding is High
The additional coil used in the lap winding is Equalizer Ring	The additional coil used in the wave winding is Dummy coil
The winding cost of the lap winding is High	The winding cost of the wave winding is Low
The **lap winding used for** high current, low voltage machines.	The **applications of wave winding** include low current and high voltage machines.

<u>TYPES OF DC GENERATORS</u>

Based on the excitation given to the field winding, the dc generators are classified in to two types

a. Separately excited dc generator
b. Self excited dc generator

SEPARATELY EXCITED DC GENERATOR:

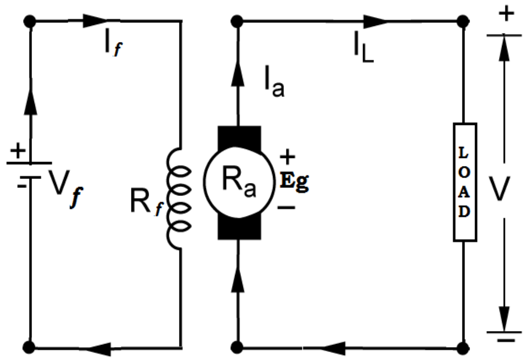
1. In a separately excited generator field winding is energized from a separate voltage source in order to produce flux in the machine and is shown in the below figure.

2. The flux produced will be proportional to the field current in unsaturated condition of the poles.
3. The armature conductors when rotated in this field will cuts the magnetic flux and generates the emf (Eg).
4. The emf will circulate the current against the armature resistance (Ra), brushes and to the load.
5. Applying KVL to the armature loop the Eg is

$$E_g = V + I_a R_a + V_{brush}$$

$I_a = I_L$ and $I_L = \frac{P_L}{V}$ and

$$I_f = \frac{V_f}{R_f}$$



SELF EXCITED DC GENERATOR:

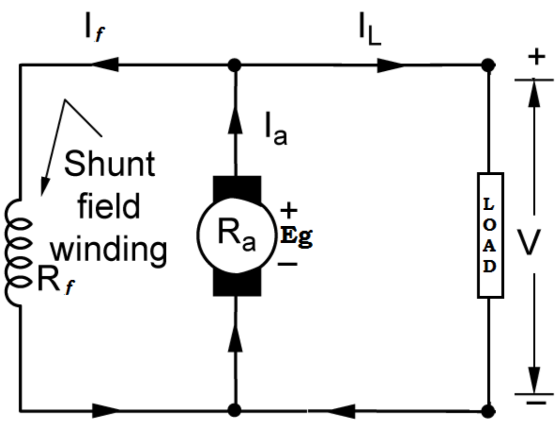
1. In self excited generator field winding is energized from the armature induced emf and there is an electrical connection in between this armature and field winding.
2. There are three possibilities of connecting the field winding to the armature they are
   a. Shunt generator
   b. Series generator
   c. Compound generator
      i. Long shunt compound generator
      ii. Short shunt compound generator

DC SHUNT GENERATOR

1. In the dc shunt generator the field winding circuit is connected in parallel to the armature circuit and as well as to the load.
2. The armature current is divided in to the field and the load as I_f and I_L.
3. The shunt field winding has ***more number of turns with thin wire***, so that resistance of the field will be in the range of hundreds and was designed to withstand for the rated voltage.
4. Applying KVL to the armature loop the E_g is

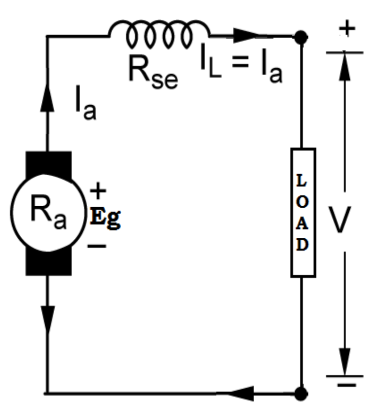
$$E_g = V + I_a R_a + V_{brush}$$

$I_a = I_L + I_f$ and $I_L = \frac{P_L}{V}$ and $I_f = \frac{V}{R_f}$



DC SERIES GENERATOR

1. In the dc series generator the field winding circuit is connected in series to the armature circuit and as well as to the load.
2. Here the armature current is equal to the series field current and also equal to the load.



5. The series field winding has ***less number of turns with thick wire***, so that resistance of the field will be in the smaller values and was designed to carry the rated current.
6. Applying KVL to the armature loop the E_g is

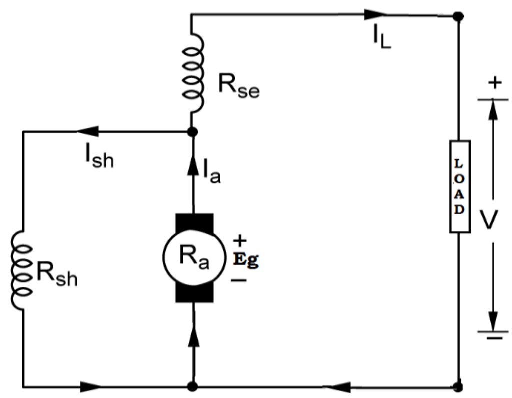
$$E_g = V + I_a(R_a + R_{se}) + V_{brush}$$

$$I_a = I_L = I_{se} \quad \text{and} \quad I_L = \frac{P_L}{V}$$

<u>DC COMPOUND GENERATORS</u>

1. A compound generator has two field coils wound over the field poles.
2. The coil having large number of turns and thinner cross sectional area is called the shunt field coil and the other coil having few numbers of turns and large cross sectional area is called the series field coil.
3. Based on the series field winding connected to the armature the compound generators are classified as long shunt generator and short shunt generator

<u>Short Shunt DC Compound Generator</u>

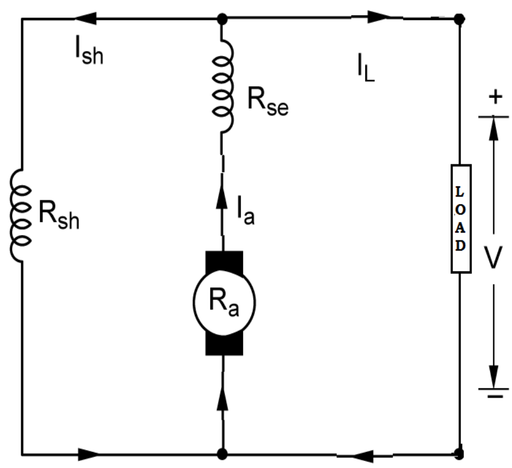


1. In a short shunt dc compound generator, the series field is connected in series to the load and shunt field winding is connected in parallel to the armature and the series combination of the load and series winding.
2. Thus, the series field current will depend on the load variations which will effect in further the shunt field current.
3. Applying KVL to the armature loop the E_g is

$$E_g = V + I_a R_a + I_L R_{se} + V_{brush}$$

$$I_a = I_L + I_{se} \quad \text{and} \quad I_L = \frac{P_L}{V} \quad \text{and} \quad I_f = \frac{V + I_L R_{se}}{R_f}$$

<u>Long Shunt DC Compound Generator</u>



1. In a long shunt dc compound generator, the series field is connected in series to the armature and shunt field winding is connected in parallel to the armature and to the load.
2. Applying KVL to the armature loop the E_g is

$$E_g = V + I_a(R_a + R_{se}) + V_{brush}$$

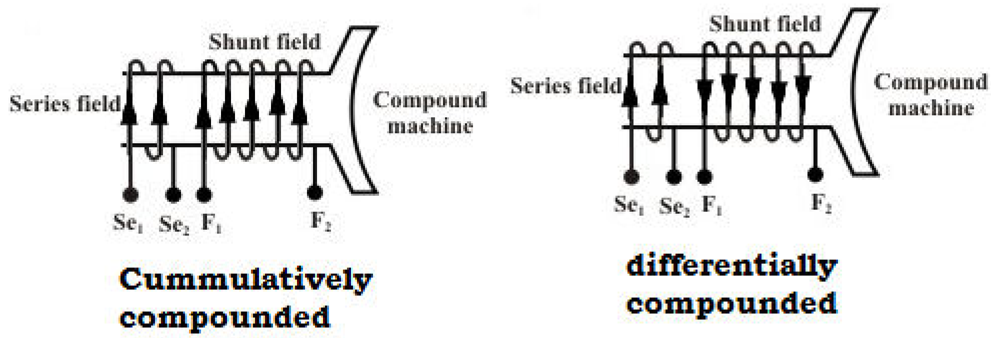
$$I_a = I_L + I_{se} \quad \text{and} \quad I_L = \frac{P_L}{V} \quad \text{and}$$

$$I_f = \frac{V}{R_f}$$

- Also, the dc compound generators are further classified into two types based on the compounding of the series flux to the shunt flux. They are cumulatively compounded and differentially compounded generators
- In the cumulatively compound generator, the series flux aids to the shunt field flux and the

net flux increases, whereas in the differentially compounded generators the series flux opposes the shunt field flux and the net resultant flux decreases.

- The below figure shows the arrangement of the series and shunt field coils iin the pole core in both cumulative and differentially compounded generators.

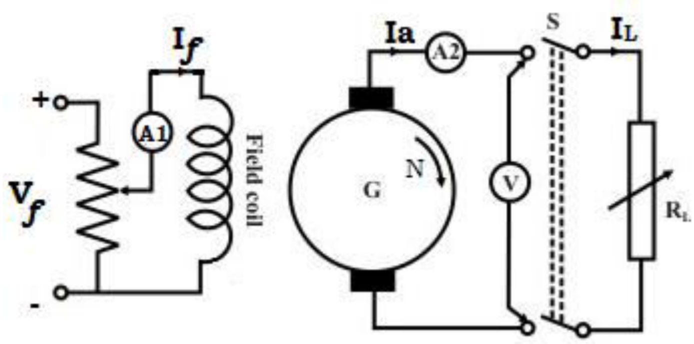


<u>CHARACTERISTICS OF DC GENERATOR</u>

There are three characteristics to be analyzed for any type of the dc generator, they are

1. Open circuit characteristics (or) No-Load characteristics (or) Magnetization characteristics (E_0 *Vs* I_f)
2. Internal characteristics (E_g *Vs* I_a)
3. External or Load characteristics (V *Vs* I_L)

<u>OCC or No-Load Characteristics of Separately excited DC Generator :</u>



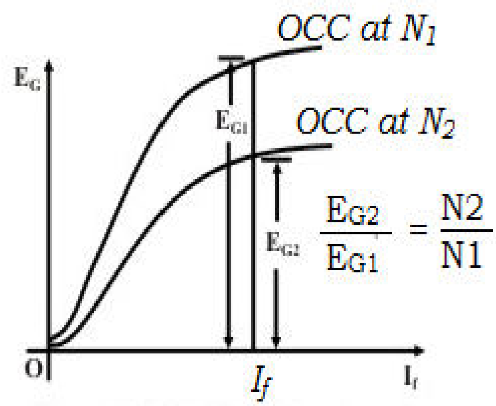
1. OCC is the characteristics drawn between open circuit voltage (E_0) for various field currents (I_f) at constant speed.
2. In this generator field winding is excited from a separate source V_f as shown in above circuit, hence field current is independent of armature terminal voltage
3. The generator is driven by a prime mover at rated speed, say constant speed *N* rpm.
4. With switch *S* in opened condition, field coil is excited via a *potential divider* connection from a separate d.c source and field current is gradually increased by moving the wiper from minimum position gradually.
5. The field current will establish the flux per pole Φ.
6. The voltmeter V connected across the armature terminals of the machine will record the generated emf $\left(E = \frac{PZ}{60A} * \phi N = k * \phi N \right)$. Where *k* is a constant of the machine.

7. As field current is increased, E_0 will increase.
8. E_0 versus I_f plot at constant speed $N\ rpm$ is shown in below figure.
9. It may be noted that even when there is no field current, a small voltage (OD) is generated due to *residual flux* and the small voltage is called *residual voltage.*
10. If field current is increased, φ increases linearly initially and O.C.C follows a straight line.
11. However, when saturation sets in, φ practically becomes constant and hence E*g* too becomes constant.
12. In other words, O.C.C follows the B-H characteristic, hence this characteristic is sometimes also called the magnetization characteristic of the machine.

Procedure to draw OCC at different speeds

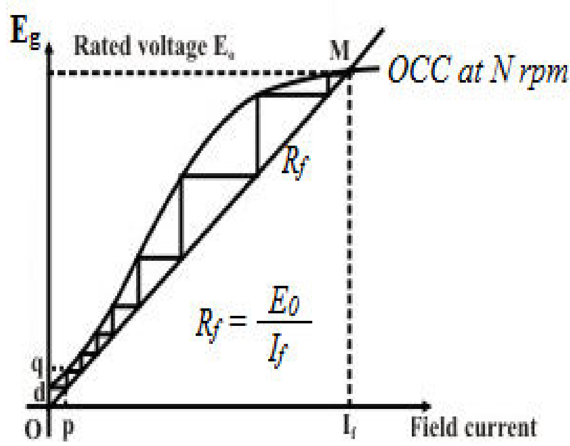
1. It is important to note that if O.C.C is known at a certain speed N_1, O.C.C at another speed N_2 can easily be predicted from the emf equation $E = k * \phi N$
2. Emf at speed N_1 rpm for a field current of I_f, producing the flux Φ is E_1 and is given by $E_1 = k * \phi N_1$
3. Emf at speed N_2 rpm for the same field current of I_f, producing the flux Φ is E_2 and is given by $E_2 = k * \phi N_2$
4. Therefore, the emf E_2 at speed N_2 is

$$\frac{E_2}{E_1} = \frac{k * \phi N_2}{k * \phi N_1} \Rightarrow \frac{E_2}{E_1} = \frac{N_2}{N_1} \Rightarrow E_2 = E_1 \times \frac{N_2}{N_1}$$



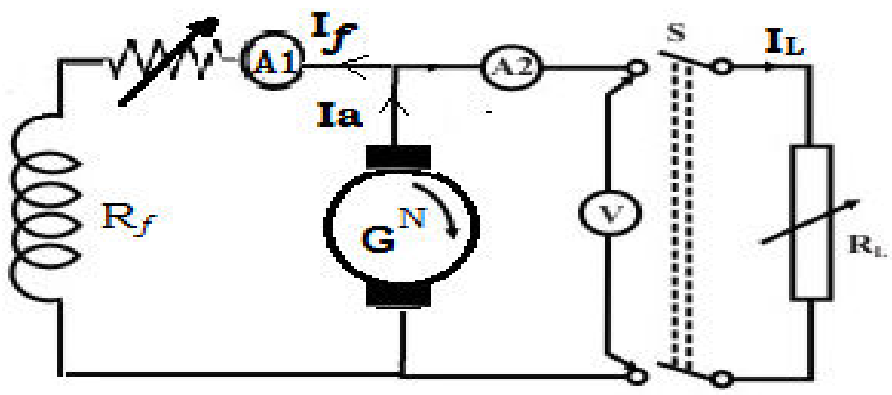
EMF BULID P PROCESS IN A SELF EXCITED DC GENERATOR

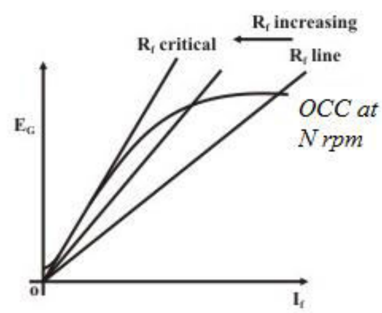
1. For the buildup of emf in the self excited dc generator, the poles or magnets ***must have residual flux*** in them.
2. Therefore, if the generator is driven at rated speed of N rpm, then a small voltage ($k\varphi_{res}N$) will be induced across the armature.
3. This small voltage will be directly applied across the field circuit since it is connected in parallel with the armature.
4. Hence a small field current flows producing additional flux.

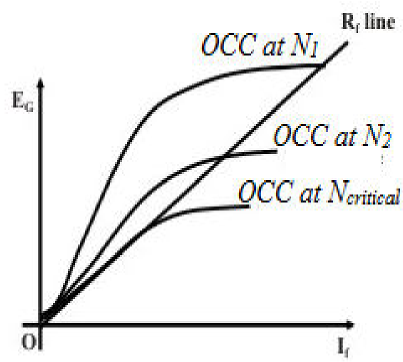


5. If it so happens that this additional flux aids the already existing residual flux, total flux now becomes more and generating more voltage.
6. This more voltage will drive more field current generating more voltage.
7. Both field current and armature generated voltage grow *cumulatively*.
8. This process will be explained clearly from the plot shown above
9. Initially voltage induced due to residual flux is observed from O.C.C as Od.
10. The field current thus produced can be obtained from field circuit resistance line and given by Op. With this Op filed current the flux is increased and correspondingly the induced voltage also increases from Od to Oq and so on. In this way voltage build up process continues along the stair case.

<u>OCC or No-Load Characteristics of self excited DC shunt Generator</u>







1. The OCC of the shunt generator is obtained in a similar way to the dc separately excited generator by disconnecting its field winding from the armature and connecting it to a separate dc source
2. Therefore, the OCC curve at rated speed N rpm is shown in the above figure, with Od as residual voltage and increases gradually.
3. Later, the R_f line is drawn which is a straight line passing through the origin having a slope of its value R_f
4. This R_f line intersects the OCC at point M and gives the rated voltage of the generator.
5. If the R_f value is increased then its slope increases and the voltage generated by the generator reduces and if the value of the R_f is such that it becomes the tangential to the given OCC, then the field resistance is called critical field resistance($R_{f\,critical}$).

6. At this critical field resistance, the emf or voltage of the generator will be very small and it doesn't generates any voltage if the R_f selected is greater than the R_{fc}
7. Thus, ***R_f must be always less than the R_{fc}***
8. Similarly, for the $R_f < R_{fc}$, if the speed decreases then also the voltage generated by the generator reduces.
9. Thus the generator doesn't generates any voltage at a speed called critical speed for which the given R_f line will become the tangent for the OCC drawn at N_c and is shown in the fig.
10. If the speed of the generator is made to run less than its critical speed then no emf will be induced, so the ***speed must be always greater than the critical speed.***

Conditions to build up the emf in the generator:

1. The magnets in the machine must have the ***residual flux.***
2. Field winding connection should be such that the residual flux is strengthened by the field current in the coil. If due to this, no voltage is being built up, reverse the field terminal connection.
3. Total field circuit resistance ***must be less than the critical field resistance.***
4. Speed of the generator ***must be greater than the critical speed.***

APPLICATIONS OF D.C.GENERATORS

Separately Excited DC Generators

1. Because of their ability of giving wide range of voltage output, they are generally used for testing purpose in the laboratories.
2. Separately excited generators operate in a stable condition with any variation in field excitation. Because of this property they are used as supply source of DC motors, whose speeds are to be controlled for various applications. Example- Ward Leonard Systems of speed control.

Applications of Shunt Wound DC Generators

- The application of shunt generators is very much restricted for its dropping voltage characteristic.
- They are used to supply power to the apparatus situated very close to its position.
- These types of DC generators generally give constant terminal voltage for small distance operation with the help of field regulators from no load to full load.

1. They are used for general lighting.
2. They are used to charge battery because they can be made to give constant output voltage.

3. They are used for giving the excitation to the alternators.
4. They are also used for small power supply (such as a portable generator).

Applications of Series Wound DC Generators

- These types of generators are restricted for the use of power supply because of their increasing terminal voltage characteristic with the increase in load current from no load to full load.
- They give constant current in the dropping portion of the characteristic curve. Because of this property they can be used as constant current source and employed for various applications.

1. They are used for supplying field excitation current in DC locomotives for regenerative breaking.
2. These are used as boosters to compensate the voltage drop in the feeder in various types of distribution systems such as railway service.
3. In series arc lightening this type of generators are mainly used.

Applications of Compound Wound DC Generators

- Among various types of DC generators, the compound wound DC generators are most widely used because of its compensating property.
- Depending upon number of series field turns, the cumulatively compounded generators may be over compounded, flat compounded and under compounded.
- Thus the desired terminal voltage can be obtained by compensating the voltage drop due to armature reaction and ohmic drop in the in the line.

  Such generators have various applications.

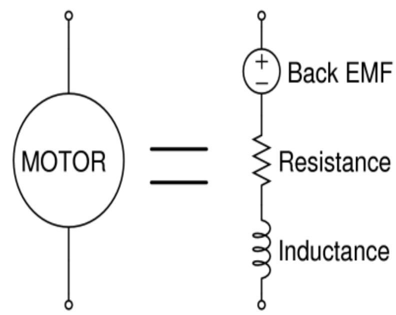
  1. Cumulative compound wound generators are generally used for lighting, power supply purpose and for heavy power services because of their constant voltage property. They are mainly made over compounded.
  2. Cumulative compound wound generators are also used for driving a motor.
  3. For small distance operation, such as power supply for hotels, offices, homes and lodges, the flat compounded generators are generally used.
  4. The differential compound wound generators, because of their large demagnetization armature reaction, are used for arc welding where huge voltage drop and constant current is required.

WORKING PRINCIPLE OF DC MOTOR

- A dc motor is a electro mechanical energy conversion device that converts *electrical energy into mechanical energy.*
- Its operation is based on the principle that ***"when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force"***.
- The direction of the force is given by Fleming's left hand rule which states that " Stretch the first three fingers of left hand mutually perpendicular to each other in such a way that central finger indicates the direction of the current in the conductor, fore finger in the direction of the magnetic field, then the thumb indicates the direction of the force developed on the conductor The magnitude of the force developed on the conductor is $F = BIL \sin\theta$

BACK EMF

When the armature of a d.c. motor rotates under the influence of the driving torque, the armature conductors move through the magnetic field and hence an e.m.f. is induced in them as per Faradays laws of electromagnetic induction.



This induced e.m.f. acts in opposite direction to the applied voltage V (Lenz's law) and is known as back or counter e.m.f. E_b .

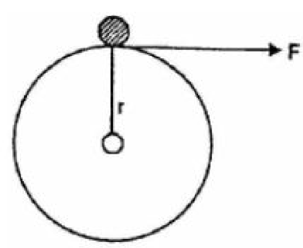
Significance of Back E.M.F

The presence of back e.m.f. makes the d.c. motor a self-regulating machine i.e., it makes the motor to draw as much armature current as is just sufficient to develop the torque required by the load. Back e.m.f. in a d.c. motor regulates the flow of armature current i.e., it automatically changes the armature current to meet the load requirement.

ARMATURE TORQUE OF A DC MOTOR

Torque is the turning and twisting moment of a force about an axis and is measured by the product of force (F) and radius (r) at right angle to which the force acts i.e $T = F*r$

Let



T = Torque developed on the rotor of the motor in Nm

Φ = Flux per pole in weber

Z = No. of the armature conductors

I_a= Armature current in A

P = No. of poles

A = No. of Parallel paths

r = radius of the pulley in mts

Work done by the pulley, W= Force * distance = $F * 2\pi r$

$$\text{Power} = \frac{\text{work done}}{\text{time}} \quad \text{P} = \frac{F \times 2\pi r}{60/N} = \frac{F \times 2\pi r \times N}{60} = \frac{2\pi N}{60} \times (F * r) = \frac{2\pi NT}{60} = \omega T \Rightarrow P = \omega T$$

As, power developed in the armature is the gross mechanical power and is given by

$\text{P} = E_g I_a$, therefore $E_g I_a = \omega T$

$$\frac{\phi ZN}{60}\left(\frac{P}{A}\right) I_a = \frac{2\pi NT}{60} \quad \because \text{E}_\text{g} = \frac{\phi ZN}{60}\left(\frac{P}{A}\right)$$

$$\frac{\phi Z}{2\pi}\left(\frac{P}{A}\right) I_a = T$$

$$\therefore T = \frac{\phi Z}{2\pi}\left(\frac{P}{A}\right) I_a$$

$$T = \frac{1}{2\pi} \phi Z I_a \frac{P}{A}$$

Also, from the fundamentals, the gross torque or armature torque is

$$P = \omega T \Rightarrow E_b I_a = \omega T$$

$$T = \frac{E_b I_a}{\omega} = \frac{E_b I_a * 60}{2\pi N} = \left(\frac{60}{2\pi}\right) * \frac{E_b I_a}{N} = 9.55 \frac{E_b I_a}{N} = 9.55 \frac{P_m}{N}$$

Also, the shaft torque or useful torque is

$$P_{sh} = \omega T_{sh}$$

$$T_{sh} = \frac{P_{sh}}{\omega} = \frac{P_m - Mechloss}{\omega} = \left(\frac{60}{2\pi}\right) * \frac{P_{sh}}{N} = 9.55 \frac{P_{sh}}{N}$$

Therefore,

$$T \,\alpha\, \phi I_a$$

Torque relations in a dc motor

$$\frac{T_2}{T_2} = \frac{\phi_2 I_{a2}}{\phi_1 I_{a1}}$$

Speed of a DC Motor

$$\text{E}_\text{b} = \text{V} - \text{I}_\text{a}\text{R}_\text{a}$$

But $$\text{E}_\text{b} = \frac{\text{P}\phi\text{ZN}}{60\text{ A}}$$

$$\therefore \quad \frac{\text{P}\phi\text{ZN}}{60\text{ A}} = \text{V} - \text{I}_\text{a}\text{R}_\text{a}$$

or $$\text{N} = \frac{(\text{V} - \text{I}_\text{a}\text{R}_\text{a})}{\phi} \frac{60\text{ A}}{\text{PZ}}$$

or $$\text{N} = \text{K}\frac{(\text{V} - \text{I}_\text{a}\text{R}_\text{a})}{\phi} \quad \text{where} \quad \text{K} = \frac{60\text{A}}{\text{PZ}}$$

But $V - I_a R_a = E_a$

$$\therefore \quad N = K \frac{E_b}{\phi}$$

or $$N \propto \frac{E_b}{\phi}$$

Therefore,

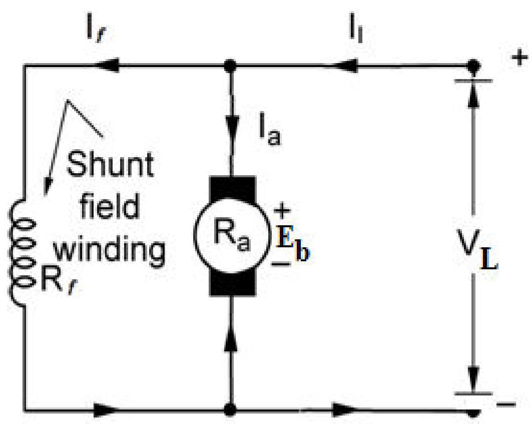
In a dc motor speed is directly proportional to back emf, E_b and inversely proportional to flux, φ.

TYPES OF D.C. MOTORS

Based on the field winding excited from the armature the dc motors are of three types

1. DC Shunt motor
2. DC Series motor
3. DC compound motor
    a. Long Shunt Compound motor
    b. Short Shunt Compound motor

DC SHUNT MOTOR



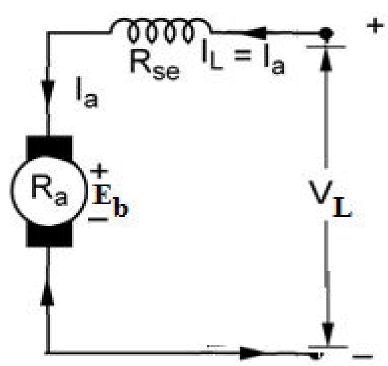
1. In the dc shunt motor the field winding circuit is connected in parallel to the armature circuit and as well as to the line.
2. The line current I_L is divided in to the field and the armature as I_f and I_a.
3. The shunt field winding has ***more number of turns with thin wire***, so that resistance of the field will be in the range of hundreds and was designed to withstand for the rated voltage.
4. Applying KVL to the armature loop the E_g is

$$E_b = V_L - I_a R_a - V_{brush}$$

$$I_a = I_L - I_f \quad \text{and} \quad I_L = \frac{P_L}{V} \quad \text{and} \quad I_f = \frac{V}{R_f}$$

DC SERIES MOTOR

3. In the dc series motor the field winding circuit is connected in series to the armature circuit and as well as to the line.
4. Here the armature current is equal to the series field current and also equal to the line.
7. The series field winding has ***less number of turns with thick wire***, so that resistance of the field will be in the smaller values and was designed to carry the rated current.
8. Applying KVL to the armature loop the E_g is



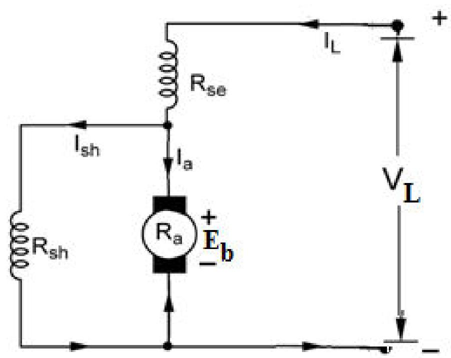
$$E_b = V_L - I_a (R_a + R_{se}) - V_{brush}$$

$$I_a = I_L = I_{se} \quad \text{and} \quad I_L = \frac{P_L}{V}$$

DC COMPOUND MOTORS

4. A compound motor has two field coils wound over the field poles.
5. The coil having large number of turns and thinner cross sectional area is called the shunt field coil and the other coil having few numbers of turns and large cross sectional area is called the series field coil.
6. Based on the series field winding connected to the armature the compound motors are classified as long shunt motor and short shunt motor

- ***SHORT SHUNT MOTOR***



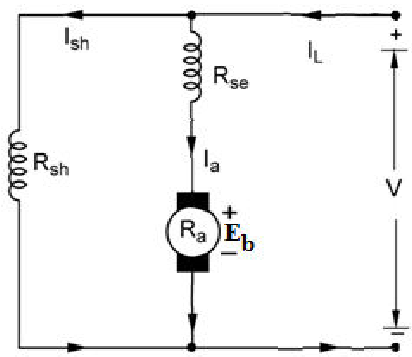
4. In a short shunt dc compound motor, the series field is connected in series to the line and shunt field winding is connected in parallel to the armature and the series combination of the line and series winding.
5. Thus, the series field current will depend on the line variations which will effect in further the shunt field current.
6. Applying KVL to the armature loop the E_g is

$$E_b = V_L - I_a R_a - I_L R_{se} - V_{brush}$$

$$I_a = I_L - I_f \quad \text{and} \quad I_L = \frac{P_L}{V} \quad \text{and}$$

$$I_f = \frac{V_L - I_L R_{se}}{R_f}$$

- ***LONG SHUNT MOTOR***

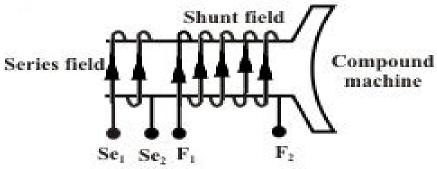


3. In a long shunt dc compound motor, the series field is connected in series to the armature and shunt field winding is connected in parallel to the armature and to the line.
4. Applying KVL to the armature loop the E_g is

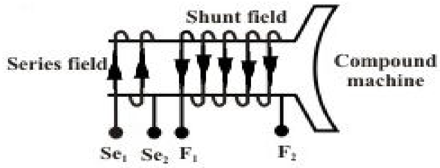
$$E_b = V_L - I_a(R_a + R_{se}) - V_{brush}$$

$$I_a = I_L - I_f \quad \text{and} \quad I_L = \frac{P_L}{V} \quad \text{and} \quad I_f = \frac{V}{R_f}$$

- Also, the dc compound motors are further classified into two types based on the compounding of the series flux to the shunt flux. They are cumulatively compounded and differentially compounded motors
- In the cumulatively compound motor, the series flux aids to the shunt field flux and the net flux increases, whereas in the differentially compounded motors the series flux opposes the shunt field flux and the net resultant flux decreases.
- The below figure shows the arrangement of the series and shunt field coils in the pole core in both cumulative and differentially compounded motors.



Cummulatively compounded



differentially compounded

APPLICATIONS OF D.C. MOTORS

1. Shunt motors

The characteristic of a shunt motor is an approximately constant speed motor. So, it is used where the speed is required to remain almost constant from no-load to full-load

***Industrial applications of shunt motor*:**

1. Lathes
2. Drills
3. Boring mills
4. Shapers
5. Spinning and weaving machines etc.

2. Series motors

It is a variable speed motor i.e., speed is low at high torque and vice-versa. It is used

(i) Where large starting torque is required e.g., in elevators and electric Traction

(ii) Where the load is subjected to heavy fluctuations and the speed is automatically required to reduce at high torques and vice-versa

***Industrial applications of series motor*:**

1. Electric traction
2. Cranes
3. Elevators,
4. Air compressors,
5. Vacuum cleaners
6. Hair drier
7. Sewing machines etc.

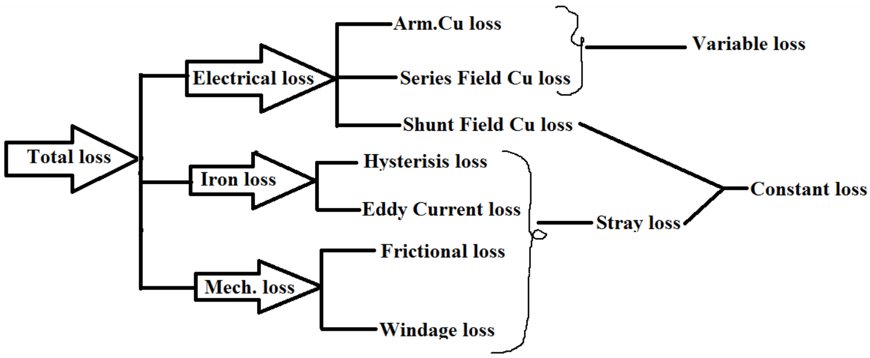
3. Compound motors

Differential-compound motors are rarely used because of their poor torque characteristics. However, cumulative-compound motors are used where a fairly constant speed is required with irregular loads or suddenly applied heavy loads.

***Industrial applications of Compound motor*:**

1. Presses,
2. Shears,
3. Reciprocating machines etc.

LOSSES IN DC MACHINE



Power Stages in DC Generator:

The power stages in a d.c. generator are represented diagrammatically in below Fig.

Mechanical Input - Electrical Power generated = A - B = Iron and friction losses

Electrical Power generated - Electrical Power output = B - C = Copper losses

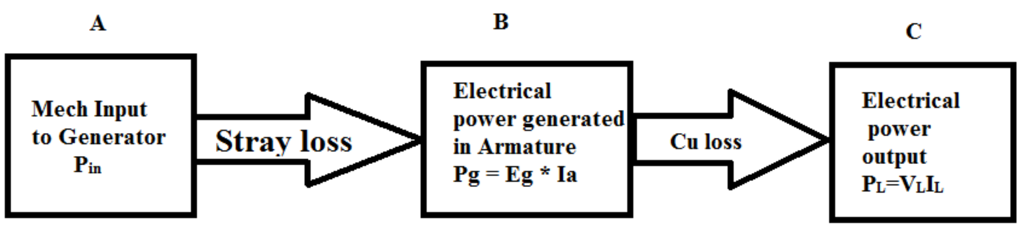
Efficiency is defined as the ratio of output power to the input power

Electrical efficiency, $\eta_e = C/B$

Mechanical efficiency, $\eta_m = B/A$

Overall efficiency, $\eta_c = C/A$

Therefore, Overall efficiency = Electrical efficiency * Mechanical efficiency

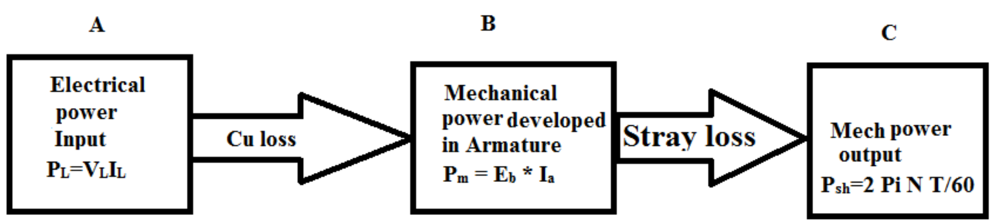


Power Stages in DC Motor:

The power stages in a d.c. motor are represented diagrammatically in below Fig.

Electrical Power input – Mechanical power developed = A - B = Copper losses

Mechanical power developed - Mechanical power output = B - C = Iron and friction losses



Electrical efficiency $\eta_e = B/A$

Mechanical efficiency $\eta_m = C/B$

Overall efficiency $\eta_c = C/A$

Condition for maximum efficiency for dc motor:

We assume that field current I_f remains constant during change of loading. Let,

$$P_{rot} = \text{constant rotational loss}$$
$$V I_f = \text{constant field copper loss}$$
$$\text{Constant loss } P_{const} = P_{rot} + V I_f$$
$$\text{Now, input power drawn from supply} = V I_L$$
$$\text{Power loss in the armature,} = I_a^2 r_a$$
$$\text{Net mechanical output power} = VI_L - I_a^2 r_a - (VI_f + P_{rot})$$
$$= VI_L - I_a^2 r_a - P_{const}$$
$$\text{so, efficiency at this load current } \eta_m = \frac{VI_L - I_a^2 r_a - P_{const}}{VI_L}$$

Now the armature copper loss $I_a^2 r_a$ can be approximated to $I_L^2 r_a$ as $I_a \approx I_L$. This is because the order of field current may be 3 to 5% of the rated current. Except for very lightly loaded motor, this assumption is reasonably fair. Therefore replacing I_a by I_f in the above expression for efficiency η_m, we get,

$$\eta_m = \frac{VI_L - I_L^2 r_a - P_{const}}{VI_L}$$
$$= 1 - \frac{I_L r_a}{V} - \frac{P_{const}}{VI_L}$$

Thus, we get a simplified expression for motor efficiency η_m in terms of the variable current (which depends on degree of loading) I_L, current drawn from the supply. So to find out the condition for maximum efficiency, we have to differentiate η_m with respect to I_L and set it to zero as shown below.

$$\frac{d\eta_m}{dI_L} = 0$$
$$\text{or, } \frac{d}{dI_L}\left(\frac{I_L r_a}{V} - \frac{P_{const}}{VI_L}\right) = 0$$
$$\text{or, } -\frac{r_a}{V} + \frac{P_{const}}{VI_L^2}$$
$$\therefore \text{Condition for maximum efficiency is } I_L^2 r_a \approx I_a^2 r_a = P_{const}$$
$$\text{So, the armature current at which efficiency becomes maximum is } I_a = \sqrt{P_{const}/r_a}$$

Necessity of starter:

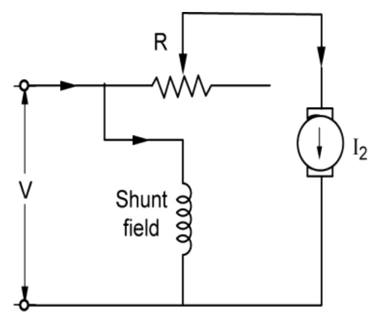
- The function of the starter is ***to limit the starting current*** in the motor.

The current drawn by the motor armature is given by $I_a = \frac{V - E_b}{R_a}$

where V is the supply voltage,

E_b is the back emf and

R_a is the armature resistance of the motor.



- At starting, when motor is at rest there is no back emf in the armature (since $E_b \alpha N$)

  Now the total supply voltage is applied across the stationary armature and it will draw a very large current because of small armature resistance.

  Consider the case of 440 V, 5 HP (3.73 KW) motor having a cold armature resistance of 0.25 Ω and full load current of 50A.

  If this motor is started from the line directly, it will draw a starting current of **Fehler!** = 1760 A which is **Fehler!** = 35.2 times its full-load current.

  This excessive current will blow out the fuses and damages the commutator and brushes. To avoid this, a resistance is placed in series to the armature for the time duration until the motor pickups the speed.

  Once the motor pickups the speed, the back emf is developed and the current was limited by the small voltage (V_L-E_b) applied to the armature against the small resistance.

  Thus, the starter is used to limit this starting current by inserting the resistance only at the starting time.

  There are three types of starters used namely

  3 point starter b) Four point starter c) Two point starter

  <u>THREE POINT STARTER</u>

  The 3 terminals of the three point starter are marked A, B and C.

  First terminal A is connected to the handle arm (L) through the overload release (OLR) from the supply terminals

  Second terminal B is connected to the field winding of the motor through the Hold ON coil from the stud 1 of the external resistance placed in series to the armature.

  Third terminal C is connected to the armature by inserting the external resistance.

  The handle initially is at OFF position and when the supply is given, to start the motor the handle is dragged towards the stud 1.

  This position of the handle divides the line current into two paths one path to the armature through the current limiting resistance and second path to the field winding.

  Thus the current is limited by this resistance placed in series with the armature. Also as the speed picks up, the handle was dragged over the studs from off position to ON position.

  At this ON position all the external resistance is removed from the armature and the spring on the other side of the handle develops the restraining torque with the spring placed.

  The soft iron piece (S) on the handle is attracted by the hold on coil in normal running conditions

The resistance that was removed from the armature circuit will be added to the field circuit. Thus the field current is reduced, to overcome the drawback of weakening of the flux the field winding terminal is connected from the brass arc placed below the studs and is shown in the figure

Hold ON coil (or) No Volt Release (NVR)

The Normal function of the HOLD-ON coil is to hold on the arm in then full running position when the motor is in normal operation.

When the supply failure (or) disconnection, it is de-energised, so that handle is released from the hold on coil and pulled back by the spring to the OFF position.

The Hold ON coil protects the motor from dangerous speed when field circuit opens.

Over Load Release (OLR)

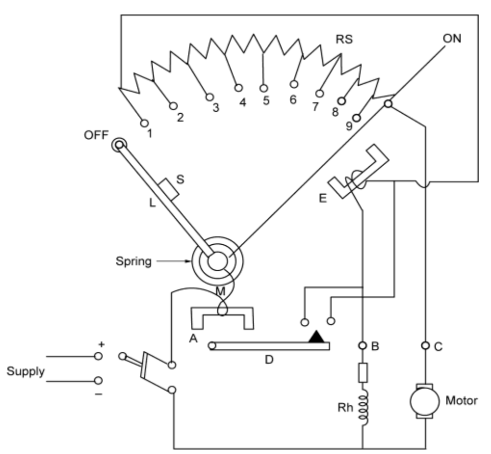
It consists of an electro-magnet connected in the supply line.

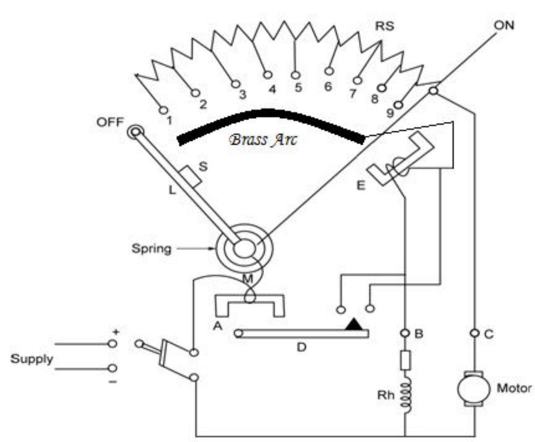
If motor becomes over loaded, then D is lifted and short circuits the electro-magnet. Hence arm is released and returns to OFF position.

Disadvantage of three point starter:

To control the speed of motor, a field rheostat is connected in the field circuit.The motor speed is increased by decreasing the flux ($N \propto I/\phi$). There is a difficulty that if too much resistance is added by the field rheostat, then field current is reduced very much so that the current in the hold on coil is unable to create enough Electromagnetic pull to overcome the spring tension. Hence arm is pulled back to OFF position.

Therefore the shunt motor with this three point starter is not suitable for adjustable speed drive applications.





Speed control of DC motors:

The speed of a d.c. motor is given by:

$N \alpha \frac{Eb}{\Phi}$ or $N \alpha \frac{V_L - I_a R}{\Phi}$ where R is Ra for shunt motor and (Ra + Rse). for series motor

From the above expression,

The speed of a d.c. motor is controlled

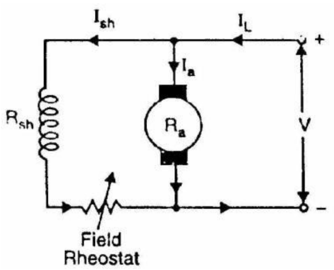
(i) By varying the flux per pole (f) known as flux control method.

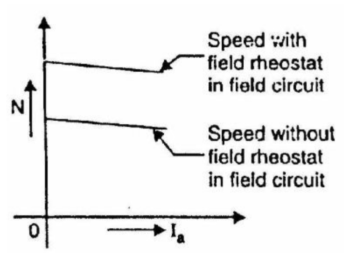
(ii) By varying the R_a and is known as armature control method.

(iii) By varying the applied voltage V and is known as voltage control method.

Speed Control of D.C. Shunt Motor

a) Field control method:





1. In this field control method the variable is flux (f)
2. The rheostat is placed in series to the field winding, as the field resistance increases the field current decreases and this weakens the flux
3. The weakening of the flux increases the speed since speed is inversely proportional to the flux.
4. Thus using the field control, above base speeds can be controlled.
5. This method is also known as constant power method or variable torque method.

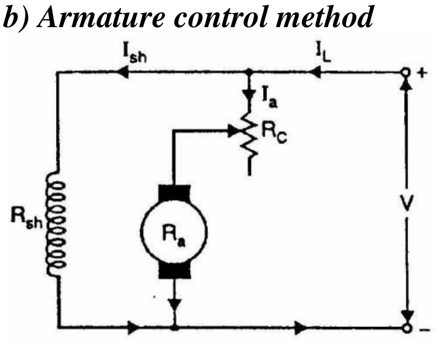
Advantages

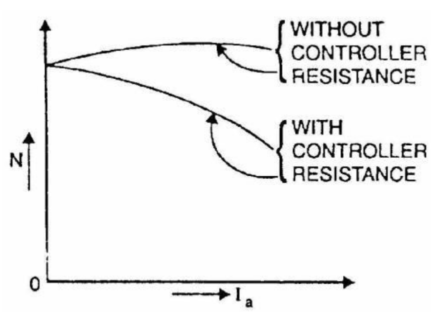
1. This is an easy and convenient method.
2. It is an inexpensive method since very little power is wasted in the shunt field rheostat due to relatively small value of I_f
3. The speed control exercised by this method is independent of load on the machine.

Disadvantages

1. Only speeds higher than the normal speed can be obtained.
2. There is a limit to the maximum speed obtainable by this method. It is because if the flux is too much weakened, commutation becomes poorer.

b) Armature control method





1. In this armature resistance control method the variable is R_a
2. The rheostat is placed in series to the armature winding, as the R_a increases the I_aR_a drop increases and this decreases the speed.
3. The decreasing of the back emf decreases the speed since speed is directly proportional to E_b.

4. Thus using the R_a control method, below base speeds can be controlled.
5. This method is also known as constant torque method or variable power method.

Disadvantages

1. A large amount of power is wasted in the controller resistance since it carries full armature current Ia.
2. The speed varies widely with load since the speed depends upon the voltage drop in the controller resistance and hence on the armature current demanded by the load.
3. The output and efficiency of the motor are reduced.
4. This method results in poor speed regulation.

c) Voltage control method by Ward-Leonard system

1. This method is used to get the wide range of speed control 10:1.
2. As the speed of the motor is directly proportional to the applied voltage to the armature, thus by applying the variable voltage the speed is controlled.
3. The armature of the shunt motor M (whose speed is to be controlled) is connected directly to a d.c. generator G driven by a constant-speed a.c. motor A.
4. The field of the shunt motor is supplied from a constant-voltage exciter E.
5. The field of the generator G is also supplied from the exciter E.
6. The voltage of the generator G can be varied by means of its field regulator.
7. By reversing the field current of generator G by controller FC, the voltage applied to the motor may be reversed.

Advantages

1. The speed of the motor can be adjusted through a wide range without resistance losses which results in high efficiency.
2. The motor can be brought to a standstill quickly, simply by rapidly reducing the voltage of generator G.
3. The disadvantage of the method is that a special motor-generator set is required for each motor and the losses in this set are high if the motor is operating under light loads for long periods.

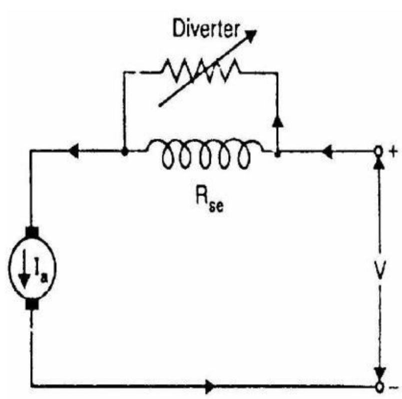
<u>Speed Control of D.C. Series Motor</u>

a) *Flux control method*

In this method, the flux produced by the series motor is varied and hence the speed.

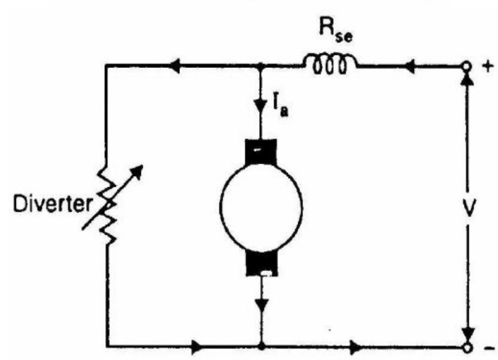
The variation of flux can be achieved in the following ways:

<u>(i) Field diverters.</u>



1. In this method, a variable resistance (called field diverter) is connected in parallel with series field winding as shown in Fig.
2. Its effect is to shunt some portion of the line current from the series field winding, thus weakening the field and increasing the speed (Nα1/Φ).
3. This method can only provide speeds above the normal speed. The series field diverter method is often employed in traction work.

<u>ii) Armature diverter</u>.

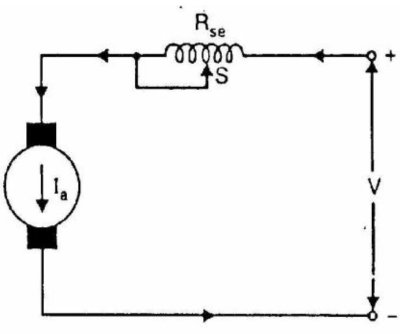


1. In order to obtain speeds below the normal speed, a variable resistance (called armature diverter) is connected in parallel with the armature as shown in Fig.
2. The diverter shunts some of the line current, thus reducing the armature current.
3. Now for a given load, if Ia is decreased, the flux Φ must increase ($T\alpha\Phi I_a$).

4. Since (Nα1/Φ). The motor speed is decreased.
5. By adjusting the armature diverter, any speed lower than the normal speed can be obtained.

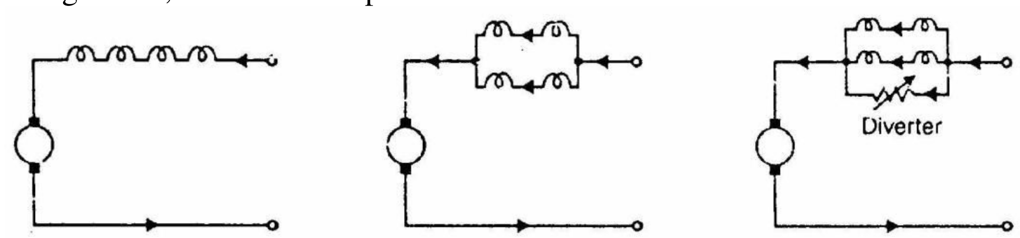
iii) Tapped field control.

1. In this method, the flux is reduced by decreasing the number of turns of the series field winding as shown in Fig, and hence speed is increased
2. The switch S can short circuit any part of the field winding, thus decreasing the flux and raising the speed.
3. With full turns of the field winding, the motor runs at normal speed and as the field turns are cut out; speeds higher than normal speed are achieved.



iv) Paralleling field coils.

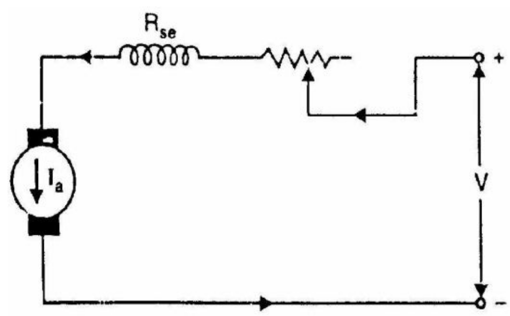
This method is usually employed in the case of fan motors. By regrouping the field coils as shown in Fig below, several fixed speeds can be obtained.



(*i*) (*ii*) (*iii*)

b) Armature-resistance control:

1. In this method, a variable resistance is directly connected in series with the supply to the complete motor as shown in Fig.
2. This reduces the voltage available across the armature and hence the speed falls.
3. By changing the value of variable resistance, any speed below the normal speed can be obtained.
4. This is the most common method employed to control the speed of d.c. series motors.
5. Although this method has poor speed regulation, this has no significance for series motors because they are used in varying speed applications.
6. The loss of power in the series resistance for many applications of series motors is not too serious since in these applications.



TESTING OF DC MACHINES:

Testing of DC machines can be broadly classified as

i) Direct method of Testing

ii) Indirect method of testing

Direct method of testing:

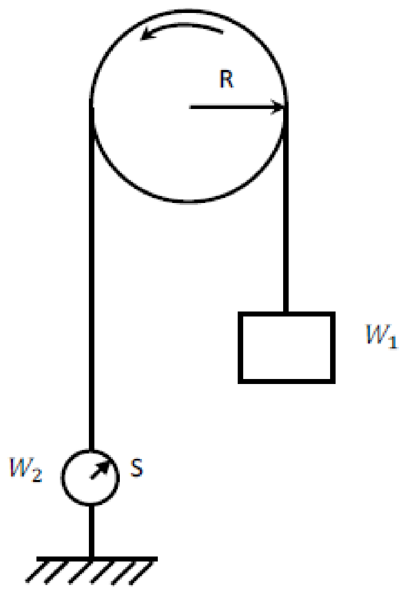
In this method, the DC machine is loaded directly by means of a brake applied to water cooled pulley coupled to the shaft of the machine. The input and output are measured and efficiency is determined by $\eta = \frac{output}{input}$

It is not practically possible to arrange loads for machines of large capacity.

Indirect method of testing:

In this method, the losses are determined without actual loading the machine. If the losses are known, then efficiency can be determined. Swinburne's test, Hopkinson's test and retardation tests are commonly used on shunt motors.

(i) **BRAKE TEST**: is a direct method of testing.



In this method of testing motor shaft is coupled to a Water cooled pulley which is loaded by means of weight as shown in figure

W_1= suspended weight in kg

W_2 = Reading in spring balance in kg

R = radius of pulley

N = speed in rpm

V = Supply voltage

I = Full Load Current

Net pull due to friction $= (W_1 - W_2)$ kg

$= 9.81\,(W_1 - W_2)$ Newton ……………….. 1

Shaft torque $T_{sh} = (W_1 - W_2)R\ kg - mt.$

$= 9.81\,(W_1 - W_2)\ R\ N - mt$ ……………… 2

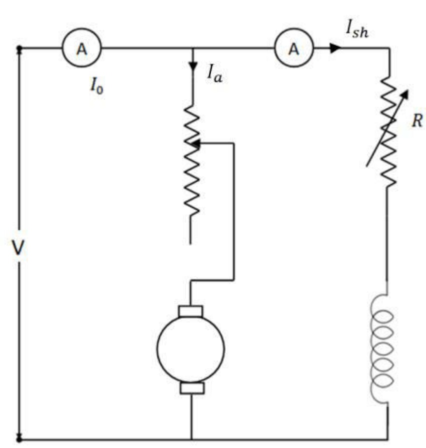
Motor output power = $T_{sh}\ X\ \frac{2\,\pi\,N}{60}$ Watt

Input power = VI watts ……………….3

Therefore efficiency = $\frac{output}{input}$

This method of testing can be used for small motors only because for a large motor it is difficult to arrange for dissipation of heat generated at the brake.

(ii)Swinburne's Test:



This test is a no load test and hence cannot be performed on series motor.
The circuit connection is shown in Figure
The machine is run on no load at rated speed which is adjusted by the shunt field resistance.

Advantages

1. Economical, because no load input power is sufficient to perform the test
2. Efficiency can be pre-determined
3. As it is a no load test, it cannot be done on a dc series motor

Disadvantages

1. Change in iron loss from no load to full load is not taken into account. (Because of armature
reaction, flux is distorted which increases iron losses).
2. Stray load loss cannot be determined by this test and hence efficiency is over estimated.
3. Temperature rise of the machine cannot be determined.
4. The test does not indicate whether commutation would be satisfactory when the machine is loaded.

I_O = No load current; I_{sh} = shunt field current

I_{ao} = No load armature current = $(I_o - I_{sh})$

V= Supply Voltage

No load input $=VI_o$ watts.

No load power input supplies

(i) Iron losses in the core

(ii) Friction and windings loss and

(iii) Armature copper loss.

Let I = load current at which efficiency is required

$I_a = I - I_{sh}$ if machine is motoring; $I + I_{sh}$ if machine is generating

Efficiency as a motor:

Input = VI; $I_a^2 r_a = (I - I_{sh})^2 r_a$

Constant losses $W_c = VI_o - (I_o - I_{sh})^2 r_a$ …………… 7

Total losses = $(I - I_{sh})^2 r_a + W_c$

Therefore efficiency of motor = $\frac{input - losses}{input}$; = $\frac{VI - ((I - Ish)2ra + Wc)}{VI}$ ……. 8

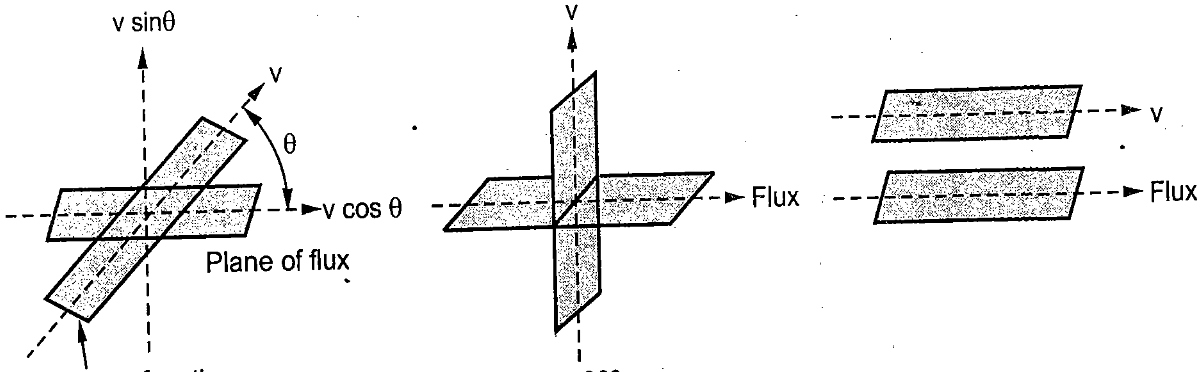
EFFICIENCY OF A GENERATOR:

Output = VI

$I_a^2 r_a = (I + I_{sh})^2 r_a$

Total losses = $W_c + (I + I_{sh})^2 r_a$ …………………………………….. 9

Efficiency of generator = $\frac{output}{output + losses} = \frac{VI}{VI + (I + I_{sh})^2 r_a + W_c}$ ……… 10



(a) E ∝ v sin θ (b) Maximum E (c) E = 0

Fig. 2.2.4

From the equation of the induced e.m.f., it can be seen that the basic nature of the induced e.m.f. in a d.c. generator is purely sinusoidal i.e. alternating. To have d.c. voltage, a device is used in a d.c. generator to convert the alternating e.m.f. to unidirectional e.m.f. This device is called **commutator**.

Review Questions

1. *Explain the principle of operation of a d.c. generator.*
JNTU : May-03, 04, Nov.-04, 07, 12, March-14, Marks 6
2. *Explain Fleming's right hand rule used to decide the direction of an induced e.m.f. in a generator.*

2.3 Constructional Features of a D.C. Machine

JNTU : Nov.-03, 04, 05, 08, 13, May-04, 05, 08, 09, 13, June-04, Dec.-04, Jan.-14, March-06

As stated earlier, whether a machine is **d.c. generator or a motor** the construction basically remains the same as shown in the Fig. 2.3.1. (See Fig. 2.3.1 on next page)

It consists of the following parts :

2.3.1 Yoke

a) Functions :

1. It serves the purpose of outermost cover of the d.c. machine. So that the insulating materials get protected from harmful atmospheric elements like moisture, dust and various gases like SO_2, acidic fumes etc.
2. It provides mechanical support to the poles.
3. And it Also Acts as the return path for magnetic flux lines. It forms a part of the magnetic circuit. It provides a path of low reluctance for magnetic flux. The low reluctance path is important to avoid wastage of power to provide same flux. Large current and hence the power is necessary if the path has high reluctance, to produce the same flux.

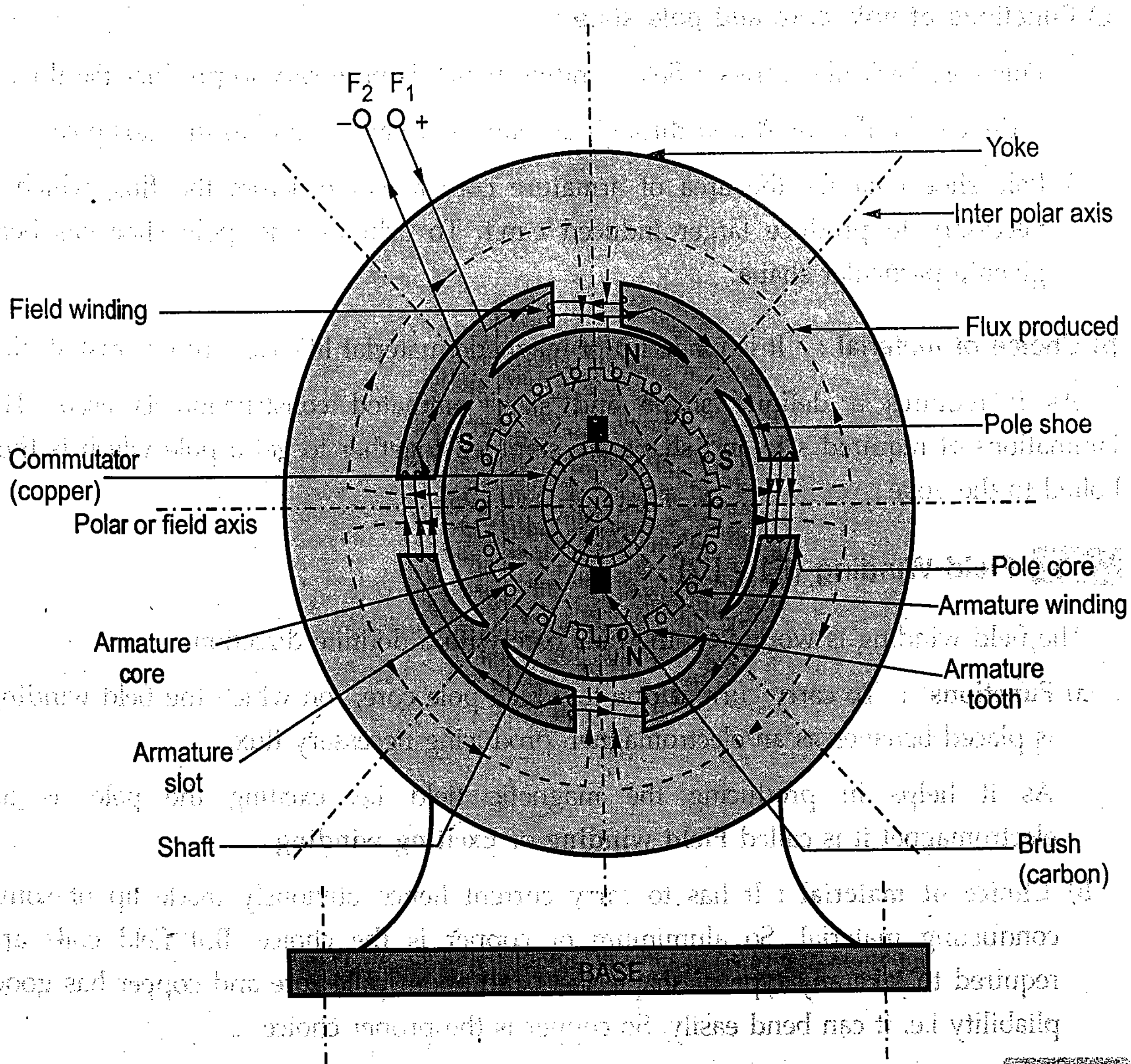


Fig. 2.3.1 A cross-section of typical d.c. machine

b) Choice of material : To provide low reluctance path, it must be made up of some magnetic material. It is prepared by using cast iron because it is cheapest. For large machines rolled steel, cast steel, silicon steel is used which provides high permeability i.e. low reluctance and gives good mechanical strength.

2.3.2 Poles

Each pole is divided into two parts namely, I) Pole core and II) Pole shoe

This is shown in the Fig. 2.3.2.

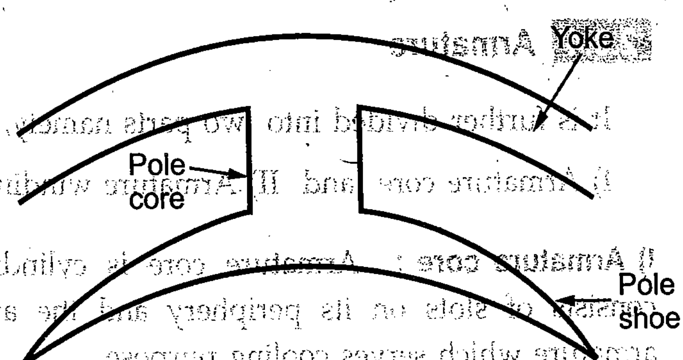


Fig. 2.3.2 Pole structure

a) Functions of pole core and 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 enlarges the area of armature core to come across the flux, which is necessary to produce larger induced e.m.f. To achieve this, pole shoe has been given a particular shape.

b) Choice of material : It is made up of magnetic material like cast iron or cast steel.

As it requires a definite shape and size, laminated construction is used. The laminations of required size and shape are stamped together to get a pole which is then bolted to the yoke.

2.3.3 Field Winding (F1 - F2)

The field winding is wound on the pole core with a definite direction.

a) **Functions :** To carry current due to which pole core, on which the field winding is placed behaves as an electromagnet, producing necessary flux.

As it helps in producing the magnetic field i.e. exciting the pole as an electromagnet it is called **Field winding** or **Exciting winding.**

b) **Choice of material :** It has to carry current hence obviously made up of some conducting material. So aluminium or copper is the choice. But field coils are required to take any type of shape and bend about pole core and copper has good pliability i.e. it can bend easily. So copper is the proper choice.

Key Point *Field winding is divided into various coils called field coils. These are connected in series with each other and wound in such a direction around pole cores, such that alternate 'N' and 'S' poles are formed.*

By using right hand thumb rule for current carrying circular conductor, it can be easily determined that how a particular core is going to behave as 'N' or 'S' for a particular winding direction around it. The direction of winding and flux can be observed in the Fig. 2.3.1.

2.3.4 Armature

It is further divided into two parts namely,

I) Armature core and II) Armature winding.

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

a) Functions :

1. Armature core provides house for armature winding i.e. armature conductors.
2. To provide a path of low reluctance to the magnetic flux produced by the field winding.

b) Choice of material : As it has to provide a low reluctance path to the flux, it is made up of magnetic material like cast iron or cast steel.

It is made up of laminated construction to keep eddy current loss as low as possible. A single circular lamination used for the construction of the armature core is shown in the Fig. 2.3.3.

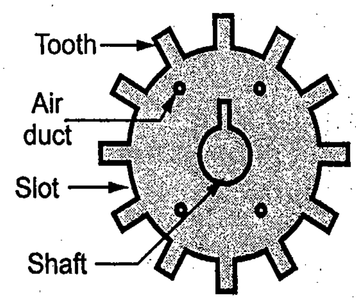


Fig. 2.3.3 Single circular lamination of armature core

II) Armature winding : Armature winding is nothing but the interconnection of the armature conductors, placed in the slots provided on the armature core periphery. When the armature is rotated, in case of generator, magnetic flux gets cut by armature conductors and e.m.f. gets induced in them.

a) Functions :

1. Generation of e.m.f. takes place in the armature winding in case of generators.
2. To carry the current supplied in case of d.c. motors.
3. To do the useful work in the external circuit.

b) Choice of material : As armature winding carries entire current which depends on external load, it has to be made up of conducting material, which is copper.

Armature winding is generally former wound. The conductors are placed in the armature slots which are lined with though insulating material.

2.3.5 Commutator

We have seen earlier that the basic nature of e.m.f. induced in the armature conductors is alternating. This needs rectification in case of d.c. generator, which is possible by a device called commutator.

a) Functions :

1. To facilitate the collection of current from the armature conductors.
2. To convert internally developed alternating e.m.f. to unidirectional (d.c.) e.m.f.
3. To produce unidirectional torque in case of motors.

b) Choice of material : As it collects current from armature, it is also made up of copper segments.

It is cylindrical in shape and is made up of wedge shaped segments of hard drawn, high conductivity copper. These segments are insulated from each other by thin layer of mica. Each commutator segment is connected to the armature conductor by means of copper lug or strip. This connection is shown in the Fig. 2.3.4.

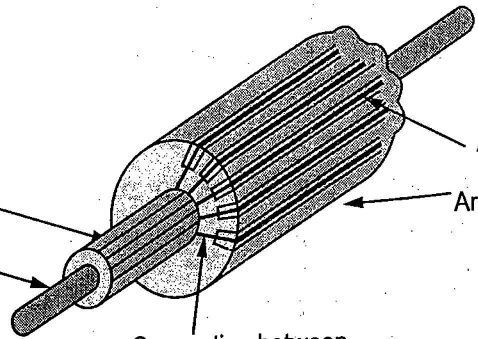


Fig. 2.3.4 Commutator

2.3.6 Brushes and Brush Gear

Brushes are stationary and resting on the surface of the commutator.

a) Function : To collect current from commutator and make it available to the stationary external circuit.

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

Brushes are rectangular in shape. They are housed in brush holders, which are usually of box type. The brushes are made to press on the commutator surface by means of a spring, whose tension can be adjusted with the help of lever. A flexible copper conductor called **pig tail** is used to connect the brush to the external circuit. To avoid wear and tear of commutator, the brushes are made up of soft material like carbon.

2.3.7 Bearings

Ball-bearings are usually used as they are more reliable. For heavy duty machines, roller bearings are preferred.

Review Questions

1. *Draw a detailed sketch of a d.c. machine and identify the different parts. Briefly explain the function of each major part.*

   JNTU : Nov.-03, 04, 05, 08, 13, May-04, 05, 09, March-06, Nov.-08, May-09, Marks 14

2. *Name the main parts of a D.C. machine and state the materials of which each part is made.*

   JNTU : Nov.-03, 05, June-04, Dec.-04, May-05, March-06, Marks 13

3. *Explain the purpose of a pole shoe in a d.c. machine with the help of diagrams.*

   JNTU : Jan.-14, Marks 6

2.4 Types of Armature Winding

JNTU : Nov.-04, 08, 09, 12, May-03, 09

We have seen that there are number of armature conductors, which are connected in specific manner as per the requirement, which is called **armature winding.** According to the way of connecting the conductors, armature winding has basically two types namely,

a) Lap winding b) Wave winding.

2.4.1 Lap Winding

In this case, if connection is started from conductor in slot 1 then connections overlap each other as winding proceeds, till starting point is reached again.

Developed view of part of the armature winding in lap fashion is shown in the Fig. 2.4.1.

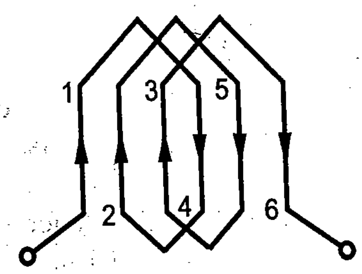


Fig. 2.4.1 Lap winding

As seen from the Fig. 2.4.1, there is overlapping of coils while proceeding.

Key Point *Due to such connection, the total number of conductors get divided into 'P' number of parallel paths, where P = Number of poles in the machine.*

Large number of parallel paths indicate high current capacity of machine hence lap winding is preferred for high current rating generators.

2.4.2 Wave Winding

In this type of connection, winding always travels ahead avoiding overlapping. It travels like a progressive wave hence called wave winding. To get an idea of wave winding a part of armature winding in wave fashion is shown in the Fig. 2.4.2.

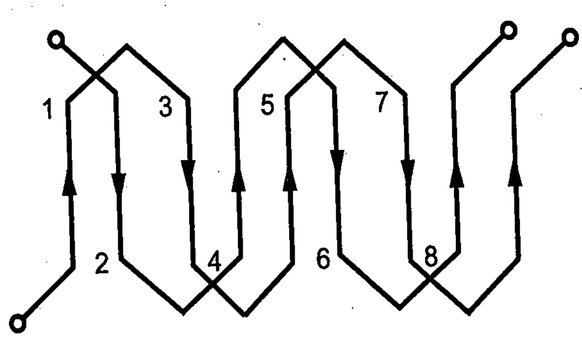


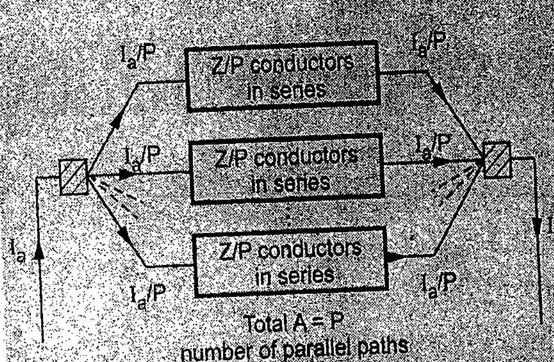
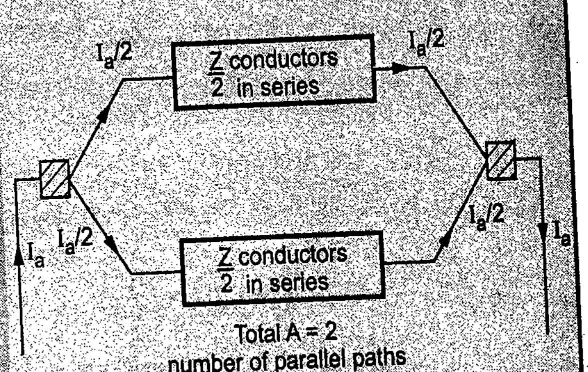
Fig. 2.4.2 Wave winding

Both coils starting from slot 1 and slot 2 are progressing in wave fashion.

Key Point *Due to this type of connection, the total number of conductors get divided into two number of parallel paths always, irrespective of number of poles of the machine. As number of parallel paths are less, it is preferable for low current, high voltage capacity generators.*

The number of parallel paths in which armature conductors are divided due to lap or wave fashion of connection is denoted as A. So **A = P** for **lap** connection and **A = 2** for **wave** connection.

2.4.3 Comparison of Lap and Wave Type Windings

Sr. No.	Lap winding	Wave winding
1.	Number of parallel paths (A) = poles (P).	Number of parallel paths (A) = 2 (always)
2.	Number of brush sets required is equal to number of poles.	Number of brush sets required is always equal to two.
3.	Preferable for high current, low voltage capacity generators.	Preferable for high voltage, low current capacity generators.
4.	Normally used for generators of capacity more than 500 A.	Preferred for generators of capacity less than 500 A.
5.	If Z = Total number of conductors then, 	If Z = Total number of conductors then, 

2.4.4 Winding Terminologies

a) Conductor : It is the actual armature conductor which is under the influence of the magnetic field, placed in the armature slot.

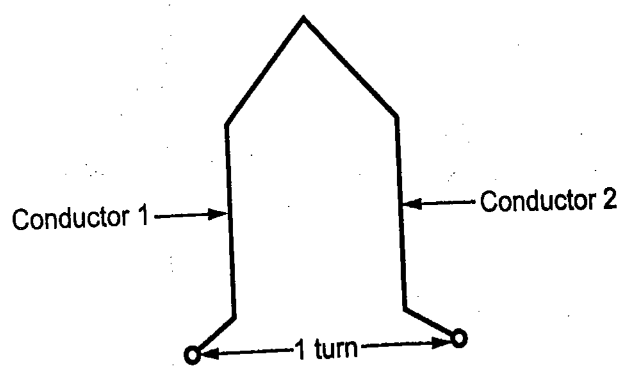


Fig. 2.4.3 Single turn

b) Turn : The two conductors placed in different slots when connected together, forms a turn. While describing armature winding the number of turns may be specified from which, the number of conductors can be decided.

$$Z = 2 \times \text{Number of turns}$$

3.1 Introduction

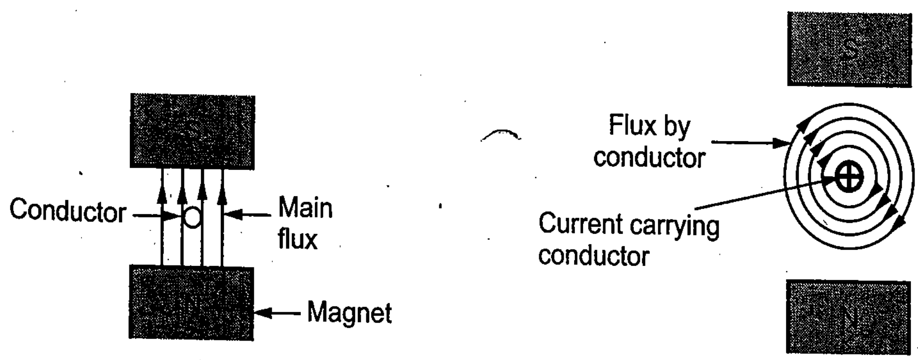
An electric motor is a device which converts an electrical energy into mechanical energy. In a d.c. motor, input electrical energy is supplied by a d.c. supply. The basic construction of d.c. machine is same whether it is a motor or a generator.

3.2 Principle of Operation of a D.C. Motor

JNTU : Nov.-03, 08, May-05

The principle of operation of a d.c. motor can be stated in a single statement as 'when a current carrying conductor is placed in a magnetic field; it experiences a mechanical force'. In a practical d.c. motor, field winding produces a required magnetic field while armature conductors play a role of a current carrying conductors and hence armature conductors experience a force. As conductors are placed in the slots which are on the periphery, the individual force experienced by the conductors acts as a twisting or turning force on the armature which is called a **torque**. The torque is the product of force and the radius at which this force acts. So overall armature experiences a torque and starts rotating. Let us study this motoring action in detail.

Consider a single conductor placed in a magnetic field as shown in the Fig. 3.2.1 (a). The magnetic field is produced by a permanent magnet but in a practical d.c. motor it is produced by the field winding when it carries a current.



(a) Conductor in a magnetic field **(b) Flux produced by current carrying conductor**

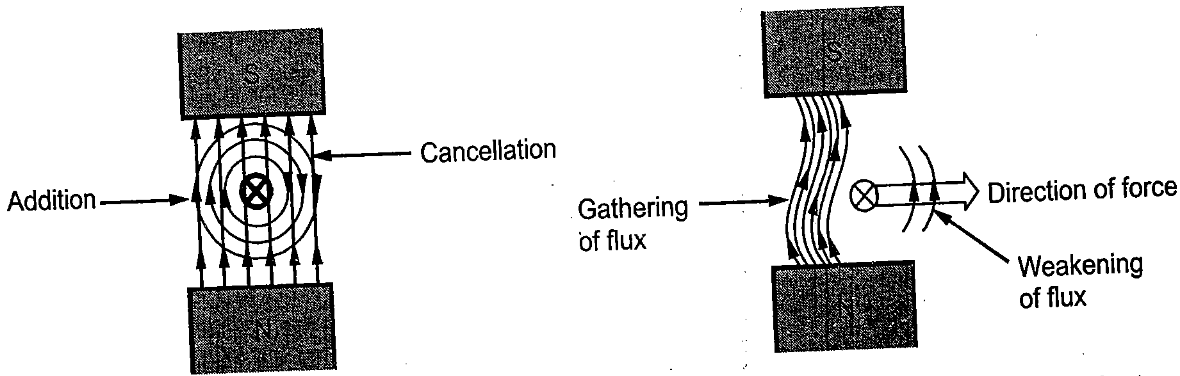
Fig. 3.2.1

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 the Fig. 3.2.1 (b). 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. For simplicity of understanding, the main flux produced by the permanent magnet is not shown in the Fig. 3.2.1 (b).

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 the Fig. 3.2.2 (a). 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 fluxes help each other. As against this, on the right of the conductor, the two fluxes are in opposite direction and hence try to cancel each other. 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 the Fig. 3.2.2 (b).



(a) Interaction of two fluxes (b) Force experienced by the conductor

Fig. 3.2.2

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 the Fig. 3.2.2 (b).

Key Point *In the practical d.c. motor, the permanent magnet is replaced by a field winding which produces the required flux called main flux and all the armature conductors, mounted on the periphery of the armature drum, get subjected to the mechanical force. Due to this, overall armature experiences a twisting force called torque and armature of the motor starts rotating.*

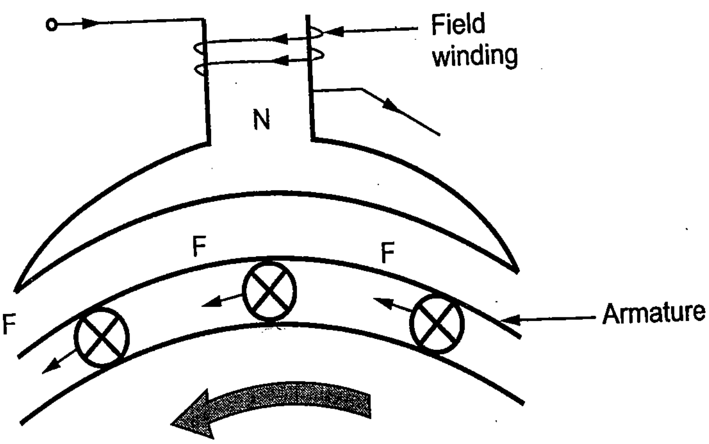


Fig. 3.2.3 Torque exerted on armature

Review Question

1. *Explain the working principle of a d.c. motor.* **JNTU : Nov.-03, 08, May-05, Marks 8**

conductor reverses its direction. However if both the directions are reversed, the direction of the force experienced remains the same.

Key Point *So in a practical motor, to reverse its direction of rotation, either direction of main field produced by the field winding is reversed or direction of the current passing through the armature is reversed.*

The direction of the main field can be reversed by changing the direction of current passing through the field winding, which is possible by interchanging the polarities of supply which is given to the field winding. In short, to have a motoring action two fluxes must exist, the interaction of which produces a torque.

Review Questions

1. *How to decide the direction of rotation of a d.c. motor ?*
2. *Explain clearly how the direction of rotation of a d.c. motor can be reversed.*

JNTU : Nov.-04, March-06, Marks 4

3.4 Significance of Back E.M.F.

JNTU : May-04, 05, Nov.-04, 06, March-06

It is seen in the generating action, that when a conductor cuts the lines of flux, e.m.f. gets induced in the conductor. The question is obvious that in a d.c. motor, after a motoring action, armature starts rotating and armature conductors cut the main flux. So is there a generating action existing in a motor ? The answer to this question is 'Yes'.

After a motoring action, there exists a generating action. There is an induced e.m.f. in the rotating armature conductors according to Faraday's law of electromagnetic induction. This induced e.m.f. in the armature always acts in the opposite direction of the supply voltage. This is according to the **Lenz's law** which states that the direction of the induced e.m.f. is always so as to oppose the cause producing it. In a d.c. motor, electrical input i.e. the supply voltage is the cause and hence this induced e.m.f. opposes the supply voltage. This e.m.f. tries to set up a current through the armature which is in the opposite direction to that, which supply voltage is forcing through the conductor.

So as this e.m.f. always opposes the supply voltage, it is called **back e.m.f.** and denoted as E_b. Though it is denoted as E_b, basically it gets generated by the generating action which we have seen earlier in case of generators. So its magnitude can be determined by the e.m.f. equation which is derived earlier. So,

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

where all symbols carry the same meaning as seen earlier.

3.17.1 Three Point Starter

The Fig. 3.17.2 shows this type of starter.

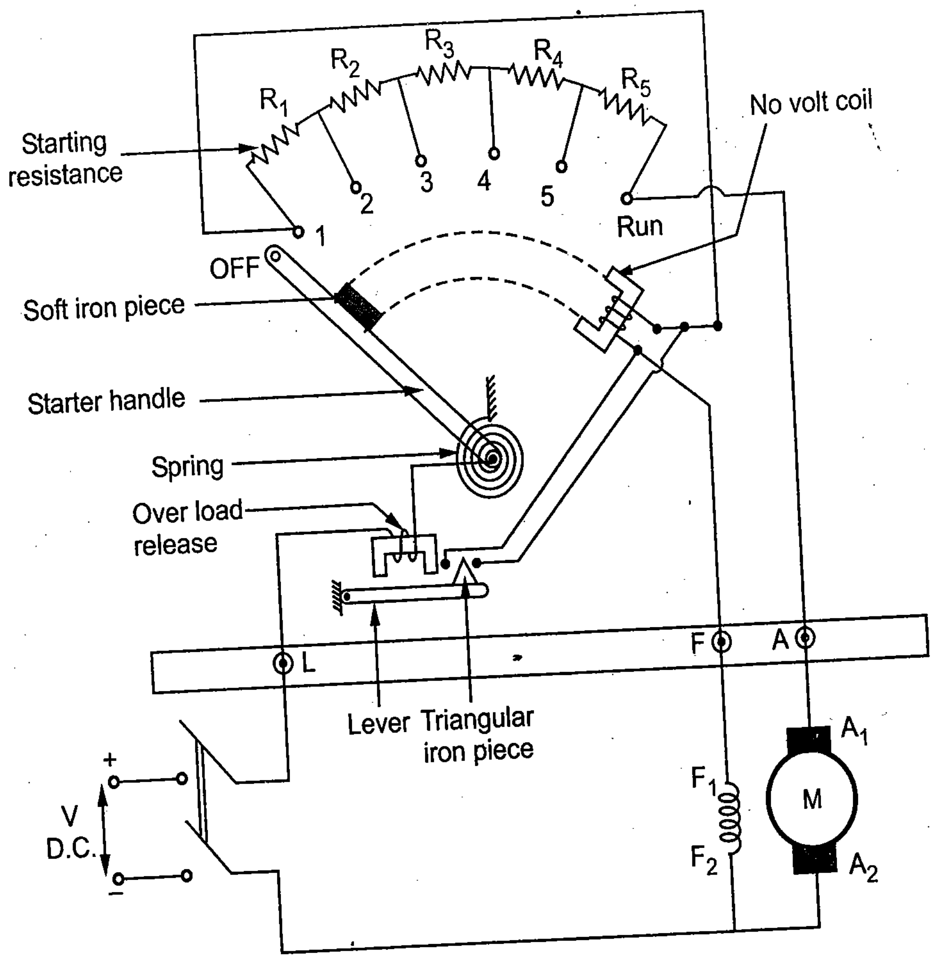


Fig. 3.17.2 Three point starter

The starter is basically a variable resistance, divided into number of sections. The contact points of these sections are called **studs** and brought out separately shown as OFF, 1, 2, ... upto RUN. There are three main points of this starter :

1. 'L' → Line terminal to be connected to positive of supply.
2. 'A' → To be connected to the armature winding.
3. 'F' → To be connected to the field winding.

Point 'L' is further connected to an electromagnet called **Overload Release** (OLR). The second end of 'OLR' is connected to a point where handle of the starter is pivoted. This handle is free to move from its other side against the force of the spring. This spring brings back the handle to the OFF position under the influence of its own force. Another parallel path is derived from the stud '1', given to the another electromagnet called **No Volt Coil** (NVC). The NVC is further connected to terminal 'F'. The starting resistance is entirely in series with the armature. The OLR and NVC are the two protecting devices of the starter.

Operation : Initially the handle is in the OFF position. The d.c. supply to the motor is switched on. Then handle is slowly moved against the spring force to make a contact with stud No. 1. At this point, field winding gets supply through the parallel path provided to starting resistance, through NVC. While entire starting resistance comes in series with the armature and armature current which is high at start, gets limited. As the handle is moved further, it goes on making contact with studs 2, 3, 4 etc., cutting out the starting resistance gradually from the armature circuit. Finally when the starter handle is in 'RUN' position, the entire starting resistance gets removed from the armature circuit and motor starts operating with normal speed. The handle is moved manually, and the obvious question is how handle will remain in the 'RUN' position, as long as motor is running ?

Let us see the action of NVC which will give the answer to this question along with some other functions of NVC.

3.17.1.1 Functions of No Volt Coil

1. The supply to the field winding is derived through NVC. So when field current flows, it magnetises the NVC. When the handle is in the 'RUN' position, soft iron piece connected to the handle gets attracted by the magnetic force produced by NVC. Design of NVC is such that it holds the handle in 'RUN' position against the force of the spring as long as supply to the motor is proper. Thus NVC holds the handle in the 'RUN' position and hence also called **hold on coil.**
2. Whenever there is supply failure or if field circuit is broken, the current through NVC gets affected. It looses its magnetism and hence not in a position to keep the soft iron piece on the handle, attracted. Under the spring force, handle comes back to OFF position, switching off the motor. So due to the combination of NVC and the spring, the starter handle always comes back to OFF position whenever there is any supply problem. The entire starting resistance comes back in series with the armature when attempt is made to start the motor everytime. This prevents the damage of the motor caused due to accidental starting.
3. NVC performs the similar action under low voltage conditions and protects the motor from such dangerous supply conditions as well.

3.17.1.2 Action of Over Load Release

The current through the motor is taken through the OLR, an electromagnet. Under overload condition, high current is drawn by the motor from the supply which passes through OLR. Below this magnet, there is an arm which is fixed at its fulcrum and normally resting in horizontal position. Under overloading, high current though OLR produces enough force of attraction to attract the arm upwards. Normally magnet is so designed that up to a full load value of current, the force of attraction produced is just enough to balance the gravitational force of the arm and hence not lifting it up. At the end of this arm, there is a triangular iron piece fitted. When the arm is pulled upwards the triangular piece touches to the two points which are connected to the two ends of NVC. This shorts the NVC and voltage across NVC becomes zero due to which NVC looses its magnetism. So under the spring force, handle comes back to the OFF position, disconnecting the motor from the supply. Thus motor gets saved from the overload conditions.

In this starter, it can be observed that as handle is moved from different studs one by one, the part of the starting resistance which gets removed from the armature circuit, gets added to the field circuit. As the value of starting resistance is very small as compared to the field winding resistance, this hardly affects the field winding performance. But this addition of the resistance in the field circuit can be avoided by providing a brass arc or copper arc connected just below the stud, the end of which is connected to NVC, as shown in the Fig. 3.17.3.

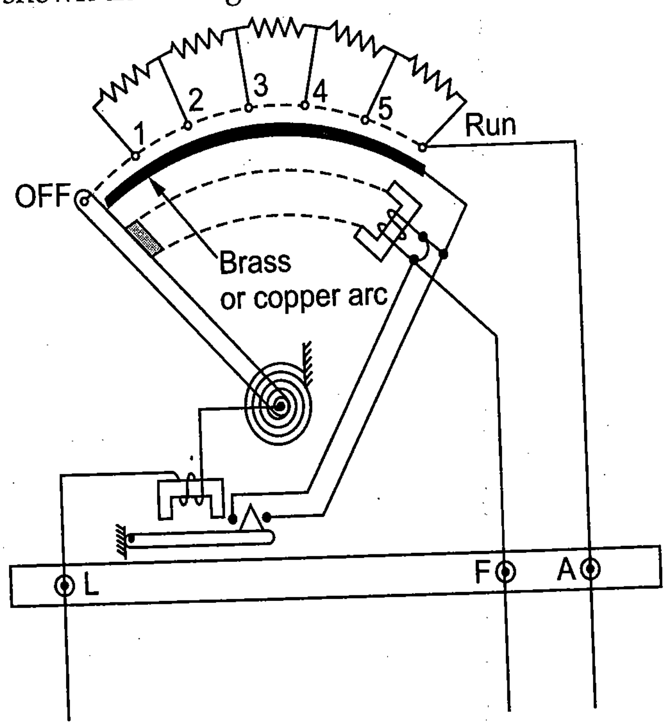


Fig. 3.17.3 Three point starter with brass arc

The handle moves over this arc, supplying the field current directly bypassing the starting resistance. When such an arc is provided, the connection used earlier to supply field winding, is removed.

3.17.1.3 Disadvantage

In this starter, the NVC and the field winding are in series. So while controlling the speed of the motor above rated, field current is reduced by adding an extra resistance in series with the field winding. Due to this, the current through NVC also reduces. Due to this, magnetism produced by NVC also reduces. This may release the handle from its RUN position switching off the motor. To avoid the dependency of NVC and the field winding, four point starter is used, in which NVC and the field winding are connected

3.19 Speed Control of D.C. Shunt Motor

JNTU : Dec.-03, May-04, 05, 08, 09, Nov.-03, 04, 05, 08, March-06

Out of the three methods, let us study flux control method.

3.19.1 Flux Control

As indicated by the speed equation, the speed is inversely proportional to the flux. The flux is dependent on the current through the shunt field winding. Thus flux can be controlled by adding a rheostat (variable resistance) in series with the shunt field winding, as shown in the Fig. 3.19.1.

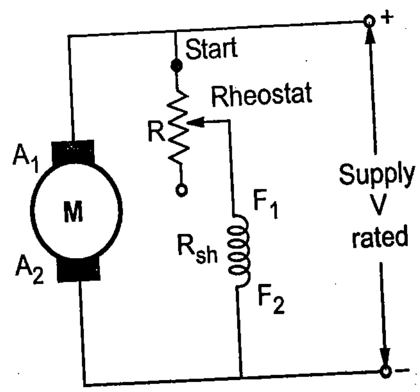


Fig. 3.19.1 Flux control of shunt motor

At the beginning the rheostat R is kept at minimum indicated as start in the Fig. 3.19.1. The supply voltage is at its rated value. So current through shunt field winding is also at its rated value. Hence the speed is also rated speed also called normal speed. Then the resistance R is increased due to which shunt field current I_{sh} decreases, decreasing the flux produced. As $N \propto (1/\phi)$, the speed of the motor increases beyond its rated value.

Thus by this method, the speed control above rated value is possible. This is shown in the Fig. 3.19.2, by speed against field current curve. The curve shows the inverse relation between N and ϕ as its nature is rectangular hyperbola.

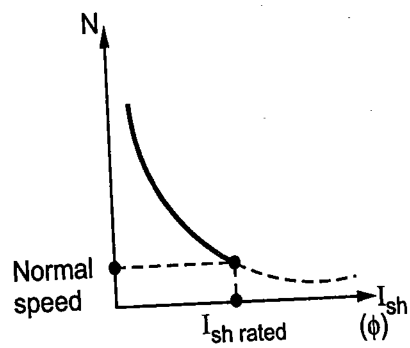


Fig. 3.19.2 N Vs I_{sh} (ϕ) for shunt motor

It is mentioned that the rated values of electrical parameters should not be exceeded but the speed which is mechanical parameter can be increased upto twice its rated value.

3.19.1.1 Advantages of Flux Control Method

1. It provides relatively smooth and easy control.
2. Speed control above rated speed is possible.
3. As the field winding resistance is high, the field current is small. Hence power loss (I_{sh}^2 R) in the external resistance is very small, which makes the method more economical and efficient.
4. As the field current is small, the size of the rheostat required is small.

3.19.1.2 Disadvantages of Flux Control Method

1. The speed control below normal rated speed is not possible as flux can be increased only upto its rated value.

2. As flux reduces, speed increases. But high speed affects the commutation making motor operation unstable. So there is limit to the maximum speed above normal, possible by this method.

3.19.2 Armature Voltage Control Method or Rheostatic Control

The speed is directly proportional to the voltage applied across the armature. As the supply voltage is normally constant, the voltage across the armature can be controlled by adding a variable resistance in series with the armature as shown in the Fig. 3.19.3.

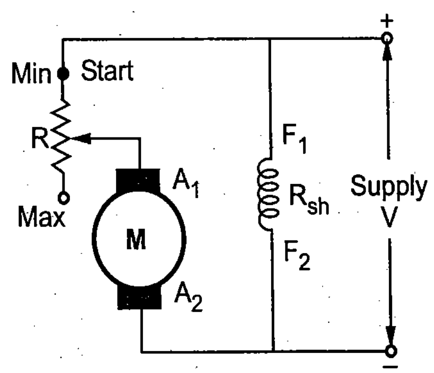


Fig. 3.19.3 Rheostatic control of shunt motor

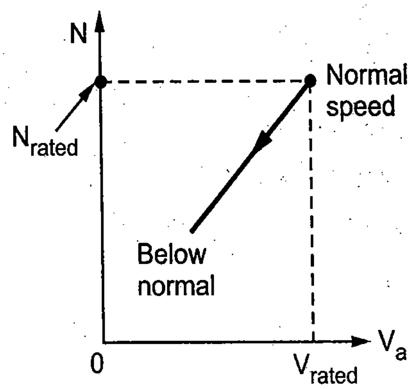


Fig. 3.19.4 N Vs voltage across armature

The field winding is excited by the normal voltage hence I_{sh} is rated and constant in this method. Initially the rheostat position is minimum and rated voltage gets applied across the armature. So speed is also rated. For a given load, armature current is fixed. So when extra resistance is added in the armature circuit, I_a remains same and there is voltage drop across the resistance added (I_a R). Hence voltage across the armature decreases, decreasing the speed below normal value. By varying this extra resistance, various speeds below rated value can be obtained.

So for a **constant load torque**, the speed is directly proportional to the voltage across the armature. The relationship between speed and voltage across the armature is shown in the Fig. 3.19.4.

3.19.2.1 Potential Divider Control

The main disadvantage of the above method is, the speed upto zero is not possible as it requires a large rheostat in series with the armature which is practically impossible. If speed control from zero to the rated speed is required, by rheostatic method then voltage across the armature can be varied by connecting rheostat in a potential divider arrangement as shown in the Fig. 3.19.5.

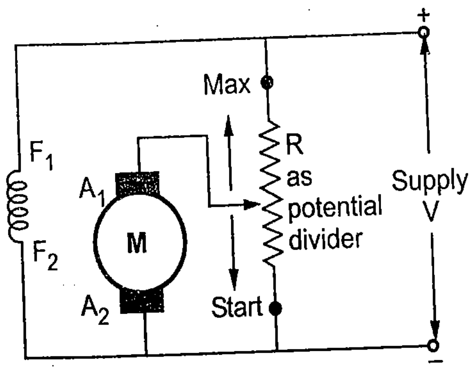


Fig. 3.19.5 Potential divider arrangement

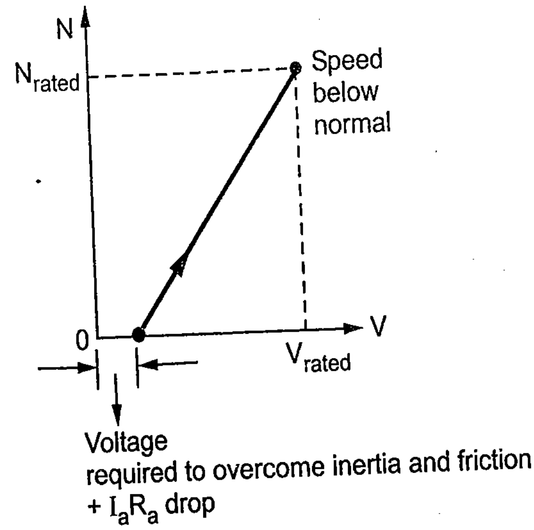


Fig. 3.19.6 N Vs V

When the variable rheostat position is at 'start' point shown, voltage across the armature is zero and hence speed is zero. As rheostat is moved towards 'maximum' point shown, the voltage across the armature increases, increasing the speed. At maximum point the voltage is maximum i.e. rated hence maximum speed possible is rated speed. The relationship is shown in the Fig. 3.19.6.

When the voltage across the armature starts increasing, as long as motor does not overcome inertial and frictional torque, the speed of the motor remains zero. The motor requires some voltage to start hence the graph of voltage and the speed does not pass through the origin as shown in the Fig. 3.19.6.

3.19.2.2 Advantages of Rheostatic Control

1. Easy and smooth speed control below normal is possible.
2. In potential divider arrangement, rheostat can be used as a starter.

3.19.2.3 Disadvantages of Rheostatic Control

1. As the entire armature current passes through the external resistance, there are tremendous power losses.
2. As armature current is more than field current, rheostat required is of large size and capacity.
3. Speed above rated is not possible by this method.
4. Due to large power losses, the method is expensive, wasteful and less efficient.
5. The method needs expensive heat dissipation arrangements.

3.19.3 Applied Voltage Control

Multiple voltage control : In this technique the shunt field of the motor is permanently connected to a fixed voltage supply, while the armature is supplied with various voltages by means of suitable switch gear arrangements.

The Fig. 3.19.7 shows a control of motor by two different working voltages which can be applied to it with the help of switch gear.

In large factories, various values of armature voltages and corresponding arrangement can be used to obtain the speed control.

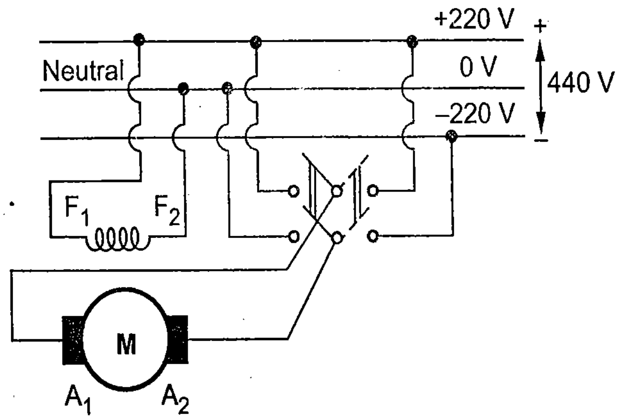


Fig. 3.19.7 Multiple voltage control

3.19.3.1 Advantages of Applied Voltage Control

1. Gives wide range of speed control.
2. Speed control in both directions can be achieved very easily.
3. Uniform acceleration can be obtained.

3.19.3.2 Disadvantages of Applied Voltage Control

1. Arrangement is expensive as provision of various auxiliary equipments is necessary. 2. Overall efficiency is low.

* General steps to solve problems on speed control

1. Identify the method of speed control i.e. in which winding of the motor, the external resistance is to be inserted.
2. Use the torque equation, $T \propto \phi I_a$ to determine the new armature current according to the condition of the torque given. Load condition indicates the condition of the torque.
3. Use the speed equation $N \propto \frac{E_b}{\phi}$ to find the unknown back e.m.f. or field current.
4. From the term calculated above and using voltage current relationship of the motor, the value of extra resistance to be added, can be determined. The above steps may vary little bit according to the nature of the problem but are always the base of any speed control problem.

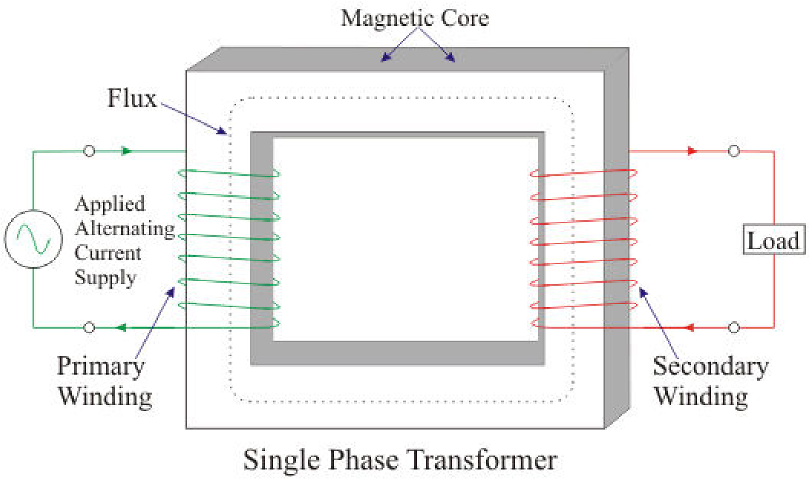
Example 3.19.1 *A 220 V D.C. shunt motor with constant field drives a load whose torque is proportional to the speed. When running at 1000 r.p.m. it takes 30 A. Find the speed at which it will run if a 10 Ω resistance is connected in series with its armature. The resistance of armature may be neglected.* **JNTU : Dec.-03, Marks 8**

Solution :

$$E_{b1} = V - I_{a1}R_a = 220 - 0 = 220 \text{ V} \ldots R_a \text{ neglected}$$

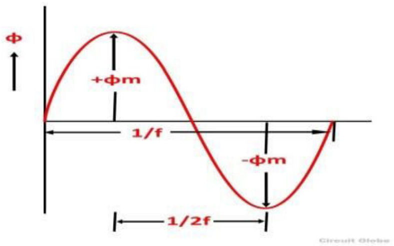
<u>**Unit – 3**</u>

1. Explain the *Working principle* of transformer



1. The basic working principle of a transformer is mutual induction between two windings linked by common magnetic flux.
2. The primary and secondary coils are electrically separated but magnetically linked to each other.
3. When, primary winding is connected to a source of alternating voltage, alternating magnetic flux is produced around the winding.
4. The core provides magnetic path for the flux, to get linked with the secondary winding. Most of the flux gets linked with the secondary winding which is called as 'useful flux' or main 'flux', and the flux which does not get linked with secondary winding is called as 'leakage flux'.
5. As the flux produced is alternating (the direction of it is continuously changing), EMF gets induced in the secondary winding according to Faraday's law of electromagnetic induction. This induced emf is called 'mutually induced emf', and the frequency of mutually induced emf is same as that of supplied emf. Thus, in a transformer the frequency is same on both sides.
6. If the secondary winding is closed circuit, then mutually induced makes the current flow through it, and hence the electrical energy is transferred from one circuit (primary) to another circuit (secondary).

2. Derive the *EMF Equation* of a Transformer



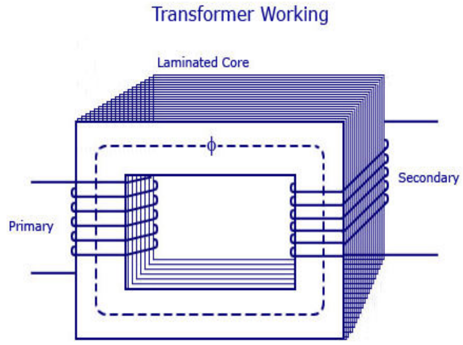
Let
ϕ_m = Maximum value of flux in Weber
f = Supply frequency in Hz
N_1 = Number of turns in the primary winding
N_2 = Number of turns in the secondary winding
Φ = flux per turn in Weber
As per the faradays laws,
The average value of the emf induced is directly proportional to the rate of change of flux.

- The flux changes from + ϕ_m to – ϕ_m in half a cycle of 1/2f seconds.
- Flux increases from its zero value to maximum value ϕ_m in one quarter of the cycle i.e. in ¼ of the timeperiod.
- Average rate of change of flux is $\frac{d\phi}{dt} = \frac{\phi_m - 0}{\frac{1}{4f}} = 4\phi_m f$ volts
- Therefore the average e.m.f per turn is $4\phi_m f$
- As $\frac{Rmsvalue}{Averagevalue} = Formfactor = 1.11$ for sinusoidal varying quatities
- Hence, RMS value of e.m.f/turn is $1.11 * 4\phi_m f = 4.44\phi_m f$

- RMS value of e.m.f in the primary & secondary winding. =(e.m.f/turn) * No:of turns
- Therefore Emf induced in primary winding having N_1turns is $E_1 = 4.44\phi_m fN_1$
- Emf induced in secondary winding having N_2 turns is $E_2 = 4.44\phi_m fN_2$

3. Explain the *Construction of Transformer*

1. The simple construction of a transformer, need two coils having mutual inductance and a laminated steel core.
2. The two coils are insulated from each other and from the steel core.
3. The device will also need some suitable container for the assembled core and windings, a medium with which the core and its windings from its container can be insulated.
4. In order to insulate and to bring out the terminals of the winding from the tank, bushings made of porcelain are used.
5. In all transformers, the core is made of transformer sheet steel laminations assembled to provide a continuous magnetic path with minimum of air-gap included.

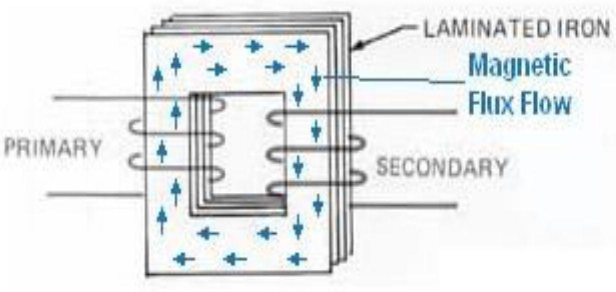


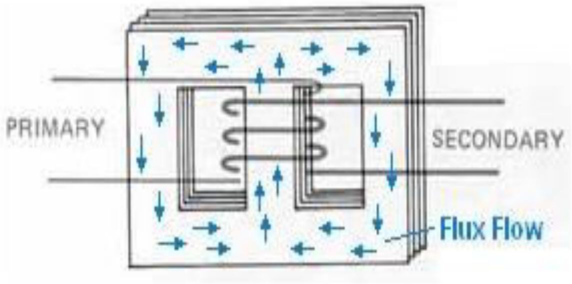
6. The steel should have high permeability and low hysteresis loss. For this to happen, the steel should be made of high silicon content and must also be heat treated.
7. By effectively laminating the core, the eddy-current losses can be reduced. The lamination can be done with the help of a light coat of core plate varnish or lay an oxide layer on the surface. For a frequency of 50 Hertz, the thickness of the lamination varies from 0.35mm to 0.5mm for a frequency of 25 Hertz.
8. To reduce the leakage fluxes in the transformer the windings of the primary and secondary coils are interleaved in the core type and sandwiched coils in the shell type.
9. To reduce the volume of the cu wire the core used must be the stepped core or cruciform core.

4. Compare and distinguish *the types of transformers*

There are two major types of transformers based on construction. 1. Core type 2. Shell type

S.No	Core type Transformer	Shell type transformer
1	The winding encircles the core	The core encircles the winding
2	The cylindrical type of coils are used	Generally multilayer disc type or sandwiched coils coils are used
3	As windings are distributed, the natural cooling is more effective	As windings are surrounded by the core, the natural cooling does not exists.
4	The coils can be easily removed from the maintenance point of view	For removing any winding for maintenance, a large number of laminations are to be removed. This is difficult.
5	The construction is preferred for low voltage transformers	The construction is used for very high voltage transformers
6	It has a single magnetic core	It has a double magnetic core
7	In a single phase type there are two limbs	In a single phase type the core has three limbs

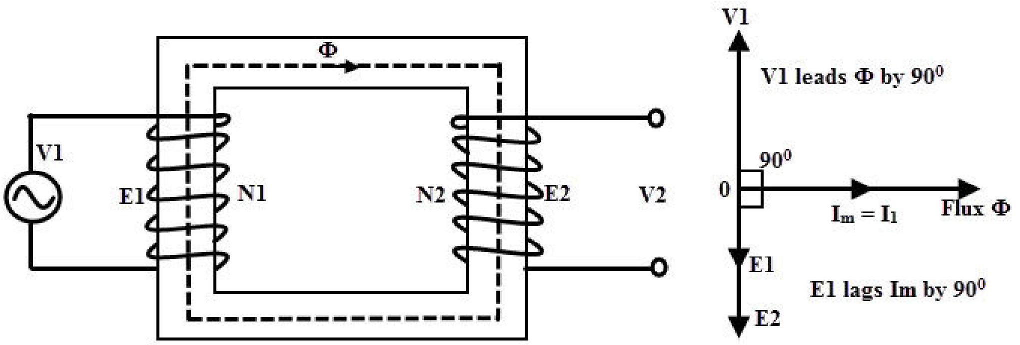




5. Explain the operation of *Transformer on No Load.*

<u>Ideal transformer at No-Load:</u>

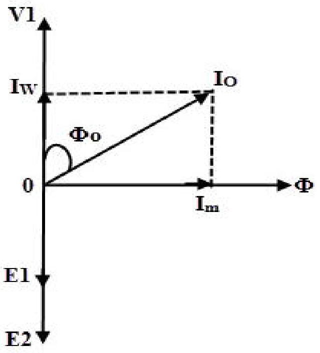
1. The transformer operating at no load, is equivalent to the secondary winding kept open circuited, which means current in the secondary is zero.
2. When primary winding is excited at its rated voltage it draws a current I_m called magnetizing current which is 2 to 10% of the rated current. This generates the magnetic flux in the core by primary mmf N_1I_m
3. As the transformer is ideal, the core loss and cu loss are zero. And the net current taken is to create the mmf or flux of alternating nature.
4. This alternating flux induces the emf's E_1 and E_2 in the coils which lags the flux by 90^0
5. The I_m is inphase to the flux and the applied voltage leads to the I_m by 90^0 being the coil with pure inductive type.
6. Hence, emf's E_1 and E_2 in the coils are inphase to each other and lags the flux by 90^0



Ideal Transformer at No-Load

<u>Transformer at No-Load:</u>

1. The transformer in the practical case draws an additional current I_w to the magnetizing current I_m and total current from the supply mains is I_0 which lags to the applied voltage by an angle Φ_0
2. There are two components of the current in I_0 namely
   i. Active (or) power (or) Watt full component of the current I_w which is in phase to the voltage, and generates the core loss in the transformer
   ii. Reactive (or) Watt less (or) magnetizing component of the current I_m which lags to the voltage by 90^0, and magnetizes the core in the transformer
3. Also, the no-load input power of the transformer is the iron loss (since the cu loss are small at no-load)
4. The no load angle (Φ_0) depends upon the losses in the transformer and is nearly equal to 90^0. So that the power factor is very low and varies from 0.1 to 0.15 lagging.



6.

Working component $I_w = I_0 \cos\varphi_0$

No load current $I_0 = \sqrt{I_w^2 + I_m^2}$

Magnetizing component $I_m = I_0 \sin\varphi_0$

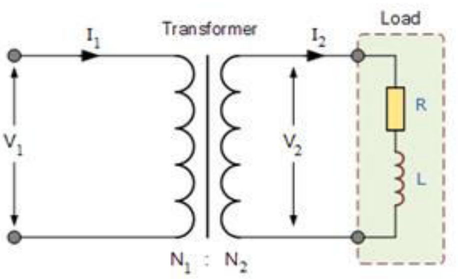
Power factor $\cos\varphi_0 = \frac{I_w}{I_0}$

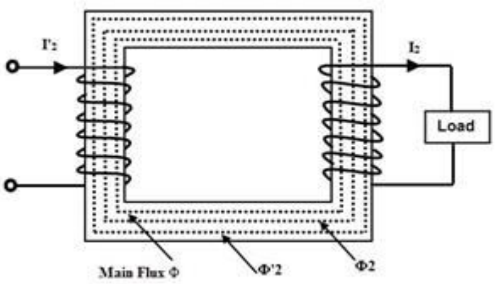
No load power input $P_0 = V_1 I_0 \cos\varphi_0$

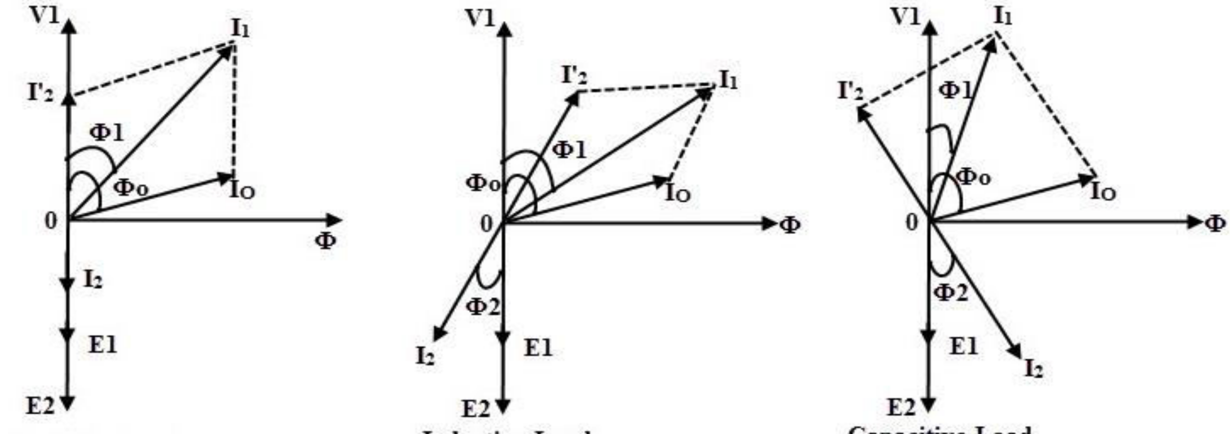
6. Explain the operation of Transformer on Load *without leakage impedances* of the coils.

1. When an electrical load is connected to the secondary winding of a transformer a current flows in the secondary winding.

2. This secondary current is due to the induced secondary voltage, set up by the magnetic flux Φ in the core from the primary current(I_0) and the main flux direction is from primary coil to secondary coil (clockwise)







Resistive Load Inductive Load Capacitive Load

3. The secondary current, I_2 which is determined by the characteristics of the load, creates an secondary or load mmf (N_2I_2) and a secondary magnetic field, Φ_2 is established in the transformer core which flows in the exact opposite direction to the main primary field, Φ_1. i.e Φ_2 is in anti clock wise.

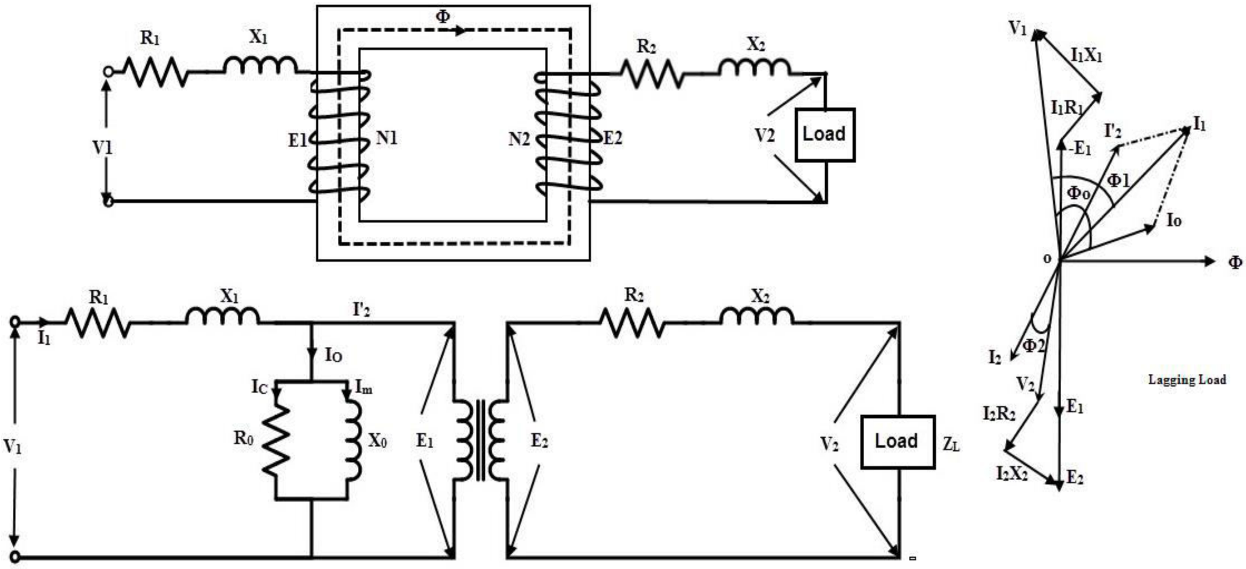
4. These two magnetic fields oppose each other resulting in a combined magnetic field of less magnetic strength than the single field produced by the primary winding alone when the secondary circuit was open circuited.

5. This in turn decreases the primary induced emf and leads to the increase in primary current $I_1=I_0+I_2^1$.
6. This additional I_2^1 current is called load component current in the primary and will be in such a way to balance the load mmf by this mmf on the primary

   i.e $N_2I_2=N_1I_2^1$ therefore $I_2^1= I_2K$ where, $K = N_2/N_1$
7. This $N_1I_2^1$ will produce a flux Φ_2^1 equal and opposite to Φ_2. These fluxes will now be cancelled and the net flux in the core will be Φ_1 even under the loading conditions.
8. For lagging load: $I_1^2 = I_0^2 + (I_2^1)^2 + 2I_0I_2^1\cos(\Phi_0\sim \Phi_2)$
9. As the flux remains constant from no-load to load, the iron loss will be same from no-load to load.

7. Explain the operation of transformer on load with *leakage impedances* of the coils

1. Below figure shows the schematic diagram, equivalent circuit and phasor diagram of the transformer with the leakage impedances of the coils.



Let,

R_1=Resistance of primary coil in Ω *R_2=Resistance of secondary coil in Ω*

X_1=Reactance of primary coil in Ω *X_2=Reactance of secondary coil in Ω*

Z_1=impedance of primary coil in Ω *Z_2=impedance of secondary coil in Ω*

E_1=emf induced in primary coil *E_2=emf induced in secondary coil*

V_1=applied voltage to primary coil *V_2= Load or terminal voltage of transformer*

$I_1Z_1 = I_1(R_1+jX_1)$ = Primary leakage impedance drop

$I_2Z_2 = I_2(R_2+jX_2)$ = Secondary leakage impedance drop

The magnetic core of the transformer is electrically represented with the parallel combination of R_0 and X_0 carrying the currents of I_w and I_m respectively and is placed across the primary coil.

Currents Analysis of the transformer in equivalent circuit

Currents in the transformer at No-load:

$$I_w = \frac{V_1}{R_0} \qquad I_m = \frac{V_1}{X_0} \qquad I_0^2 = I_w^2 + I_m^2 \qquad I_0 = \sqrt{I_w^2 + I_m^2} \qquad \phi_0 = \tan^{-1}\left(\frac{I_m}{I_w}\right)$$

Currents in the transformer with load

$$I_1 = (I_0\angle -\phi_0) + (I_2^1\angle \pm\phi_2) \quad \textit{Where } I_2^1 = I_2 \times K \quad \textit{and} \quad K = \frac{N_2}{N_1}$$

$$I_1 = (I_0 \cos\phi_0 + I_2^1 \cos\phi_2) + j(I_0 \sin(-\phi_0) + I_2^1 \sin(\pm\phi_2))$$ - for lag and + for lead

Primary phase angle (Φ_1)

$$\phi_1 = \tan^{-1}\left(\frac{I_0 \sin(-\phi_0) + I_2^1 \sin(\pm\phi_2)}{I_0 \cos\phi_0 + I_2^1 \cos\phi_2}\right)$$ *and primary power factor is cosΦ_1*

Voltages Analysis of the transformer in equivalent circuit

Primary induced emf

$$E_1 = (V_1\angle 0) - (I_1\angle\phi_1 * Z_1)$$

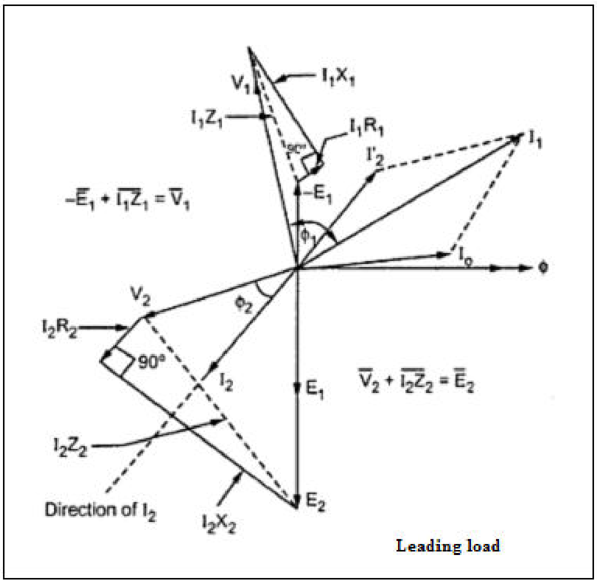
$$E_1 = (V_1 + j0) - \{(I_1 \cos\phi_1 + jI_1 \sin\phi_1) \times (R_1 + jX_1)\}$$

Using transformation ratio $E_2 = E_1 * K$

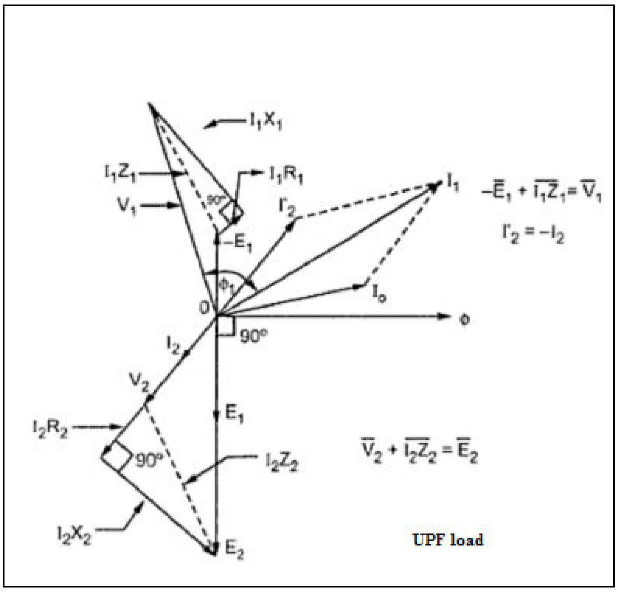
Knowing the E_2 and applying KVL to the secondary loop the load voltage is

$$V_2 = E_2 - I_2 Z_2$$

$$V_2 = E_2\angle\phi' - (I_2\angle\pm\phi_2)Z_2 \qquad V_2 = E_2\angle\phi' - (I_2\angle\pm\phi_2)(R_2 + jX_2)$$



Leading load



UPF load

8. Explain the *equivalent circuits* referred to both primary and secondary of the transformer

The equivalent circuit of the transformer referred to primary is shown in the below figure in which the winding parameters of the secondary are transformed and was referred to primary based on the voltage balancing principle before and after the transformation.

Secondary Resistance referred to primary:

$$R_2^1 = \frac{V_1}{I_1} = \frac{V_1}{I_1} \times \frac{V_2 I_2}{V_2 I_2} = \times \frac{V_1 I_2}{V_2 I_1} \times \frac{V_2}{I_2} = \frac{R_2}{K^2} \qquad \left(\because \frac{V_1}{V_2} = \frac{I_2}{I_1} = \frac{1}{K} \right) also \frac{V_2}{I_2} = R_2$$

$\therefore R_2^1 = \frac{R_2}{K^2}$ Thus, it is the secondary resistance referred to primary

Secondary Reactance referred to primary:

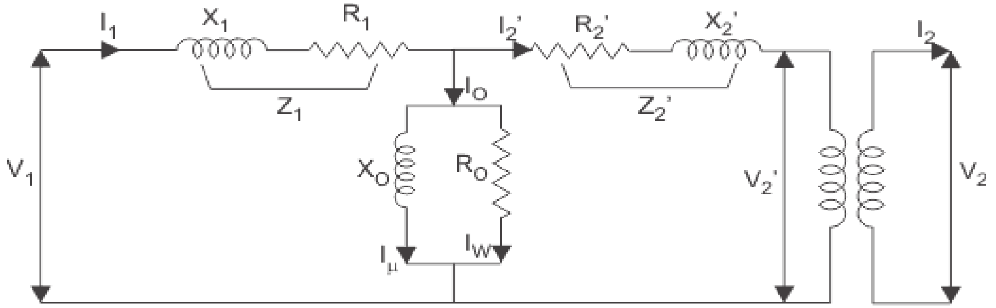
$$X_2^1 = \frac{V_1}{I_1} = \frac{V_1}{I_1} \times \frac{V_2 I_2}{V_2 I_2} = \times \frac{V_1 I_2}{V_2 I_1} \times \frac{V_2}{I_2} = \frac{X_2}{K^2} \qquad \left(\because \frac{V_1}{V_2} = \frac{I_2}{I_1} = \frac{1}{K} \right) also \frac{V_2}{I_2} = X_2$$

$\therefore X_2^1 = \frac{X_2}{K^2}$ Thus, it is the secondary reactance referred to primary

Secondary Impedance referred to primary:

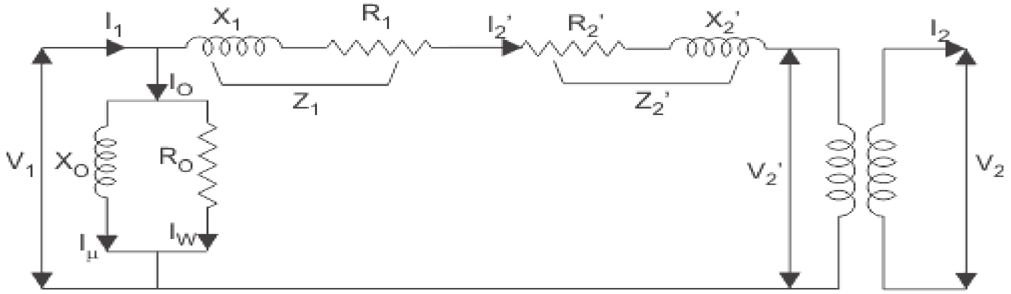
$$Z_2^1 = \frac{V_1}{I_1} = \frac{V_1}{I_1} \times \frac{V_2 I_2}{V_2 I_2} = \times \frac{V_1 I_2}{V_2 I_1} \times \frac{V_2}{I_2} = \frac{Z_2}{K^2} \qquad \left(\because \frac{V_1}{V_2} = \frac{I_2}{I_1} = \frac{1}{K} \right) also \frac{V_2}{I_2} = Z_2$$

$\therefore Z_2^1 = \frac{Z_2}{K^2}$ Thus, it is the secondary impedance referred to primary



Equivalent Circuit of Transformer referred to Primary

To have simplified calculations the equivalent circuit is modified as bringing the core branch towards the supply voltage instead of having in between the primary and secondary parameters



simplified equivalent circuit of transformer reffered to primary

In this simplified circuit the total resistance, reactance and impedances referred to primary are

$$\therefore R_{eq1} = R_1 + R_2^1 = R_1 + \frac{R_2}{K^2} \qquad \therefore X_{eq1} = X_1 + X_2^1 = X_1 + \frac{X_2}{K^2}$$

$$\therefore Z_{eq1} = Z_1 + Z_2^1 = Z_1 + \frac{Z_2}{K^2}$$

Similarly, the equivalent circuit referred to secondary of the transformer is shown below with their formulas

Primary Resistance referred to secondary:

$$R_1^1 = \frac{V_2}{I_2} = \frac{V_2}{I_2} \times \frac{V_1 I_1}{V_1 I_1} = \times \frac{V_2 I_1}{V_1 I_2} \times \frac{V_1}{I_1} = K^2 R_1 \qquad \left(\because \frac{V_2}{V_1} = \frac{I_1}{I_2} = K \right) also \frac{V_1}{I_1} = R_1$$

$\therefore R_1^1 = R_1 K^2$ Thus, it is the primary resistance referred to secondary

Primary Reactance referred to secondary:

$$X_1^1 = \frac{V_2}{I_2} = \frac{V_2}{I_2} \times \frac{V_1 I_1}{V_1 I_1} = \times \frac{V_2 I_1}{V_1 I_2} \times \frac{V_1}{I_1} = K^2 X_1 \qquad \left(\because \frac{V_2}{V_1} = \frac{I_1}{I_2} = K \right) also \frac{V_1}{I_1} = X_1$$

$\therefore X_1^1 = X_1 K^2$ Thus, it is the primary reactance referred to secondary

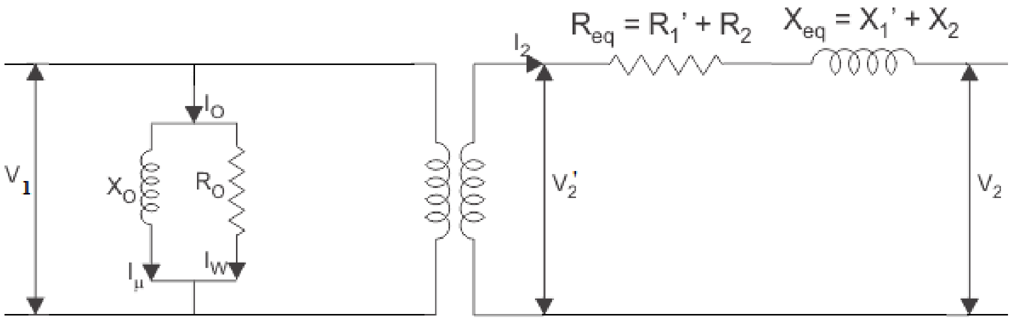
Primary Impedance referred to secondary:

$$Z_1^1 = \frac{V_2}{I_2} = \frac{V_2}{I_2} \times \frac{V_1 I_1}{V_1 I_1} = \times \frac{V_2 I_1}{V_1 I_2} \times \frac{V_1}{I_1} = K^2 Z_1 \qquad \left(\because \frac{V_2}{V_1} = \frac{I_1}{I_2} = K \right) also \frac{V_1}{I_1} = Z_1$$

$\therefore Z_1^1 = Z_1 K^2$ Thus, it is the primary impedance referred to secondary

$$\therefore R_{eq2} = R_2 + R_1^1 = R_2 + R_1 K^2 \qquad \therefore X_{eq2} = X_2 + X_1^1 = X_2 + X_1 K^2$$

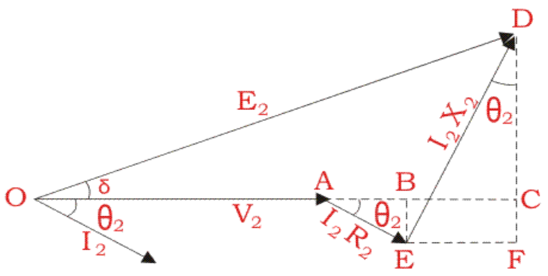
$$\therefore Z_{eq2} = Z_2 + Z_1^1 = Z_2 + Z_1 K^2$$



Approximate Equivalent Circuit of Transformer referred to Secondary

9. Derive the expression for *voltage regulation and efficiency* of the transformer

Definition of voltage regulation : Voltage regulation is defined as the percentage change in the output voltage from no-load to full-load expressed in full load voltage.



$OC = OA + AB + BC$

$Here,\ OA = V_2$

$Here,\ AB = AE\cos\theta_2 = I_2 R_2 \cos\theta_2$

$and,\ BC = DE\sin\theta_2 = I_2 X_2 \sin\theta_2$

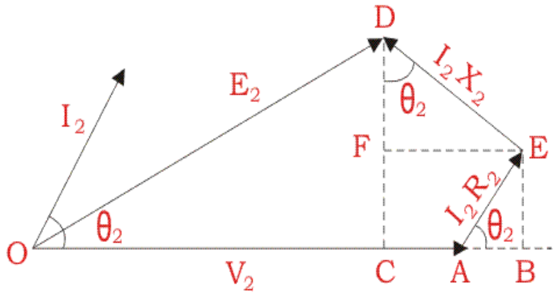
Derivation of voltage regulation for the lagging power factor load,
assuming the angle between OC and OD as very small, and neglected it, OD is nearly equal to OC ($E_2 > V_2$)

$E_2 = OC = OA + AB + BC$, $\quad E_2 = OC = V_2 + I_2 R_{eq2} \cos\phi + I_2 X_{eq2} \sin\phi$

Thus, the % voltage regulation is

$$\frac{E_2 - V_2}{V_2} * 100 = \frac{V_2 + I_2 R_{eq2}\cos\phi + I_2 X_{eq2}\sin\phi - V_2}{V_2} \times 100 = \frac{I_2 R_{eq2}\cos\phi + I_2 X_{eq2}\sin\phi}{V_2} \times 100$$

Derivation of voltage regulation for the leading power factor load,
Similarly, from the phasor diagram of the leading pf load , ($E_2 < V_2$)



Here

$EF = DE \sin\theta = I_2 X_2 \sin\theta$

$AB = AE \cos\theta = I_2 R_2 \cos\theta$

$OA = V_2$ and $OD = E_2$

assuming the angle between OA and OD as very small, and neglected it, OD is nearly equal to OC ($E_2 < V_2$)

$V_2 - E_2 = OA - OC = CA = CB - AB$, thus $V_2 = E_2 + CB - AB$

Thus, the % voltage regulation is

$$\frac{E_2 - V_2}{V_2} * 100 = \frac{E_2 - E_2 - CB + AB}{V_2} \times 100 = \frac{I_2 R_{eq2}\cos\phi - I_2 X_{eq2}\sin\phi}{V_2} \times 100$$

Therefore,

$$\%regulation = \frac{I_2 R_{eq2}\cos\phi \pm I_2 X_{eq2}\sin\phi}{V_2} \times 100$$ (+) for lagging pf and (-) for leading pf

10. Discuss the losses and efficiency in the transformer

Transformer is a static device, i.e. it doesn't have any parts, so no mechanical losses exist in the transformer and only electrical losses are observed.

So there are two primary types of losses in the transformer:

1. Copper losses
2. Iron losses

Other than these, some small amount of power losses in the form of 'stray losses' are also observed, which are produced due to the leakage of magnetic flux.

Copper losses

1. These losses occur in the windings of the transformer when heat is dissipated due to the current passing through the windings and the internal resistance offered by the windings.
2. So these are also known as ohmic losses or I^2R losses, where 'I' is the current passing through the windings and R is the internal resistance of the windings.
3. These losses are present both in the primary and secondary windings of the transformer and depend upon the load attached across the secondary windings since the current varies with the variation in the load, so these are *variable losses.*

Iron losses or Core Losses

1. These losses occur in the core of the transformer and are generated due to the variations in the flux.
2. These losses depend upon the magnetic properties of the materials which are present in the core, so they are also known as iron losses, as the core of the Transformer is made up of iron. And since they do not change like the load, so these losses are also *constant losses.*

There are two types of Iron losses in the transformer:

1. Eddy Current losses
2. Hysteresis Loss

Eddy Current Losses

1. When an alternating current is supplied to the primary windings of the transformer, it generates an alternating magnetic flux in the winding which is then induced in the secondary winding also through Faraday's law of electromagnetic induction, and is then transferred to the externally connected load.
2. During this process, the other conduction materials of which the core is composed of; also gets linked with this flux and an emf is induced.
3. But this magnetic flux does not contribute anything towards the externally connected load or the output power and is dissipated in the form of heat energy.
4. So such losses are called Eddy Current losses and are mathematically expressed as:

$$P_e = K_e f^2 K_f^2 B_m^2$$

Where;

K_e = Constant of Eddy Current

K_f^2 = Form Constant

B_m = Strength of Magnetic Field

Hysteresis Loss

1. Hysteresis loss is defined as the electrical energy which is required to realign the domains of the ferromagnetic material which is present in the core of the transformer.
2. These domains loose their alignment when an alternating current is supplied to the primary windings of the transformer and the emf is induced in the ferromagnetic material of the core which disturbs the alignment of the domains and afterwards they do not realign properly.
3. For their proper realignment, some external energy supply, usually in the form of current is required. This extra energy is known as Hysteresis loss.

   Mathematically, they can be defined as;

$$P_h = K_h B_m^{1.6} f V$$

- The **Efficiency** of the transformer is defined as the ratio of power output to the input power.

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

$$\eta = \frac{\text{output power}}{\text{output power + iron losses + copper losses}}$$

$$\eta = \frac{V_2 I_2 \cos\varphi_2}{V_2 I_2 \cos\varphi_2 + P_i + P_c}$$

Where,

V_2 = Secondary terminal voltage

I_2 = Full load secondary current in A

$\cos\phi_2$ = power factor of the load

P_i = Iron losses = hysteresis losses + eddy current loss

Pc = Full load copper losses = $I_2^2 R_{eq}$

Also, the efficiency at any amount of load(x) is given by

$$\eta = \frac{outputinwatts}{inputinwatts} = \frac{xVA\cos\phi}{xVA\cos\phi + W_i + x^2 W_{FLCu}} \times 100$$

Condition for maximum efficiency in the transformer:

$$\eta = \frac{outputinwatts}{inputinwatts} = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + W_i + I_2^2 r_{e2}} = \frac{1}{1 + \frac{W_i}{V_2 I_2 \cos\phi} + \frac{I_2^2 r_{e2}}{V_2 I_2 \cos\phi}} = \frac{1}{1 + \frac{W_i}{V_2 I_2 \cos\phi} + \frac{I_2 r_{e2}}{V_2 \cos\phi}}$$

To get the maximum efficiency the denominator must be small, therefore condition to be the denominator minimum is

$$\frac{d\left(1 + \frac{W_i}{V_2 I_2 \cos\phi} + \frac{I_2 r_{e2}}{V_2 \cos\phi}\right)}{dI_2} = 0$$

$$\frac{d\left(1 + \frac{W_i}{V_2 I_2 \cos\phi} + \frac{I_2 r_{e2}}{V_2 \cos\phi}\right)}{dI_2} = 0 + \left((-)\frac{W_i}{V_2 I_2^2 \cos\phi}\right) + \left(\frac{r_{e2}}{V_2 \cos\phi}\right) = 0$$

$$\frac{r_{e2}}{V_2 \cos\phi} = \frac{W_i}{V_2 I_2^2 \cos\phi} \qquad r_{e2} = \frac{W_i}{I_2^2} \qquad I_2^2 r_{e2} = W_i$$

Therefore the condition for obtaining the maximum efficiency is the variable loss $\left(I_2^2 r_{e2}\right)$ must be equal to the constant loss W_i.

Also, the load current at which the maximum efficiency occurs is $I_{2\max} = \sqrt{\left(\frac{W_i}{r_{e2}}\right)}$

Multiplying both sides with 1000 *V_2

$$1000 * V_2 * I_{2\max} = 1000 * V_2 * \sqrt{\left(\frac{W_i}{r_{e2}}\right)} \qquad \text{Load KVA}_{\max} = 1000 * V_2 * \sqrt{\left(\frac{W_i}{r_{e2}}\right)}$$

$$\text{Load KVA}_{\max} = 1000 * V_2 * \frac{I_{2\text{Fullload}}}{I_{2\text{Fullload}}} \sqrt{\left(\frac{W_i}{r_{e2}}\right)}$$

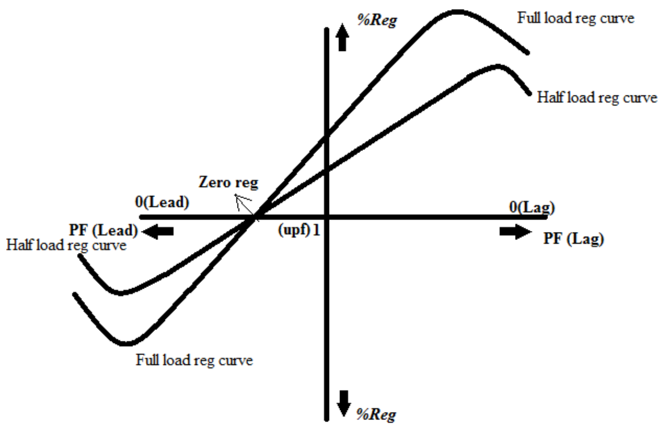
$$\text{Load KVA}_{\max} = 1000 * V_2 * I_{2\text{Fullload}} \sqrt{\left(\frac{W_i}{I_{2\text{Fullload}}^2 r_{e2}}\right)}$$

$$\text{Load KVA}_{\max} = \text{Full load KVA} \sqrt{\left(\frac{W_i}{I_{2\text{Fullload}}^2 r_{e2}}\right)}$$

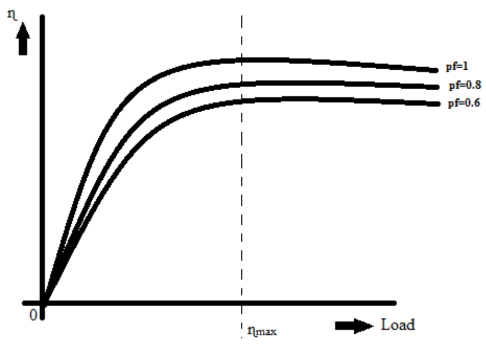
$$\text{The Load KVA at which maximum efficiency} = \text{Full load KVA} \sqrt{\left(\frac{W_i}{W_{\text{cuFullload}}}\right)}$$

$$\boxed{\text{The Load KVA at which maximum efficiency} = \text{Full load KVA} \sqrt{\frac{W_i}{W_{\text{cuFullload}}}}}$$

Variation of voltage regulation and efficiency with respect to load and load powerfactors



Regulation curves w.r.t load pf and amount of loads



Varaiation of efficiency with respect to load and load power factor

11. Explain OC and SC tests on a single phase transformer

Ans: Purpose of conducting OC and SC tests is to find

i) Equivalent circuit parameters ii) Efficiency iii) Regulation

<u>Open Circuit Test:</u>

1. The OC test is performed on LV side at rated voltage and HV side is kept opened.
2. As the test is conducted on LV side the meters selected will be at low range values like smaller voltmeter, smaller ammeter and low pf wattmeter
3. As the no-load current is quite small about 2 to 5% of the rated current, the ammeter required here will be smaller range even after on LV side which are designed for higher current values.
4. The voltmeter, ammeter and the wattmeter readings V_0, I_0 and W_0 respectively are noted by applying rated voltage on LV side.
5. The wattmeter will record the core loss because of noload input power.

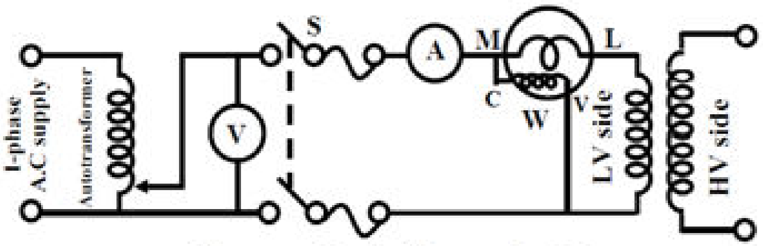


Figure : Circuit diagram for O.C test

<u>Calculations from OC test readings:</u>

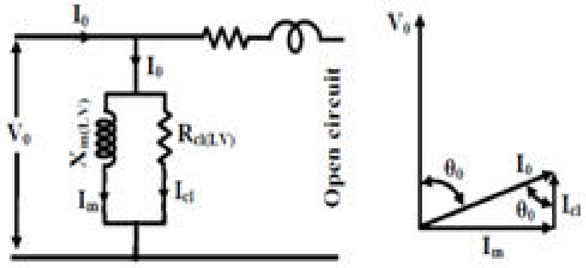
R_0, X_0 and Iron loss are calculated from the OC test results as

Core resistance $R_0 = \frac{V_0}{I_w} = \frac{V_0}{I_0 \cos\phi_0}$

Magnetizing reactance $X_0 = \frac{V_0}{I_m} = \frac{V_0}{I_0 \sin\phi_0}$

Where $\cos\phi_0 = \frac{P_0}{V_0 I_0}$

and iron loss $W_i = P_0$ (No load input power)



(a) Equivalent circuit under O.C test (b) phasor diagram

Figure 2.2: Equivalent circuit & phasor diagram during O.C test

<u>Short Circuit Test:</u>

1. The SC test is performed on HV side at rated current and LV side is kept Shorted.
2. As the test is conducted on HV side the meters selected will be at low range values like smaller voltmeter, smaller ammeter and unity pf wattmeter

3. As the voltage required to circulate the short circuit rated current is very small about 10 to 15% of the rated HV voltage, so the voltmeter required here will be smaller range even the test is conducted on HV side.
4. The voltmeter, ammeter and the wattmeter readings V_{sc}, I_{sc} and W_{sc} respectively are noted by passing rated current on HV side.
5. The wattmeter will record thecopper loss corresponding to the I_{sc}.

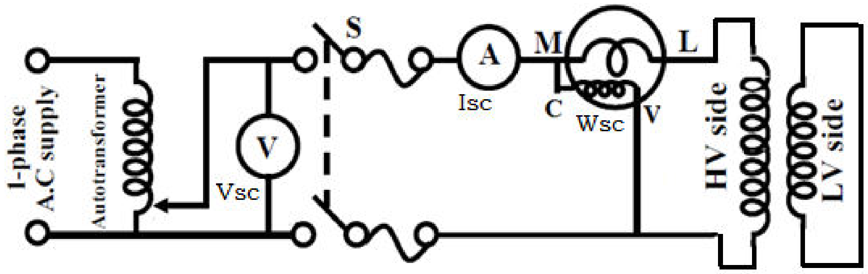
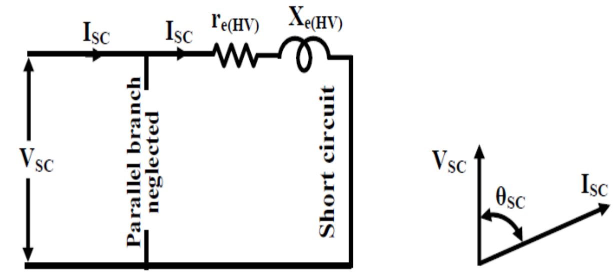


Figure 2.3: Circuit diagram for S.C test



(a) Equivalent circuit under S.C test (b) phasor diagram

Figure 2.4: Equivalent circuit & phasor diagram during S.C test

Calculations from SC test readings:

$r_{e(HV)}$, $x_{e(HV)}$ and cu loss are calculated from the SC test results as

Equivalent resistance referred to HV side is

$$R_{sc} = \frac{P_{sc}}{I_{sc}^2} = r_{e(HV)}$$

Equivalent impedance referred to HV side is

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} = z_{e(HV)}$$

Equivalent reactance referred to HV side is $X_{sc} = \sqrt{Z_{sc}^2 - R_{sc}^2} = x_{e(HV)}$

The culoss is equal to the wattmeter reading W_{sc}

- Thus, the approximate equivalent circuit of the transformer can be drawn by the calculated values of R_0 and X_0 on LV side and $r_{e(HV)}$ and $x_{e(HV)}$ *on* HV side.
- The efficiency at any load is calculated from the losses W_i and W_{cufl} as

$$\eta_x = \frac{xVA\cos\phi}{xVA\cos\phi + W_i + x^2 W_{FLCu}} \times 100$$

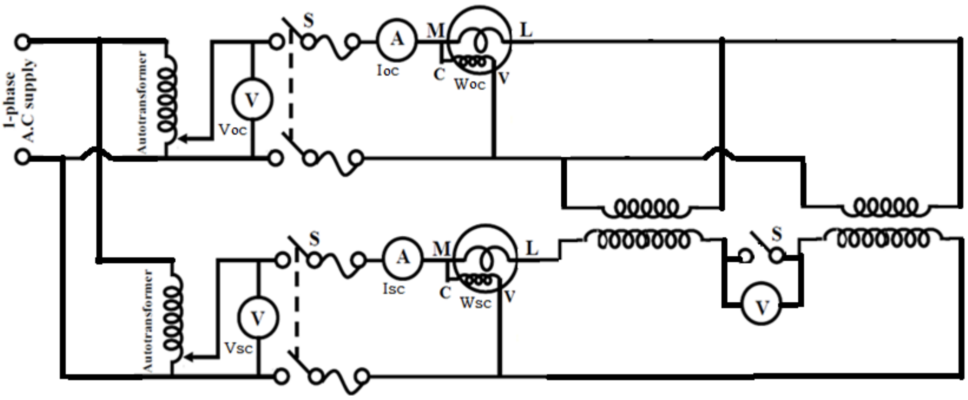
The regulation of the transformer is calculated from the $r_{e(HV)}$ and $x_{e(HV)}$ as

$$\%reg = \frac{I_{HV} r_{eHV} \cos\phi \pm I_{HV} x_{eHV} \sin\phi}{V_{HV}} \times 100 \text{ where } + \text{is for lagging pf and} - \text{is for leading pf}$$

12. Explain Sumpner's test or back to back test

Ans: Purpose of Sumpner's test or back to back test on transformer is to determine efficiency, voltage regulation considering the **heating under loaded** conditions.

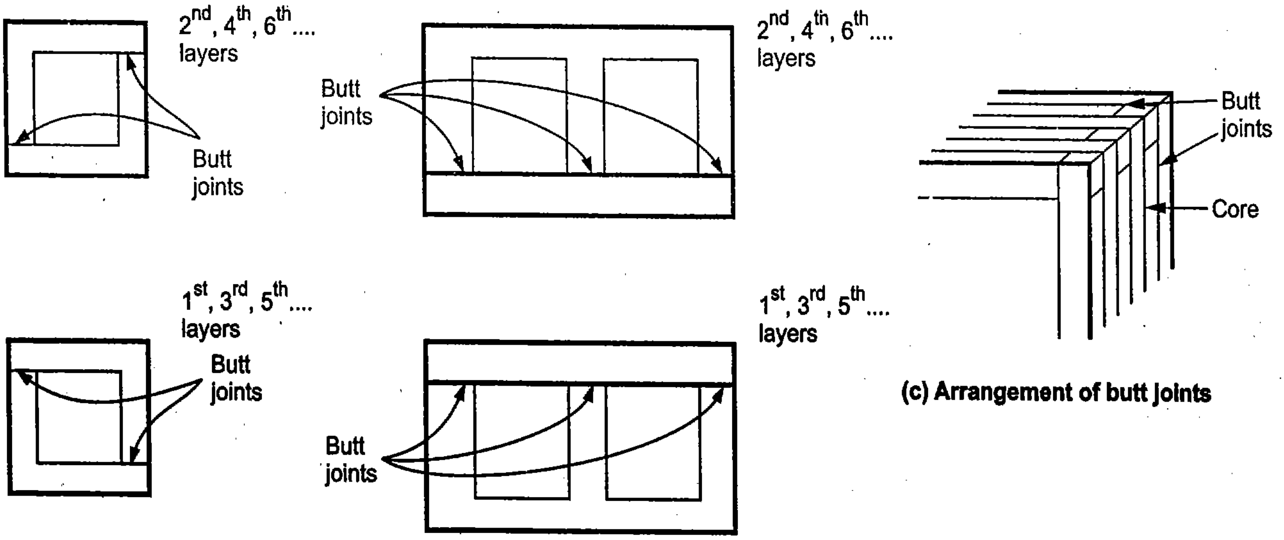
1. Two identical transformers are required to conduct the Sumpner's test
2. Both transformers are connected to supply such that one transformer is loaded on another.
3. Both Primaries are connected in parallel and both secondaries are connected in series opposition which is checked by the voltmeter showing zero volts when the switch S is closed.



<u>Procedure for sumpner's test:</u>

1. Both the emf's cancel each other, as transformers are identical. In this case, as per superposition theorem, no current flows through secondary. And thus the no load test is simulated.
2. The current drawn from V_{oc} is $2I_0=I_{oc}$ and the input power measured by wattmeter W_{oc} is equal to iron losses of both transformers. i.e. iron loss per transformer $P_i = W_{oc}/2$.
3. Now, a small voltage V_{sc} is injected into secondary with the help of a low voltage transformer.
4. The voltage V_{sc} is adjusted so that, the rated current I_{sc} flows through the secondary. In this case, both primaries and secondary's carry rated current.
5. Thus short circuit test is simulated and wattmeter W_{sc} shows total full load copper losses of both transformers. i.e. copper loss per transformer $P_{Cu} = W_{sc}/2$.
6. From above test results, the full load efficiency of each transformer is calculated and is given as

$$\%\eta = \frac{xVA\cos\phi}{xVA\cos\phi + \frac{W_{oc}}{2} + x^2\frac{W_{sc}}{2}} \times 100$$



(a) Core type (b) Shell type (c) Arrangement of butt joints

Fig. 4.3.3 Staggering in transformer

The **advantages of staggering** in transformer are,

1. It avoids continuous air gap.
2. The reluctance of magnetic circuit gets reduced.
3. The continuous air gap reduces the mechanical strength of the core. The staggering helps to increase the mechanical strength of the core.

In large transformers, the core is corrugated. The tank walls are corrugated means having folds and ridges. It has following advantages.

1. It allows changes in the effective volume of the oil with temperature. It helps in accomodating expansion and contraction of oil.
2. It helps to dissipate the losses effectively, by increasing the surface area of the tank. It provides large heat radiation area.

4.3.2 Types of Windings

The coils used are wound on the limbs and are insulated from each other. In the basic transformer shown in the Fig. 4.2.1, the two windings wound are shown on two different limbs i.e. primary on one limb while secondary on other limb. But due to this leakage flux increases which affects the transformer

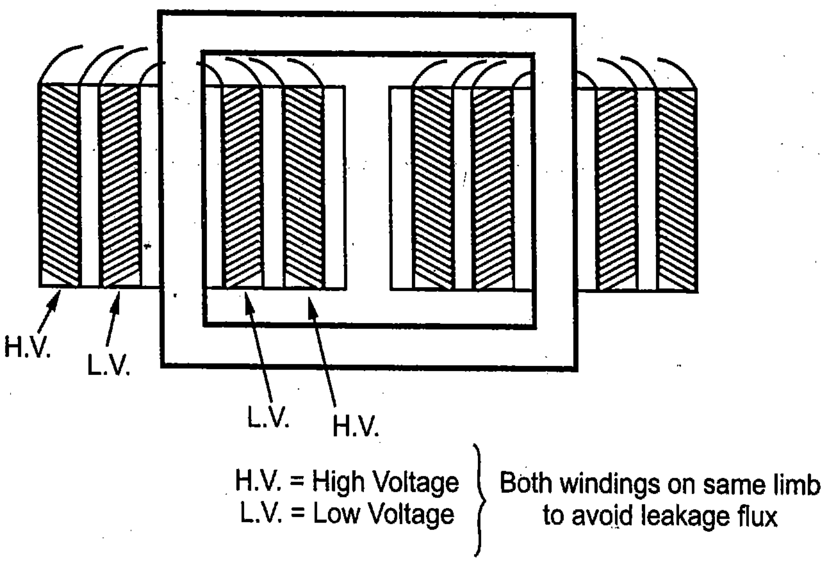


Fig. 4.3.4 (a) Cylindrical concentric coils

performance badly. Similarly it is necessary that the windings should be very close to each other to have high mutual inductance. To achieve this, the two windings are split into number of coils and are wound adjacent to each other on the same limb. A very common arrangement is cylindrical concentric coils as shown in the Fig. 4.3.4 (a).

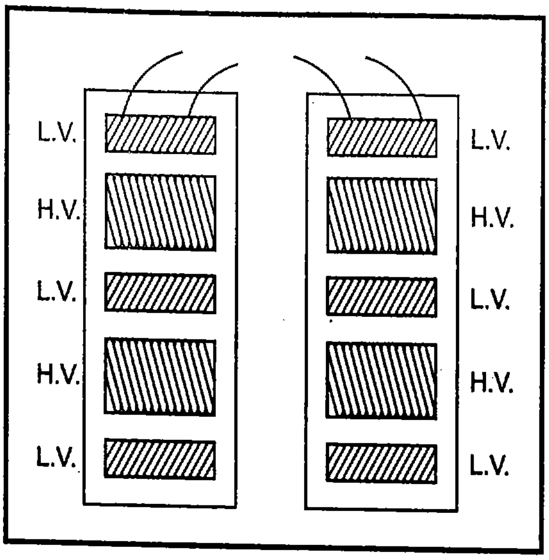


Fig. 4.3.4 (b) Sandwich coils

Such cylindrical coils are used in the core type transformer. These coils are mechanically strong. These are wound in the helical layers. The different layers are insulated from each other by paper, cloth or mica. The low voltage winding is placed near the core from ease of insulating it from the core. The high voltage is placed after it.

The other type of coils which is very commonly used for the shell type of transformer is **sandwich coils.** Each high voltage portion lies between the two low voltage portion sandwiching the high voltage portion. Such subdivision of windings into small portions reduces the leakage flux. Higher the degree of subdivision, smaller is the reactance. The **sandwich coil** is shown in the Fig. 4.3.4 (b). The top and bottom coils are low voltage coils. All the portions are insulated from each other by paper.

Review Questions

1. *Discuss the constructional features of transformers. Draw neat diagrams.*

   JNTU : May-03, 04, 05, Nov.-03, 05, Dec.-04, March-06, Marks 8

2. *What are the different parts of a transformer and explain their functions clearly.*

   JNTU : Nov.-06, Marks 16

4.4 Construction of Single Phase Transformers

JNTU : Nov.-05, 08

The various constructions used for the single phase transformers are,

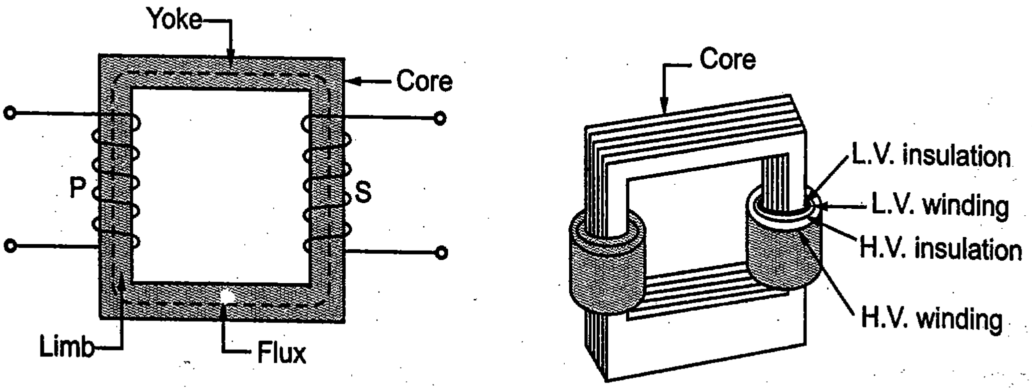
1. Core type 2. Shell type and 3. Berry type

4.4.1 Core Type Transformer

It has a single magnetic circuit. The core is rectangular having two limbs. The winding encircles the core. The coils used are of cylindrical type. As mentioned earlier, the coils are wound in helical layers with different layers insulated from each other by paper or mica. Both the coils are placed on both the limbs. The low voltage coil is placed inside near the core while high voltage coil surrounds the low voltage coil. Core is made up of large number of thin laminations.

As the windings are uniformly distributed over the two limbs, the natural cooling is more effective. The coils can be easily removed by removing the laminations of the top yoke, for maintenance.

The Fig. 4.4.1 (a) shows the schematic representation of the core type transformer while the Fig. 4.4.1 (b) shows the view of actual construction of the core type transformer.



(a) Representation

(b) Construction

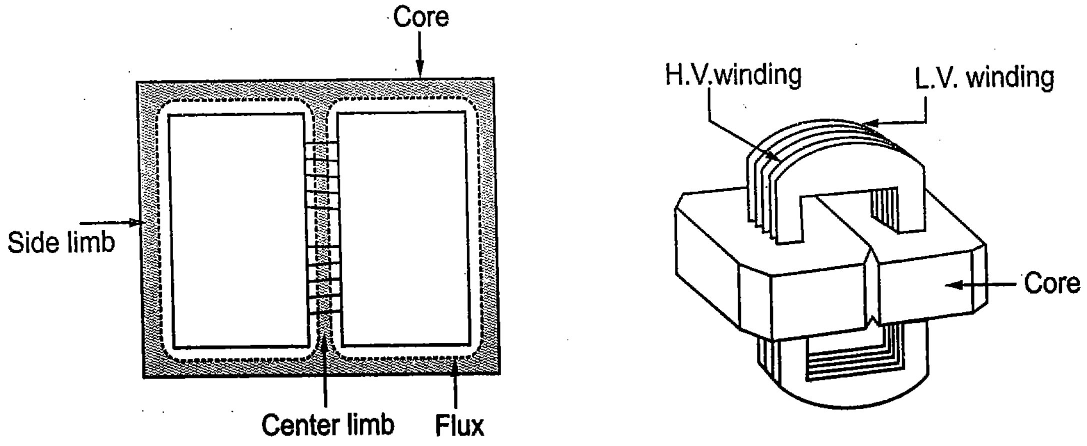
Fig. 4.4.1 Core type transformer

4.4.2 Shell Type Transformer

It has a double magnetic circuit. The core has three limbs. Both the windings are placed on the central limb. The core encircles most part of the windings. The coils used are generally multilayer disc type or sandwich coils. As mentioned earlier, each high voltage coil is in between two low voltage coils and low voltage coils are nearest to top and bottom of the yokes.

The core is laminated. While arranging the laminations of the core, the care is taken that all the joints at alternate layers are staggered. This is done to avoid narrow air gap at the joint, right through the cross-section of the core. Such joints are called over lapped or imbricated joints. Generally for very high voltage transformers, the shell type construction is preferred. As the windings are surrounded by the core, the natural cooling does not exist. For removing any winding for maintenance, large number of laminations are required to be removed.

The Fig. 4.4.2 (a) shows the schematic representation while the Fig. 4.4.2 (b) shows the outaway view of the construction of the shell type transformer.



(a) Representation (b) Construction

Fig. 4.4.2 Shell type transformer

4.4.3 Berry Type Transformer

This has distributed magnetic circuit. The number of independent magnetic circuits are more than 2. Its core construction is like spokes of a wheel. Otherwise it is symmetrical to that of shell type.

Diagramatically it can be shown as in the Fig. 4.4.3.

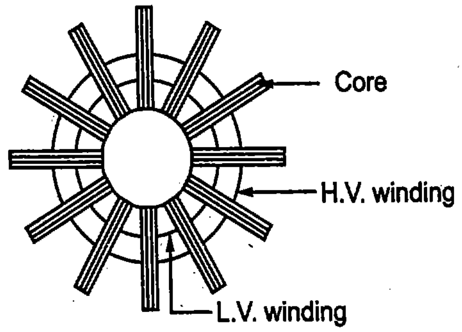


Fig. 4.4.3 Berry type transformer

Review Question

1. *Explain the constructional details of core and shell type transformers.*

JNTU : Nov.-05, 08, Marks 8

4.5 Comparison of Core and Shell Type Transformers

JNTU : Nov.-04, 07, May-05

The comparison of core type and shell type transformers is given in the Table 4.5.1.

Sr. No.	Core type	Shell type
1.	The winding encircles the core.	The core encircles most part of the windings.
2.	The cylindrical type of coils are used.	Generally, multilayer disc type or sandwich coils are used.
3.	As windings are distributed, the natural cooling is more effective.	As windings are surrounded by the core, the natural cooling does not exist.
4.	The coils can be easily removed from maintenance point of view.	For removing any winding for the maintenance, large number of laminations are required to be removed. This is difficult.
5.	The construction is preferred for low voltage transformers.	The construction is used for very high voltage transformers.

6.	It has a single magnetic circuit.	It has a double magnetic circuit.
7.	In a single phase type, the core has two limbs.	In a single phase type, the core has three limbs.

Table 4.5.1

Review Question

1. *Distinguish between core type and shell type transformers.*

JNTU : Nov.-04, 07, May-05, Marks 6

4.6 E.M.F. Equation of a Transformer

JNTU : May-05, 08, 13, Dec.-03, Nov.-04, 05, 08, 12, March-05, 06

When the primary winding is excited by an alternating voltage V_1, it circulates alternating current, producing an alternating flux ϕ. The primary winding has N_1 number of turns. The alternating flux ϕ linking with the primary winding itself induces an e.m.f. in it denoted as E_1. The flux links with secondary winding through the common magnetic core. It produces induced e.m.f. E_2 in the secondary winding. This is mutually induced e.m.f. Let us derive the equations for E_1 and E_2.

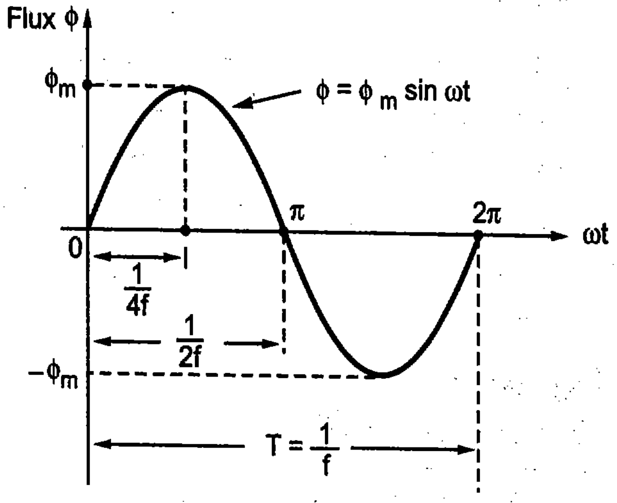


Fig. 4.6.1 Sinusoidal flux

The primary winding is excited by purely sinusoidal alternating voltage. Hence the flux produced is also sinusoidal in nature having maximum value of ϕ_m as shown in the Fig. 4.6.1.

The various quantities which affect the magnitude of the induced e.m.f. are :

ϕ = Flux, and ϕ_m = Maximum value of flux

N_1 = Number of primary winding turns, N_2 = Number of secondary winding turns

f = Frequency of the supply voltage

E_1 = R.M.S. value of the primary induced e.m.f.

E_2 = R.M.S. value of the secondary induced e.m.f.

From Faraday's law of electromagnetic induction the average e.m.f. induced in each turn is proportional to the average rate of change of flux.

$\therefore$ Average e.m.f. per turn = Average rate of change of flux

$$\therefore \quad \phi_m = B_m \times A = 6 \times 36 \times 10^{-4} = 0.0216 \text{ Wb}$$

$$E_1 = 4.44\, \phi_m f N_1 \quad \text{i.e.} \quad 2200 = 4.44 \times 0.0216 \times 50 \times N_1$$

$$\therefore \quad N_1 = 458.792 \approx \mathbf{459}$$

$$\frac{N_1}{N_2} = \frac{E_1}{E_2} \quad \text{i.e.} \quad N_2 = \frac{N_1 \times E_2}{E_1} = 52.13 \approx \mathbf{52}$$

Review Questions

1. *Derive the e.m.f. equation of a 1-phase transformer.*

   JNTU : May-05, 08, March-06, Nov.-04, 05, Marks 8

2. *What is an ideal transformer ?* **JNTU : Nov.-08, May-08, Marks 4**
3. *What is kVA rating of a transformer ?*
4. *A single phase transformer has 480 turns on primary and 90 turns on the secondary. The mean length of flux path in the core is 1.8 m and joints are equivalent to an air gap of 1 mm. The maximum value of the flux density is to be 1.1 T when a potential difference of 2200 volts at 50 Hz is applied to the primary. Assume value of magnetic field strength corresponding to the flux density of 1.1 T in the core to be 400 A/m.*

   Calculate

   i) The cross-section area of the core ii) Maximum value of the magnetizing current

   iii) Secondary voltage on no load. **[Ans.: i) 0.01876 m^2 ii) 1.500 A iii) 412.5 volts]**

5. *A single phase transformer has 350 primary and 1050 secondary turns. The primary is connected to 400 V, 50 Hz a.c. supply. If the net cross sectional area of the core is 50 cm^2, calculate i) The maximum value of the flux density in the core ii) The induced e.m.f. in the secondary winding.*

   [Ans.: B_m = 1.0296 Wb/m^2, E_2 = 1200 V]

6. *A single phase transformer has 500 turns on primary and 1000 turns on secondary. The voltage per turn in the primary winding is 0.2 volts. Calculate,*

   i) Voltage induced in the primary winding ii) Voltage induced in the secondary winding

   iii) The maximum value of the flux density if the cross section area of the core is 200 cm^2

   iv) kVA rating of the transformer if the current in primary at full load is 10 A, the frequency is 50 Hz. **[Ans.: i) E_1 = 100 volts, ii) E_2 = 200 volts, iii) ϕ_m = 9.009 × 10^{-4} Wb, iv) B_m = 0.045 web/m^2 or Tesla]**

4.7 Ideal Transformer on No Load

JNTU : Nov.-04, 05, 06, 08, 12, May-05, 08, 13, March-06

Consider an ideal transformer on no load as shown in the Fig. 4.7.1. The supply voltage is V_1 and as it is an no load the secondary current $I_2 = 0$.

The primary draws a current I_1 which is just necessary to produce flux in the core. As it is magnetising the core, it is called **magnetising current** denoted as I_m. As the transformer is ideal, the winding resistance is zero and it is purely inductive in nature. The magnetising current I_m is very small and lags V_1 by 30° as the winding is purely inductive. This I_m produces an alternating flux ϕ which is in phase with I_m .

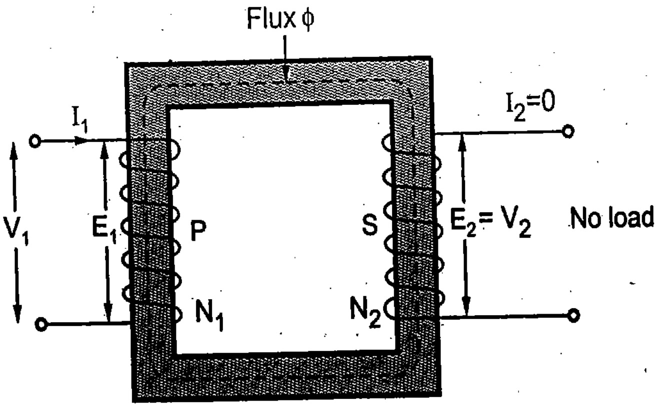


Fig. 4.7.1 Ideal transformer on no load

The flux links with both the winding producing the induced e.m.f.s E_1 and E_2, in the primary and secondary windings respectively. According to Lenz's law, the induced e.m.f. opposes the cause producing it which is supply voltage V_1. Hence E_1 is in antiphase with V_1 but equal in magnitude. The induced E_2 also opposes V_1 hence in antiphase with V_1 but its magnitude depends on N_2. Thus E_1 and E_2 are in phase.

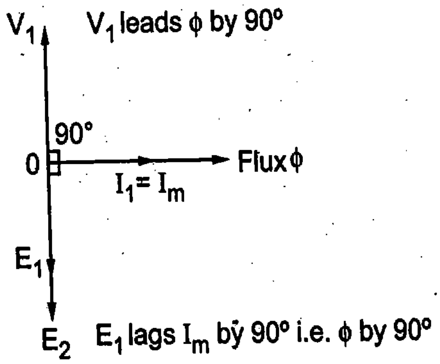


Fig. 4.7.2 Phasor diagram for ideal transformer on no load

The phasor diagram for the ideal transformer on no load is shown in the Fig. 4.7.2.

It can be seen that flux ϕ is reference. I_m produces ϕ hence in phase with ϕ . V_1 leads I_m by 90° as winding is purely inductive so current has to lag voltage by 90°.

E_1 and E_2 are in phase and both opposing supply voltage V_1.

The power input to the transformer is $V_1 I_1 \cos(V_1 \wedge I_1)$ i.e. $V_1 I_m \cos(90°)$ i.e. zero. This is because on no load output power is zero and for ideal transformer there are no losses hence input power is also zero. Ideal no load p.f. of transformer is zero lagging.

4.7.1 Practical Transformer on No Load

Actually in practical transformer iron core causes hysteresis and eddy current losses as it is subjected to alternating flux. While designing the transformer the efforts are made to keep these losses minimum by,

1. Using high grade material as silicon steel to reduce hysteresis loss.
2. Manufacturing core in the form of laminations or stacks of thin laminations to reduce eddy current loss.

Apart from this there are iron losses in the practical transformer. Practically primary winding has certain resistance hence there are small primary copper loss present.

Thus the primary current under no load condition has to supply the iron losses i.e. hysteresis loss and eddy current loss and a small amount of primary copper loss. This current is denoted as I_0

8

Synchronous Machines

8.1 Introduction

It is known that the electric supply used, now a days for commercial as well as domestic purposes, is of alternating type.

Similar to d.c. machines, the a.c. machines associated with alternating voltages, are also classified as generators and motors.

The machines generating a.c. e.m.f. are called **alternators** or **synchronous generators**. While the machines accepting input from a.c. supply to produce mechanical output are called **synchronous motors**. Both these machines work at a specific constant speed called **synchronous speed** and hence in general called **synchronous machines**.

8.2 Difference between D.C. Generator and Alternator

It is seen that in case of a d.c. generator, basically the nature of the induced e.m.f. in the armature conductors is of alternating type. By using commutator and brush assembly it is converted to d.c. and made available to the external circuit. If commutator is dropped from a d.c. generator and induced e.m.f. is tapped outside from an armature directly, the nature of such e.m.f. will be alternating. Such a machine without commutator, providing an a.c. e.m.f. to the external circuit is called an **alternator**. The obvious question is how is it possible to collect an e.m.f. from the rotating armature without commutator ?

Key Point : *So the arrangement which is used to collect an induced e.m.f. from the **rotating armature** and make it available to the **stationary circuit** is called **slip ring and brush assembly**.*

8.2.1 Concept of Slip Rings and Brush Assembly

Whenever there is a need of developing a contact between rotating element and the stationary circuit without conversion of an e.m.f. from a.c. to d.c., the slip rings and brush assembly can be used.

In case of three phase alternators, the armature consist of three phase winding and an a.c. e.m.f. gets induced in these windings. After connecting windings in star or delta, the three ends of the windings are brought out. Across these terminals three phase supply is ranging from 125 r.p.m. to 500 r.p.m. The prime movers used to drive such rotor are generally water turbines and I.C. engines.

8.6.2 Smooth Cylindrical Type Rotor

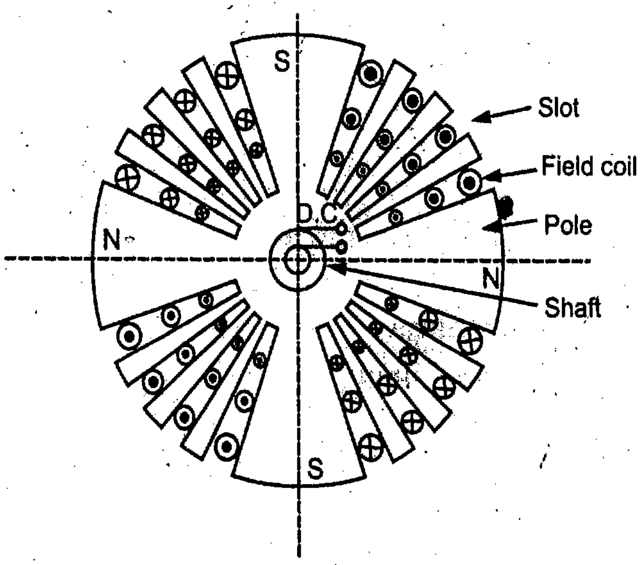


Fig. 8.4 Smooth cylindrical rotor

This is also called **non salient type** or **non-projected pole type of rotor.**

The rotor consists of smooth solid steel cylinder, having number of slots to accommodate the field coil. The slots are covered at the top with the help of steel or manganese wedges. The unslotted portions of the cylinder itself act as the poles. The poles are not projecting out and the surface of the rotor is smooth which maintains uniform air gap between stator and the rotor. These rotors have small diameters and large axial lengths. This is to keep peripheral speed within limits. The main advantage of this type is that these are mechanically very strong and thus preferred for high speed alternators ranging between 1500 to 3000 r.p.m. Such high speed alternators are called '**turboalternators**'. The prime movers used to drive such type of rotors are generally steam turbines, electric motors.

The Fig. 8.4 shows smooth cylindrical type of rotor.

Let us list down the differences between the two types in tabular form.

8.6.3 Difference between Salient and Cylindrical Type of Rotor

Sr. No.	Salient Pole Type	Smooth Cylindrical Type
1.	Poles are projecting out from the surface.	Unslotted portion of the cylinder acts as poles hence poles are non projecting.
2.	Air gap is non uniform.	Air gap is uniform due to smooth cylindrical periphery.
3.	Diameter is high and axial length is small.	Small diameter and large axial length is the feature.
4.	Mechanically weak.	Mechanically robust.
5.	Preferred for low speed alternators.	Preferred for high speed alternators i.e. for turboalternators.
6.	Prime mover used are water turbines, I.C. engines.	Prime movers used are steam turbines, electric motors.

7.	For same size, the rating is smaller than cylindrical type.	For same size, rating is higher than salient pole type.
8.	Separate damper winding is provided.	Separate damper winding is not necessary.

8.7 Working Principle

The alternators work on the principle of **electromagnetic induction**. When there is a relative motion between the conductors and the flux, e.m.f. gets induced in the conductors. The d.c. generators also work on the same principle. The only difference in practical alternator and a d.c. generator is that in an alternator the conductors are stationary and field is rotating. But for understanding purpose we can always consider relative motion of conductors with respect to the flux produced by the field winding.

Consider a relative motion of a single conductor under the magnetic field produced by two stationary poles. The magnetic axis of the two poles produced by field is vertical, shown dotted in the Fig. 8.5.

Let conductor starts rotating from position 1. At this instant, the entire velocity component is **parallel** to the flux lines. Hence there is no cutting of flux lines by the conductor. So $\frac{d\phi}{dt}$ at this instant is zero and hence induced e.m.f. in the conductor is also zero.

As the conductor moves from position 1 towards position 2, the part of the velocity component becomes perpendicular to the flux lines and proportional to that, e.m.f. gets induced in the conductor. The magnitude of such an induced e.m.f. increases as the conductor moves from position 1 towards 2.

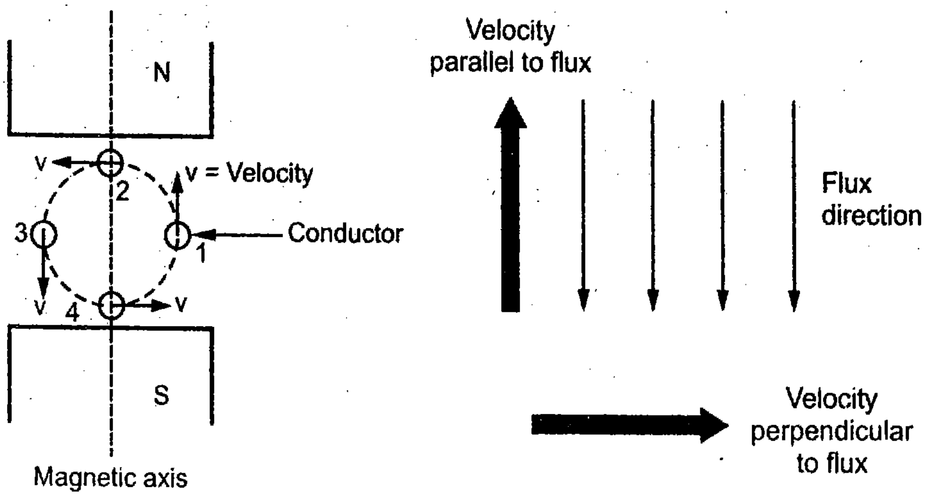


Fig. 8.5 Two pole alternator

At position 2, the entire velocity component is **perpendicular** to the flux lines. Hence there exists maximum cutting of the flux lines. And at this instant, the induced e.m.f. in the conductor is at its maximum.

As the position of conductor changes from 2 towards 3, the velocity component perpendicular to the flux starts decreasing and hence induced e.m.f. magnitude also starts decreasing. At position 3, again the entire velocity component is parallel to the flux lines and hence at this instant induced e.m.f. in the conductor is zero.

As the conductor moves from position 3 towards 4, the velocity component perpendicular to the flux lines again starts increasing. But the direction of velocity component now is opposite to the direction of velocity component exsisting during the movement of the conductor from position 1 to 2. Hence an induced e.m.f. in the conductor increases but in the opposite direction.

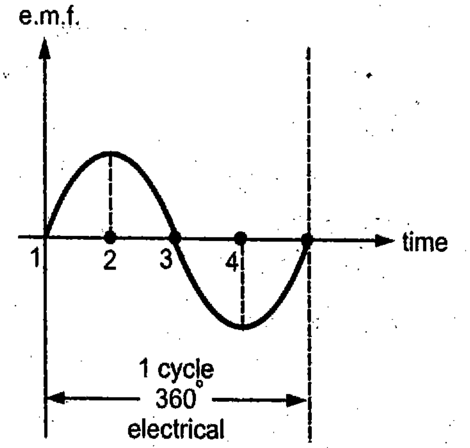


Fig. 8.6 Alternating nature of the induced e.m.f.

At position 4, it achieves maxima in the opposite direction, as the entire velocity component becomes **perpendicular** to the flux lines.

Again from position 4 to 1, induced e.m.f. decreases and finally at position 1, again becomes zero. This cycle continues as conductor rotates at a certain speed.

So if we plot the magnitudes of the induced e.m.f. against the time, we get an alternating nature of the induced e.m.f. as shown in the Fig. 8.6.

This is the working principle of an alternator.

8.7.1 Mechanical and Electrical Angle

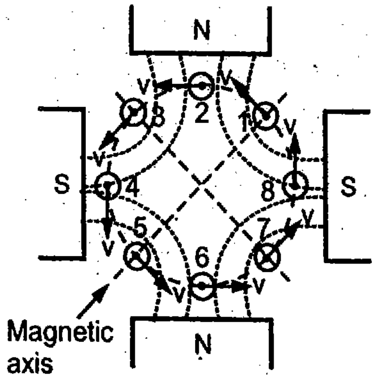


Fig. 8.7 (a) 4 Pole alternator

We have seen that for 2 pole alternator, one mechanical revolution corresponds to one electrical cycle of an induced e.m.f. Now consider 4 pole alternator i.e. the field winding is designed to produce 4 poles. Due to 4 poles, the magnetic axis exists diagonally shown dotted in the Fig. 8.7.

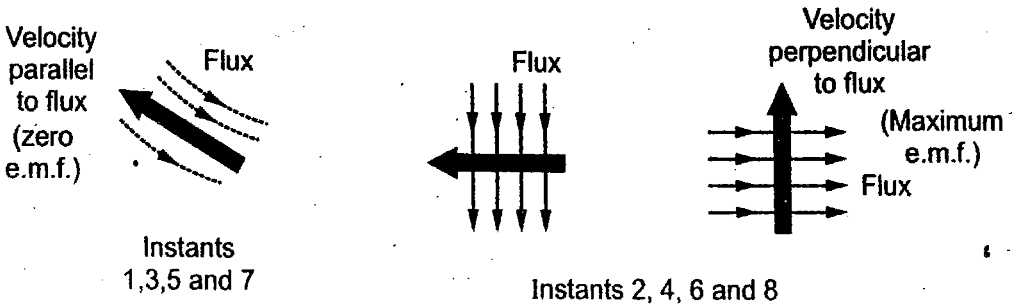


Fig. 8.7 (b) Veclocity components at different instants

5.1 Introduction

An electric motor is a device which converts an electrical energy into a mechanical energy. This mechanical energy then can be supplied to various types of loads. The motors can operate on d.c. as well as single and three phase a.c. supply. The motors operating on d.c. supply are called d.c. motors while motors operating on a.c. supply are called a.c. motors. As a.c. supply is commonly available, the a.c. motors are very popularly used in practice. The a.c. motors are classified as single and three phase induction motors, synchronous motors and some special purpose motors. Out of all these types, three phase induction motors are widely used for various industrial applications. Hence this chapter gives the emphasis on the working principle, types and features of three phase induction motors. The important advantages of three phase induction motors over other types are self starting property, no need of starting device, higher power factor, good speed regulation and robust construction. The working principle of three phase induction motors is based on the production of **rotating magnetic field**. Hence before beginning the actual discussion of three phase induction motors, let us discuss the production of rotating magnetic field from a three phase a.c. supply.

5.2 Rotating Magnetic Field (R.M.F.) JNTU : Nov.-04, 06, 12, March-06, May-08

The rotating magnetic field can be defined as the field or flux having constant amplitude but whose axis is continuously rotating in a plane with a certain speed. So if the arrangement is made to rotate a permanent magnet, then the resulting field is a rotating magnetic field. But in this method, it is necessary to rotate a magnet physically to produce rotating magnetic field.

But in three phase induction motors such a rotating magnetic field is produced by supplying currents to a set of **stationary** windings, with the help of three phase a.c. supply. The current carrying windings produce the magnetic field or flux. And due to interaction of three fluxes produced due to three phase supply, resultant flux has a constant magnitude and its axis rotating in space, without physically rotating the windings. This type of field is nothing but rotating magnetic field. Let us study how it happens ?

5.2.1 Production of R.M.F.

A three phase induction motor consists of three phase winding as its stationary part called **stator**. The three phase stator winding is connected in star or delta. The three phase windings are displaced from each other by 120°. The windings are supplied by a balanced three phase a.c. supply. This is shown in the Fig. 5.2.1. The three phase windings are denoted as R-R′, Y-Y′ and B-B′.

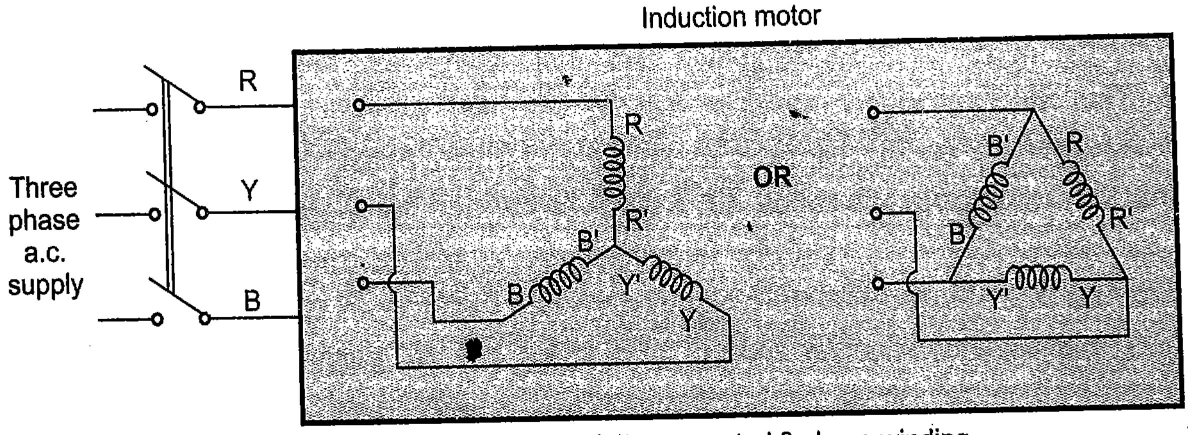


Fig. 5.2.1

The three phase currents flow simultaneously through the windings and are displaced from each other by 120° electrical. Each alternating phase current produces its own flux which is sinusoidal. So all three fluxes are sinusoidal and are separated from each other by 120°. If the phase sequence of the windings is R-Y-B, then mathematical equations for the instantaneous values of the three fluxes ϕ_R, ϕ_Y and ϕ_B can be written as,

$$\phi_R = \phi_m \sin(\omega t) = \phi_m \sin\theta \quad \text{... (5.2.1)}$$

$$\phi_Y = \phi_m \sin(\omega t - 120°) = \phi_m \sin(\theta - 120°) \quad \text{... (5.2.2)}$$

$$\phi_B = \phi_m \sin(\omega t - 240°) = \phi_m \sin(\theta - 240°) \quad \text{... (5.2.3)}$$

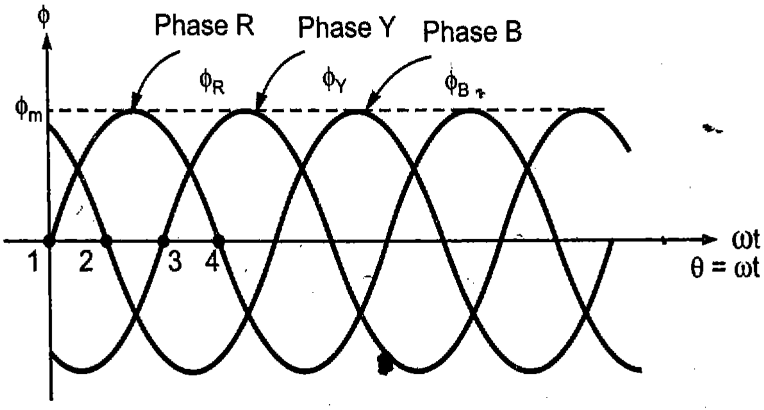
As windings are identical and supply is balanced, the magnitude of each flux is ϕ_m. Due to phase sequence R-Y-B, flux ϕ_Y lags behind ϕ_R by 120° and ϕ_B lags ϕ_Y by 120°. So ϕ_B ultimately lags ϕ_R by 240°. The flux ϕ_R is taken as reference while writing the equations.

The Fig. 5.2.2 (a) shows the waveforms of three fluxes in space. The Fig. 5.2.2 (b) shows the phasor diagram which clearly shows the **assumed positive directions** of each flux. Assumed positive direction means whenever the flux is positive it must be represented along the direction shown and whenever the flux is negative it must be represented along the opposite direction to the assumed positive direction.

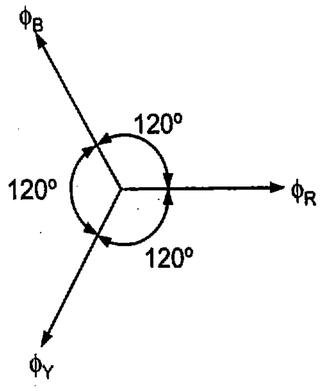
Let ϕ_R, ϕ_Y and ϕ_B be the instantaneous values of three fluxes. The resultant flux ϕ_T is the phasor addition of ϕ_R, ϕ_Y and ϕ_B.

$$\therefore \quad \bar{\phi}_T = \bar{\phi}_R + \bar{\phi}_Y + \bar{\phi}_B$$

Let us find ϕ_T at the instants 1, 2, 3 and 4 as shown in the Fig. 5.2.2 (a) which represents the values of θ as 0°, 60°, 120° and 180° respectively. The phasor addition can be performed by obtaining the values of ϕ_R, ϕ_Y and ϕ_B by substituting values of θ in the equations (5.2.1), (5.2.2) and (5.2.3).



(a) Waveforms of three fluxes



(b) Assumed positive directions

Fig. 5.2.2

Case 1 : $\theta = 0°$

Substituting in the equations (5.2.1), (5.2.2) and (5.2.3) we get,

$$\phi_R = \phi_m \sin 0° = 0$$

$$\phi_Y = \phi_m \sin(-120°) = -0.866\,\phi_m$$

$$\phi_B = \phi_m \sin(-240°) = +0.866\,\phi_m$$

The phasor addition is shown in the Fig. 5.2.3 (a). The positive values are shown in assumed positive directions while negative values are shown in opposite direction to the assumed positive directions of the respective fluxes. Refer to assumed positive directions shown in the Fig. 5.2.2 (b).

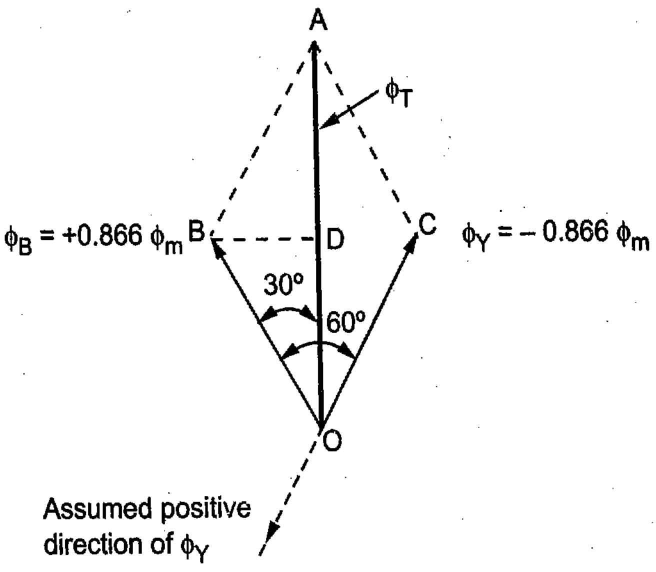


Fig. 5.2.3 (a) Vector diagram for θ = 0°

BD is drawn perpendicular from B on ϕ_T. It bisects ϕ_T.

$$\therefore \quad OD = DA = \frac{\phi_T}{2}$$

In triangle OBD, ∠BOD = 30°

$$\therefore \quad \cos 30° = \frac{OD}{OB} = \frac{\phi_T/2}{0.866\phi_m}$$

$$\therefore \quad \phi_T = 2 \times 0.866\phi_m \times \cos 30°$$

$$= 1.5\,\phi_m$$

So magnitude of ϕ_T is 1.5 ϕ_m and its position is vertically upwards at θ = 0°.

Case 2 : $\theta = 60°$

Equations (5.2.1), (5.2.2) and (5.2.3) give us,

$$\phi_R = \phi_m \sin 60° = +0.866\,\phi_m$$

$$\phi_Y = \phi_m \sin(-60°) = -0.866\,\phi_m$$

$$\phi_B = \phi_m \sin(-180°) = 0$$

So ϕ_R is positive and ϕ_Y is negative and hence drawing in appropriate directions we get phasor diagram as shown in the Fig. 5.2.3 (b).

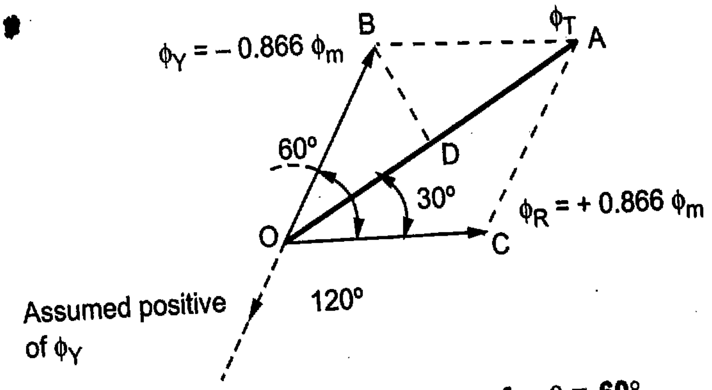


Fig. 5.2.3 (b) Vector diagram for θ = 60°

Doing the same construction, drawing perpendicular from B on ϕ_T at D we get the same result as,

$$\phi_T = 1.5\,\phi_m$$

But it can be seen that **though its magnitude is 1.5 ϕ_m it has rotated through 60° in space, in clockwise direction, from its previous position.**

Case 3 : $\theta = 120°$

Equations (5.2.1), (5.2.2) and (5.2.3) give us,

$$\phi_R = \phi_m \sin 120 = +0.866\,\phi_m$$

$$\phi_Y = \phi_m \sin 0 = 0$$

$$\phi_B = \phi_m \sin(-120) = -0.866\,\phi_m$$

So ϕ_R is positive and ϕ_B is negative. Showing ϕ_R and ϕ_B in the appropriate directions, we get the phasor diagram as shown in the Fig. 5.2.3 (c).

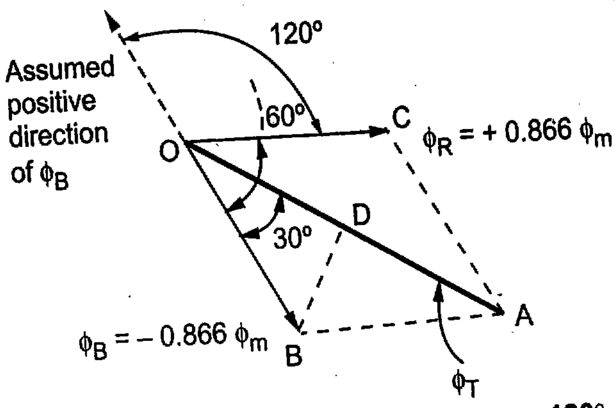


Fig. 5.2.3 (c) Vector diagram for θ = 120°

After doing the construction same as before i.e. drawing perpendicular from B on ϕ_T, it can be proved again that,

$$\phi_T = 1.5\,\phi_m$$

But the position of ϕ_T is such that it has rotated further through 60° from its previous position, in clockwise direction. **And from its position at θ = 0°, it has rotated through 120° in space, in clockwise direction.**

Case 4 : $\theta = 180°$

From the equations (5.2.1), (5.2.2) and (5.2.3),

$$\phi_R = \phi_m \sin(180°) = 0$$

$$\phi_Y = \phi_m \sin(60°) = +0.866\ \phi_m$$

$$\phi_B = \phi_m \sin(-60°) = -0.866\ \phi_m$$

So $\phi_R = 0$, ϕ_Y is positive and ϕ_B is negative. Drawing ϕ_Y and ϕ_B in the appropriate directions, we get the phasor diagram as shown in the Fig. 5.2.3 (d).

From phasor diagram, it can be easily proved that,

$$\phi_T = 1.5\ \phi_m$$

Thus the magnitude of ϕ_T once again remains same. But it can be seen that it has further rotated through 60° from its previous position in clockwise direction.

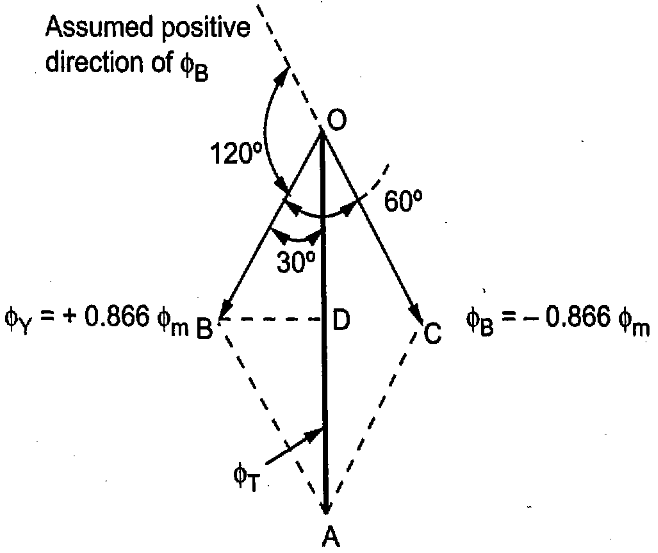


Fig. 5.2.3 (d) Vector diagram for θ = 180°

So for an electrical half cycle of 180°, the resultant ϕ_T has also rotated through 180°. This is applicable for the windings wound for 2 poles.

From the above discussion we have following conclusions :

a) The resultant of the three alternating fluxes, separated from each other by 120°, has a constant amplitude of 1.5 ϕ_m where ϕ_m is maximum amplitude of an individual flux due to any phase.

b) The resultant always keeps on rotating with a certain speed in space.

Key Point *This shows that when a three phase stationary windings are excited by balanced three phase a.c. supply then the resulting field produced is* ***rotating magnetic field****. Though nothing is physically rotating, the field produced is rotating in space having constant amplitude.*

5.2.2 Speed of R.M.F.

There exists a fixed relation between frequency f of a.c. supply to the windings, the number of poles P for which winding is wound and speed N r.p.m. of rotating magnetic

5.5 Working Principle

JNTU : Nov.-03, 04, 06, 08, May-04, 05, 13

Induction motor works on the principle of electromagnetic induction.

When a three phase supply is given to the three phase stator winding, a rotating magnetic field of constant magnitude is produced as discussed earlier. The speed of this rotating magnetic field is synchronous speed, N_s r.p.m.

$$N_s = \frac{120\,f}{P} = \text{Speed of rotating magnetic field}$$

where f = Supply frequency

P = Number of poles for which stator winding is wound.

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 the Fig. 5.5.1 (a).

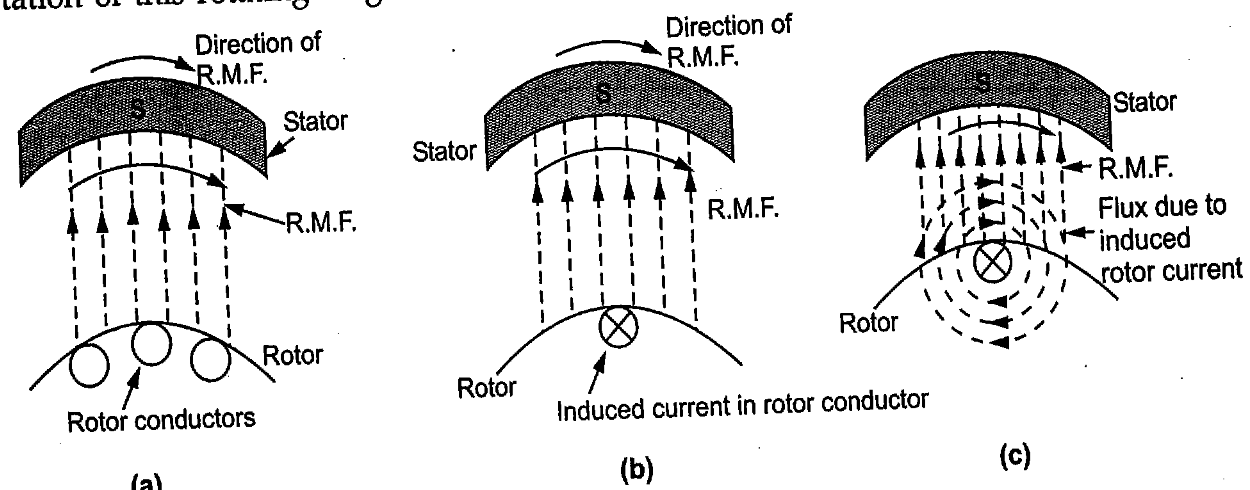


Fig. 5.5.1 Working principle

Now at this instant rotor is **stationary** and stator flux R.M.F. is **rotating.** So its obvious that there exists a relative motion between the R.M.F. and rotor conductors. Now the R.M.F. gets cut by rotor conductors as R.M.F. sweeps over rotor conductors. Whenever conductor cuts the flux, e.m.f. gets induced in it. So e.m.f. gets induced in the rotor conductors called **rotor induced e.m.f.** This is electro-magnetic induction. As rotor forms closed circuit, induced e.m.f. circulates current through rotor called **rotor current** as shown in the Fig. 5.5.1 (b). Let direction of this current is going into the paper denoted by a cross as shown in the Fig. 5.5.1 (b).

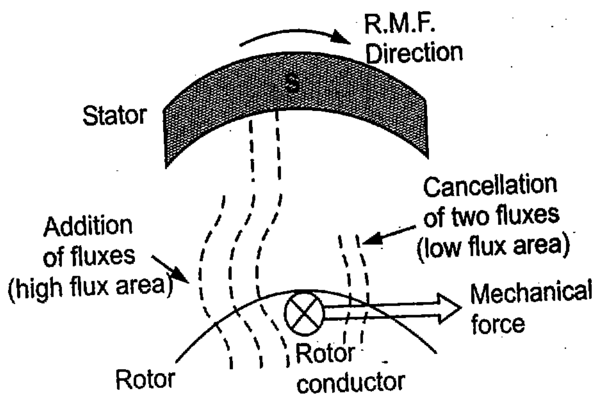


Fig. 5.5.1 (d) Interaction of fluxes

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 the Fig. 5.5.1 (c). This direction can be easily determined using right hand thumb rule. Now there are two fluxes, one R.M.F. and other rotor flux. Both the fluxes interact with each as shown in the Fig. 5.5.1 (d). 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 exerts 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. 5.5.1 (d), due to **interaction of the two fluxes.**

As all the rotor conductors experience a force, the overall rotor experiences a torque and starts rotating. So **interaction of the two fluxes is very essential for a motoring action.** As seen from the Fig. 5.5.1 (d), the direction of force experienced is same as that of rotating magnetic field. Hence rotor starts rotating in the same direction as that of rotating magnetic field.

Alternatively this can be explained as : According to Lenz's law the direction of induced current in the rotor is so as oppose the cause producing it. The cause of rotor current is the induced e.m.f. which is induced because of relative motion present between the rotating magnetic field and the rotor conductors. Hence to oppose the relative motion i.e. to reduce the relative speed, the rotor experiences a torque in the same direction as that of R.M.F. and tries to catch up the speed of rotating magnetic field.

So, N_S = Speed of rotating magnetic field in r.p.m.

N = Speed of rotor i.e. motor in r.p.m.

$N_S - N$ = Relative speed between the two, rotating magnetic field and the rotor conductors.

Thus rotor always rotates in same direction as that of R.M.F.

5.5.1 Can $N = N_S$?

When rotor starts rotating, it tries to catch the speed of rotating magnetic field.

If it catches the speed of the rotating magnetic field, the relative motion between rotor and the rotating magnetic field will vanish ($N_S - N = 0$). In fact the relative motion is the main cause for the induced e.m.f. in the rotor. So induced e.m.f. will vanish and hence there cannot be rotor current and the rotor flux which is essential to produce the torque on the rotor. Eventually motor will stop. But immediately there will exist a relative motion between rotor and rotating magnetic field and it will start. But due to inertia of rotor, this does not happen in practice and rotor continues to rotate with a speed slightly less than the synchronous speed of the rotating magnetic field in the steady state. The **induction motor never rotates at synchronous speed**. The speed at which it rotates is hence called **subsynchronous speed** and motor sometimes called **asynchronous motor.**

$$\therefore \quad N < N_s$$

So it can be said that rotor slips behind the rotating magnetic field produced by stator. The difference between the two is called **slip speed** of the motor.

$$N_s - N = \text{Slip speed of the motor in r.p.m.}$$

This speed decides the magnitude of the induced e.m.f. and the rotor current, which in turn decide the torque produced. The torque produced is as per the requirements of overcoming the friction and iron losses of the motor along with the torque demanded by the load on the motor.

Review Questions

1. *Can induction motor rotate at synchronous speed ? Why ?*
   JNTU : Nov.-03, 04, May-04, 05, Marks 6

2. *Explain the principle of operation of a 3-phase induction motor.*
   JNTU : Nov.-04, 06, 08, May-13, Marks 8

5.6 Slip of Induction Motor

JNTU : May-13

We have seen that rotor rotates in the same direction as that of R.M.F. but in steady state attains a speed less than the synchronous speed. The difference between the two speeds i.e. synchronous speed of R.M.F. (N_s) and rotor speed (N) is called slip speed. This slip speed is generally expressed as the percentage of the synchronous speed.

So slip of the induction motor is defined as the difference between the synchronous speed (N_s) and actual speed of rotor i.e. motor (N) expressed as a fraction of the synchronous speed (N_s). This is also called absolute slip or fractional slip and is denoted as 's'.

Thus

$$s = \frac{N_s - N}{N_s} \quad \text{... (Absolute slip)}$$

The percentage slip is expressed as,

$$\% \, s = \frac{N_s - N}{N_s} \times 100 \quad \text{... (Percentage slip)}$$

In terms of slip, the actual speed of motor (N) can be expressed as,

$$N = N_s(1 - s) \quad \text{... (From the expression of slip)}$$

At start, motor is at rest and hence its speed N is zero.

$$\therefore \quad s = 1 \text{ at start}$$

This is maximum value of slip s possible for induction motor which occurs at start. While s = 0 gives us $N = N_s$ which is not possible for an induction motor. So **slip of induction motor cannot be zero** under any circumstances.

Practically motor operates in the slip range of 0.01 to 0.05 i.e. 1 % to 5 %. The slip corresponding to full load speed of the motor is called **full load slip.**

Example 5.6.1 *A 4 pole, 3 phase induction motor is supplied from 50 Hz supply. Determine its synchronous speed. On full load, its speed is observed to be 1410 r.p.m. Calculate its full load slip.*

Solution : Given values are,

$$P = 4, \quad f = 50 \text{ Hz}, \quad N = 1410 \text{ r.p.m.}$$

$$N_s = \frac{120 f}{P} = \frac{120 \times 50}{4} = 1500 \text{ r.p.m.}$$

Full load absolute slip is given by,

$$s = \frac{N_s - N}{N_s} = \frac{1500 - 1410}{1500} = 0.06$$

$$\therefore \quad \% s = 0.06 \times 100 = \mathbf{6\ \%}$$

Example 5.6.2 *A 4 pole, 3 phase, 50 Hz, star connected induction motor has a full load slip of 4 %. Calculate full load speed of the motor.*

Solution : Given values are,

$$P = 4, \quad f = 50 \text{ Hz}, \quad \% s_{fl} = 4 \%$$

$$s_{fl} = \text{Full load absolute slip} = 0.04$$

$$N_s = \frac{120 f}{P} = \frac{120 \times 50}{4} = 1500 \text{ r.p.m.}$$

$$s_{fl} = \frac{N_s - N_{fl}}{N_s} \quad \text{where } N_{fl} = \text{Full load speed of motor}$$

$$\therefore \quad 0.04 = \frac{1500 - N_{fl}}{1500}$$

$$\therefore \quad N_{fl} = \mathbf{1440 \text{ r.p.m.}}$$

This is the full load speed of the motor.

2. *A 3-phase induction motor has a 4-pole, star connected stator winding. The motor runs on a 50 Hz supply with 200 V between lines. The rotor resistance and standstill rotor reactance per phase are 0.1 Ω and 0.9 Ω respectively. The ratio of rotor to stator turns in 0.67. Calculate :*
   i) Total torque at 4 % slip *ii) Maximum torque developed*
   iii) Speed at maximum torque *iv) Maximum mechanical power*
   Neglect stator impedance. **[Ans. : 40.4786 Nm, 63.5065 Nm, 1333.333 r.p.m., 8867.1801 W]**

3. *A 3-phase induction motor has a 4-pole, star connected stator winding. The motor runs on a 50 Hz supply with 200 V between lines. The rotor resistance and standstill rotor reactance per phase are 0.1 Ω and 0.9 Ω respectively. The ratio of rotor to stator turns in 0.67. Calculate :*
   i) Total torque at 4 % slip *ii) Maximum torque developed*
   iii) Speed at maximum torque *iv) Maximum mechanical power*
   Neglect stator impedance.
   [Ans. : i) 40.47 Nm, ii) 63.50 Nm, iii) 1333.33 r.p.m. iv) $P_m = T_m \times \omega_m$ = 8.867 kW]

5.11 Torque-Slip Characteristics

JNTU : Nov.-06, 12, May-07

As the induction motor is loaded from no load to full load, its speed decreases hence slip increases. Due to the increased load, motor has to produce more torque to satisfy load demand. The torque ultimately depends on slip as explained earlier. The behaviour of motor can be easily judged by sketching a curve obtained by plotting torque produced against slip of induction motor. The curve obtained by plotting torque against slip from s = 1 (at start) to s = 0 (at synchronous speed) is called **torque-slip characteristics** of the induction motor. It is very interesting to study the nature of torque-slip characteristics.

We have seen that for a constant supply voltage, E_2 is also constant. So we can write torque equation as,

$$T \propto \frac{s R_2}{R_2^2 + (sX_2)^2}$$

Now to judge the nature of torque-slip characteristics let us divide the slip range (s = 0 to s = 1) into two parts and analyze them independently.

i) Low slip region :

In low slip region, 's' is very very small. Due to this, the term $(s X_2)^2$ is so small as compared to R_2^2 that it can be neglected.

$$\therefore \quad T \propto \frac{s R_2}{R_2^2} \propto s \qquad \text{... As } R_2 \text{ is constant.}$$

Hence in **low slip region torque is directly proportional to slip**. So as load increases, speed decreases, increasing the slip. This increases the torque which satisfies the load demand.

Hence the graph is straight line in nature.

At $N = N_s$, $s = 0$ hence $T = 0$. As no torque is generated at $N = N_s$, motor stops if it tries to achieve the synchronous speed. Torque increases linearly in this region, of low slip values.

ii) High slip region :

In this region, slip is high i.e. slip value is approaching to 1. Here it can be assumed that the term R_2^2 is very very small as compared to $(s X_2)^2$. Hence neglecting R_2^2 from the denominator, we get

$$T \propto \frac{s R_2}{(sX_2)^2} \propto \frac{1}{s}$$

where R_2 and X_2 are constants.

So in high slip region torque is inversely proportional to the slip. Hence its nature is like rectangular hyperbola.

Now when load increases, load demand increases but speed decreases. As speed decreases, slip increases. In high slip region as $T \propto 1/s$, torque decreases as slip increases. But torque must increase to satisfy the load demand. As torque decreases, due to extra loading effect, speed further decreases and slip further increases. Again torque decreases as $T \propto 1/s$ hence same load acts as an extra load due to reduction in torque produced. Hence speed further drops. Eventually motor comes to standstill condition. The **motor cannot continue to rotate at any point in this high slip region**. Hence this region is called **unstable region** of operation.

So torque - slip characteristics has two parts,

1. Straight line called **stable region of operation.**

2. Rectangular hyperbola called **unstable region of operation.**

Now the obvious question is upto which value of slip, torque-slip characteristic represents stable operation ?

In low slip region, as load increases, slip increases and torque also increases linearly. Every motor has its own limit to produce a torque. The maximum torque, the motor can produce as load increases is T_m which occurs at $s = s_m$. So linear behaviour continues till $s = s_m$.

If load is increased beyond this limit, motor slip acts dominantly pushing motor into high slip region. Due to unstable conditions, motor comes to standstill condition at such a load. Hence T_m i.e. maximum torque which motor can produce is also called

breakdown torque or **pull out torque**. So range s = 0 to s = s_m is called low slip region, known as stable region of operation. Motor always operates at a point in this region. And range s = s_m to s = 1 is called high slip region which is rectangular hyperbola, called unstable region of operation. Motor cannot continue to rotate at any point in this region.

At s = 1, N = 0 i.e. at start, motor produces a torque called **starting torque** denoted as T_{st}.

The entire torque-slip characteristics is shown in the Fig. 5.11.1.

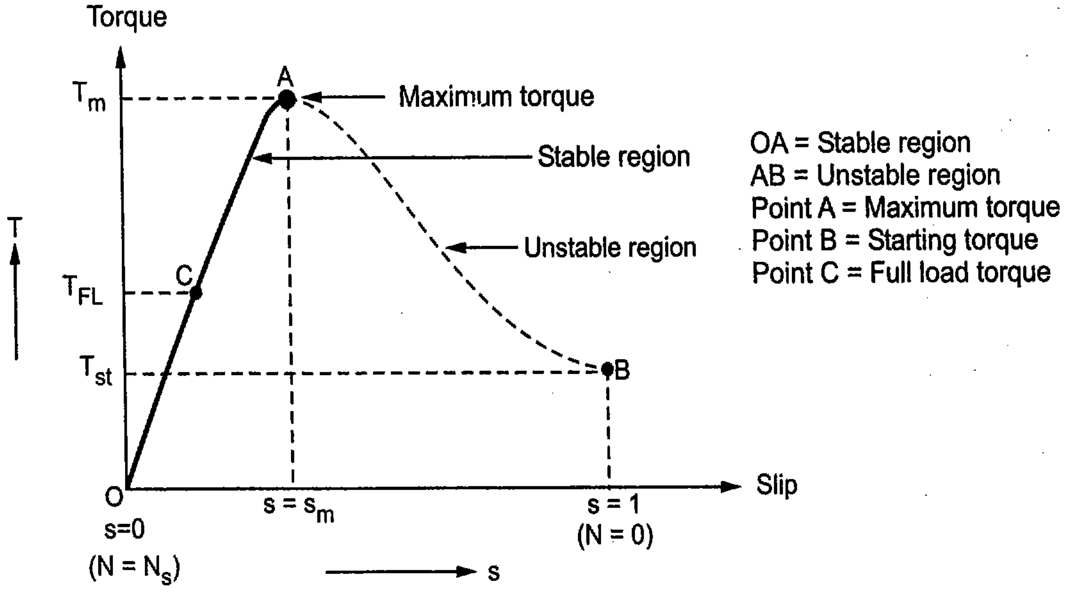


Fig. 5.11.1 Torque-slip characteristics

5.11.1 Full Load Torque

When the load on the motor increases, the torque produced increases as speed decreases and slip increases. The increased torque demand is satisfied by drawing more current from the supply.

The load which motor can drive safely while operating continuously and due to such load, the current drawn is also within safe limits is called **full load condition** of motor. When current increases, due to heat produced the temperature rises. The safe limit of current is that which when drawn for continuous operation of motor, produces a temperature rise well within the limits. Such a full load point is shown on the torque-slip characteristics as point C in the Fig. 5.11.1 and corresponding torque as $T_{F.L.}$.

The interesting thing is that the load on the motor can be increased beyond point C till maximum torque condition. But due to high current and hence high temperature rise there is possibility of damage of winding insulation, **if motor is operated for longer time** duration in this region i.e. from point C to B. But motor can be used to drive loads more than full load, producing torque upto maximum torque for short duration of time. Generally full load torque is less than the maximum torque.

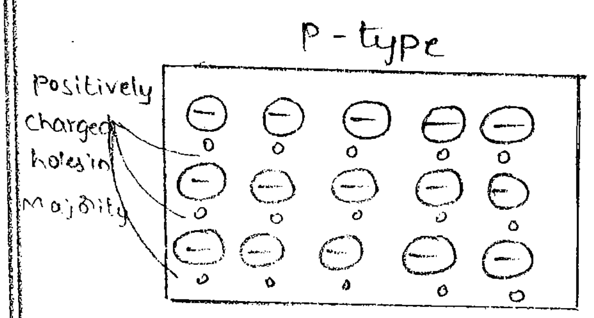
UNIT-4 Rectifiers & Linear Ic's

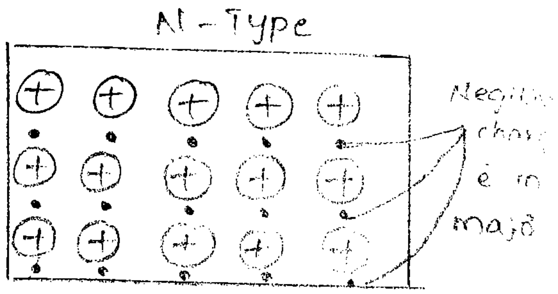
BEEE

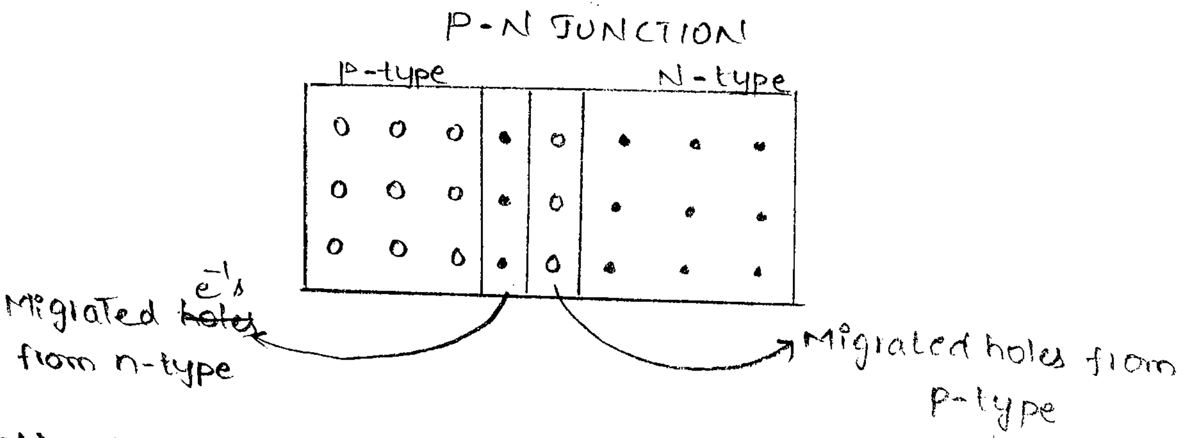
P-n Junction Diode :—

When a p type materiaal is intimately joined to n type then a p-n Junction is formed. The below diagram shows the p type & n type semi conductor before they are Joined. In p type semi conductor has negative acceptor ions & positively charged free holes which about moves on p-side.

Similarilly n-type semi conductor has positively donor ions and negitively charged free electrons which move about n side



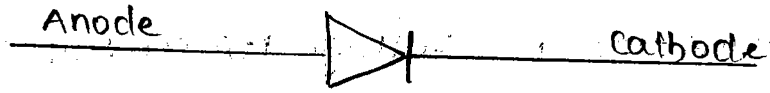




Function :

In p-type material has high concentaration of holes and n-type material has high concentration of free electrons and hence there is a tendency of holes to diffuse over to n-side & ē To p-side. This process is known as Diffusion.

Diode Symbol :—



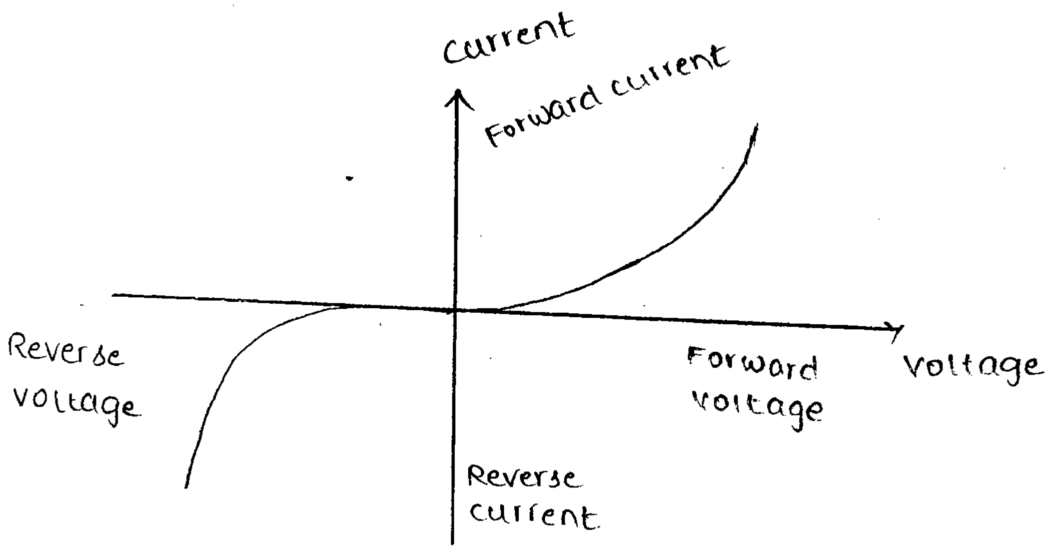
Forward Biased Diode :—

When an external voltage is applied to p-n junction in such a following way the positive terminal of the battery is connected to p-type while the negitive termmal is connected to n-type then it is called Forward Biased Diode.

Reverse Biased Diode :—

When an external voltage is applied to p-n junction in such a following way the positive terminal of the battery is connected to n-type while the negitive terminal of the battery is connected to p-type then it is called Reverse Biased Diode

V-I characterstics of P-n Junction diode :—

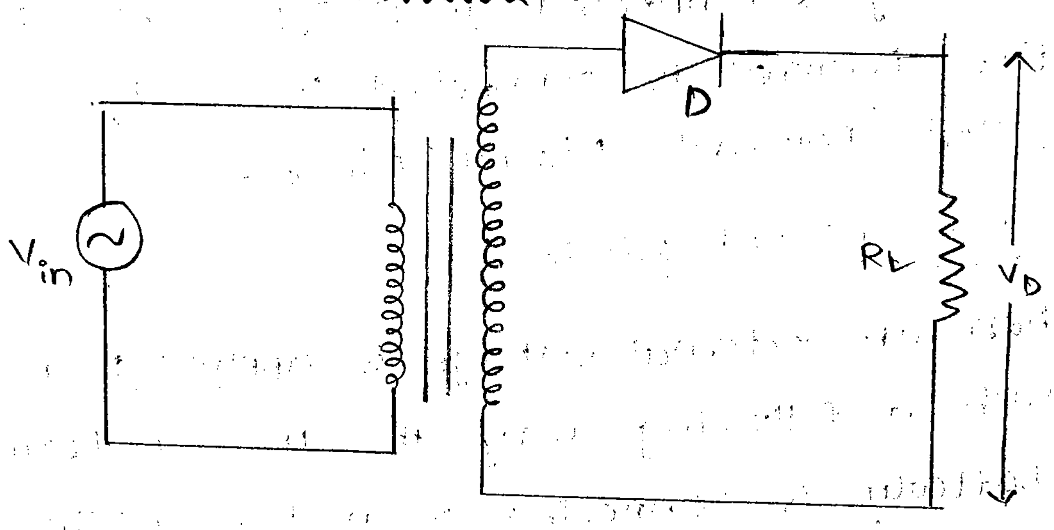


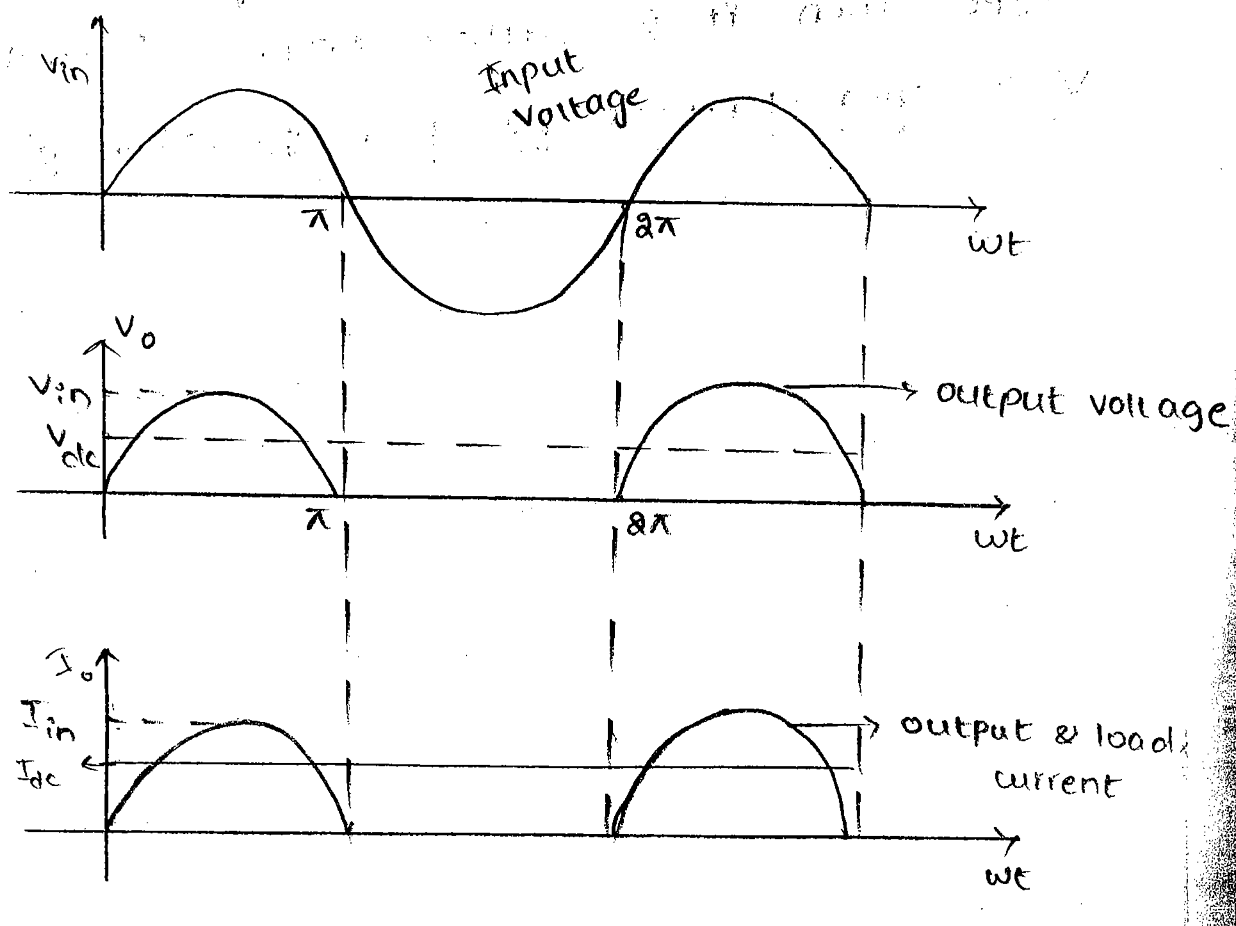
Rectifier :-

A Rectifier is defined as an electronic device used for converting Ac voltage (or) current into uni-directional voltage (or) current (D.C)

For this purpose a uni directional conduction device such as p-n Junction Diode is used.

Half wave Rectifier :-





In this half wave rectifier AC voltage to be rectified is applied to a single Diode connected in Series with a load resistance (R_L) as shown in above dig

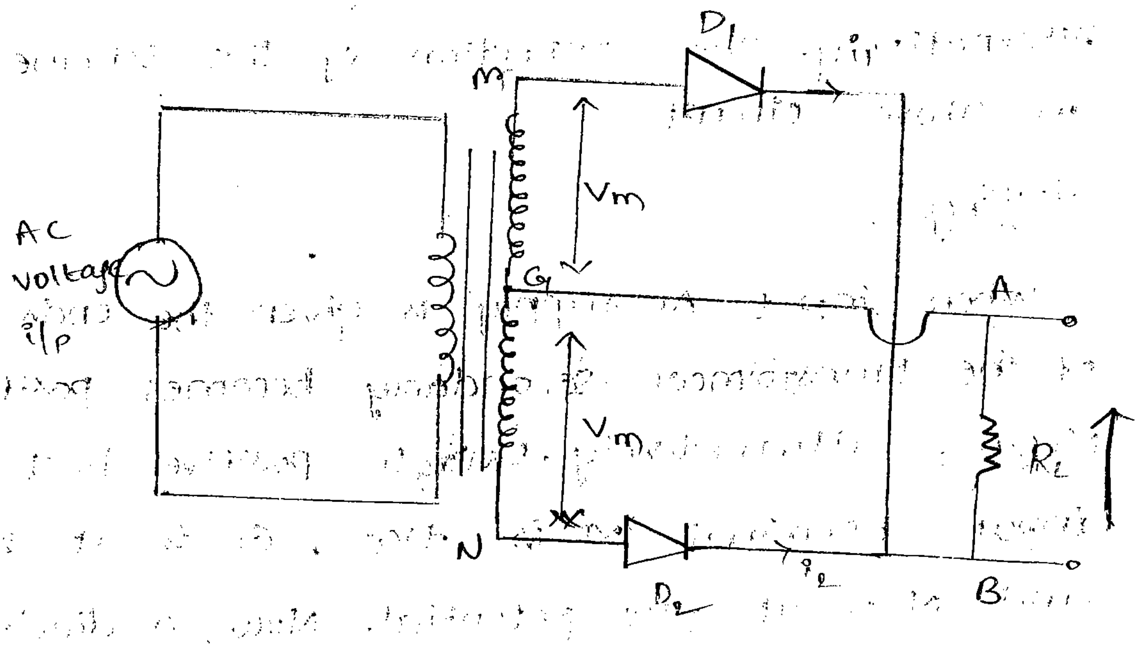
Working of Half wave Rectifier :—

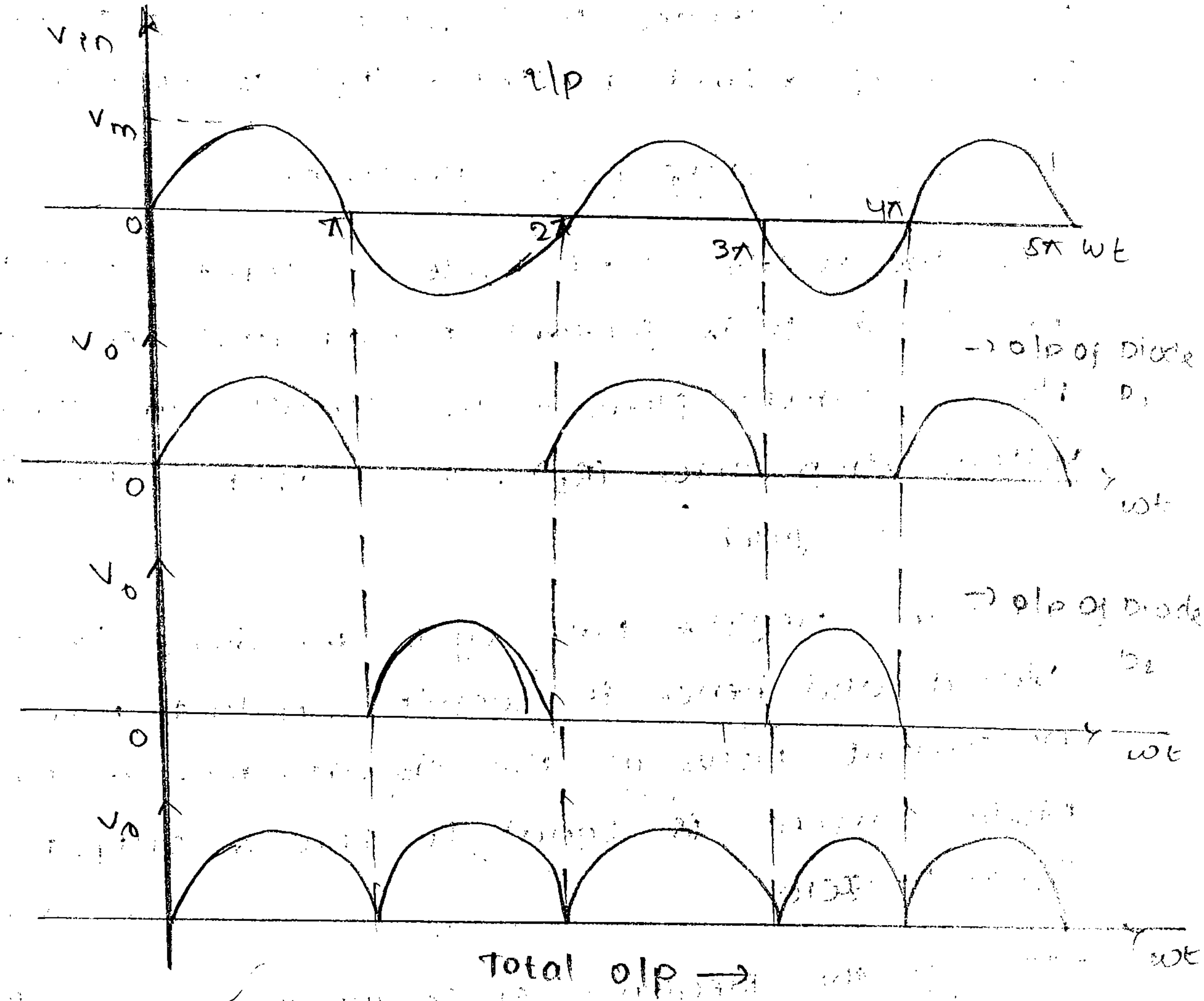
For the positive half cycle of Input AC voltage the diode 'D' is forward Biased and hence it conducts Now a current flows in the circuit and there is a Voltage drop across (R_L). this output voltage & current as shown in above graph.

For the Negitive half cycle the diode 'D' is reverse Biased and hence it doesn't conduct. Now there is no current flows in the circuit i.e load current (or) Diode current is Equal to zero & output voltage is Equal to zero

- thus for the Negitive cycle no power is delivered to the load

Full Wave Rectifier :—





In full wave Rectifier both Half cycle of the input are utilized with the help of two diodes working Alternatively. The connection of this scheme as shown in above circuit

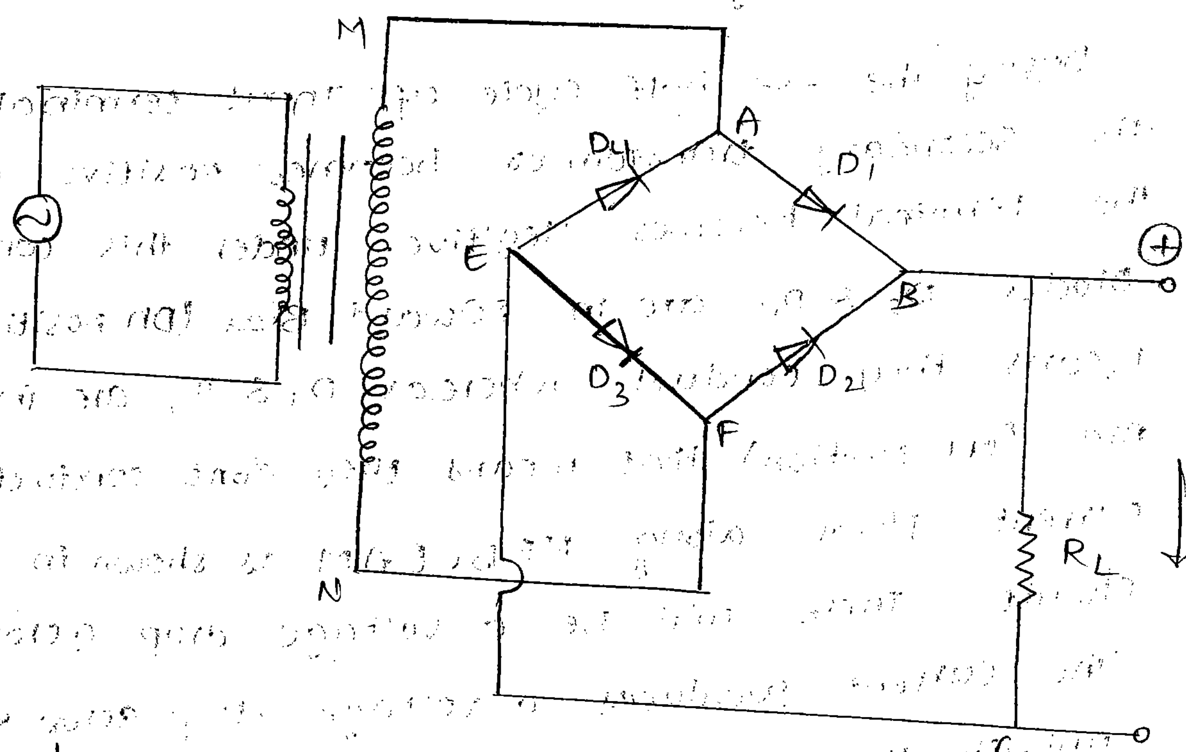
Working :—

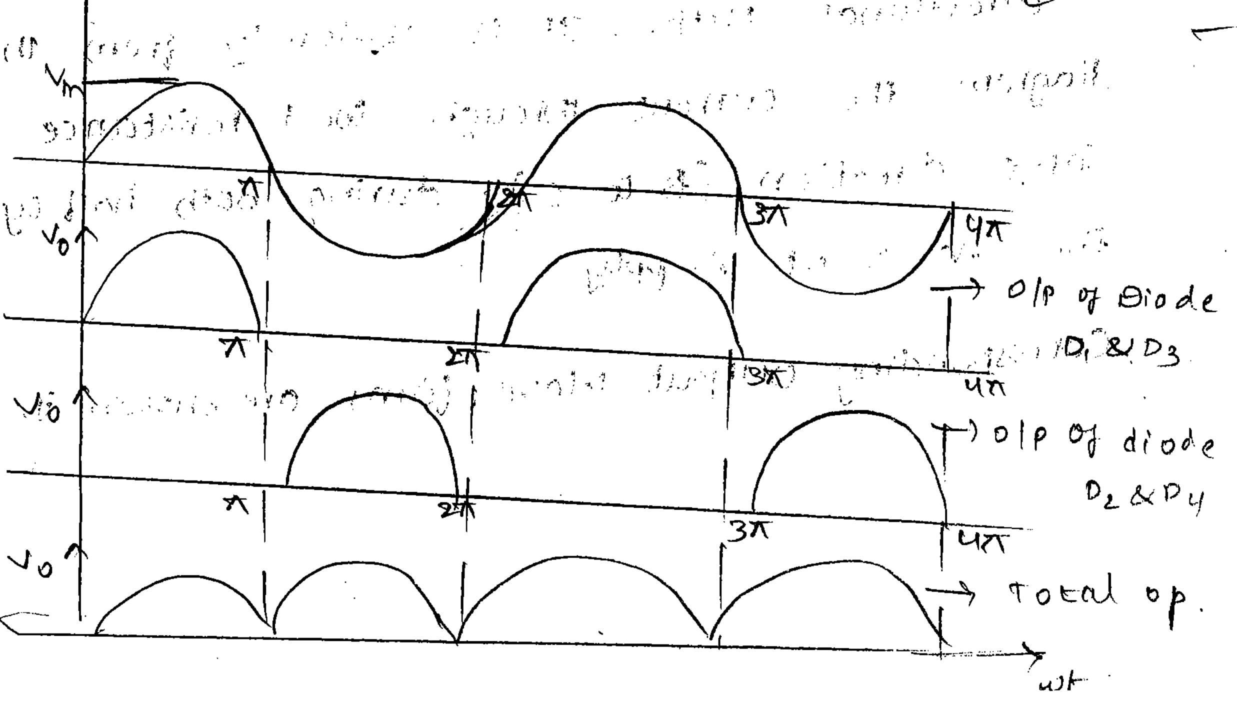
When input AC supply is given the ends M & N of the transformer secondary becomes positive & Negitive alternatively. During to positive half of ac input terminal M is +ve, G is at zero potential and N is at −ve potential. Now, a diode D_1 is Forward Biased that means it conducts and causes a current (i_1) in load Resistance (R_L)

Diode D_2 remains non conducting being reverse Biased.

During the negitive half cycle terminal N becomes +ve, G is at zero potential & M is at -ve potential. Now, a Diode D_2 ~~(is in Reverse Bias)~~ conducts and current i_2 flows through the Load Resistance R_L. Diode D_1 is non conducting thus the current flows through R_L in the same direction (from A to B) in both cycles of AC input.

Bridge Rectifier :-





The above diagram shows the full wave bridge rectifier and corresponding output wave forms.

During the +ve half cycle of input, terminal m attains positive of secondary of Transformer. while the terminal N is negitive. In this situation Diode D_1 & D_3 are in Foward Bias (on position) that means they conduct whereas diodes D_2 & D_4 are in Reverse Bias (off position) that means they dont conduct. So the current flows along MABCEFN as shown in above circuit. There will be a voltage drop across RL

During the -ve half cycle of Input terminal N of the Secondary transformer becomes positive while the terminal becomes Negitive. under this condition Diodes D_2 & D_4 are in Foward Bias (On position) that means they conduct whereas D_1 & D_3 are in reverse Bias (OFF position) that means they dont conduct. So the current flows along NFBCEAM as shown in above circuit. There will be a voltage drop across RL. The current produces a voltage drop across R_L in uni directional path. It is obviously from the above diagram the current through load resistance is in Same direction (B to C) during both half cycles of the AC input supply

Corresponding output wave forms are shown in above

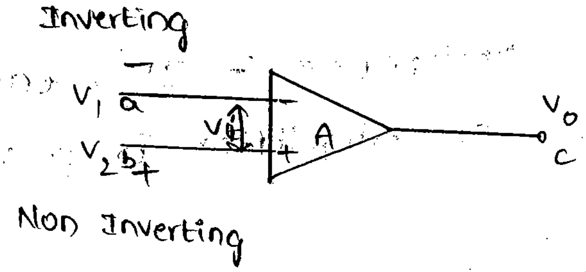
Advantages :

* No centre Tap is required on Transformer
* It is suitable for high voltage Application

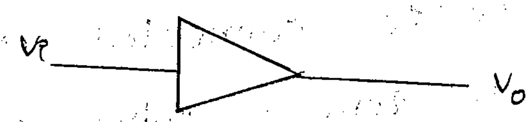
Operational Amplifiers :— (Op Amp)

An op Amp with high gain and high input Impedance used especially in circuits for performing mathematical operations on an input voltage.

Circuit symbol for op Amp :—



(b)



(a)

Standard Regctangular symbol is generally used for an Op Amp. The early operational Amplifiers had only one input and one output terminal as shown in (a) The output was always inverted w.r.t input.

The Op Amp's now available are usually of differential type with 2 input terminals and a single output terminal as shown in (b)

The Negative sign Indicates that the signal applied at the terminal 'A' will appear amplified but phase inverted (opposite polarity) at terminal 'C'. similarly the terminal 'B' is called Non inverting input terminal here the positive sign indicates that a signal applied at the terminal 'B' will appear amplified but inphase (same polarity) at terminal 'c'.

The output voltage is directly propotional to the input voltage which is difference of V_1 & V_2 that means

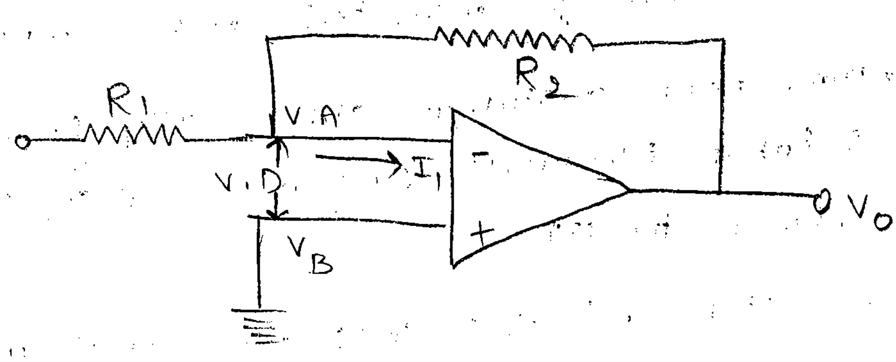
$$V_{in} = V_2 - V_1$$

$$V_o \propto V_{in}$$

Characterstics of (Op-Amp) :—

* It has an Infinite voltage gain
* It has an Infinite Band width
* Infinite Input Resistance - It means the input current is zero. ∴ Amplifier is a voltage control Input Device
* zero output Resistance - It means V_o is Independent of the load Resistor connected across o/p.
* The output is zero - when equal voltages are applied at the two input terminals $V_2 = V_1$

Virtual ground concept of an op-Amp :—



Inverting Amplifier

This is an impoltant concept of an op Amp. It Plays a virtual role while deriving the expression for o/p voltage

V_B is a potential defined at Non inverting I/p
V_A is a potential defined at Feed back point of Inverting I/p
V_D is the diff b/w V_B & V_A i.e $V_D = V_B - V_A$
According to Ideal characteristics of Op-Amp
Input Resistance R_I is Infinite. ∴ The current entering into the op Amp (I_I) will be zero That means differential voltage V_D will be zero

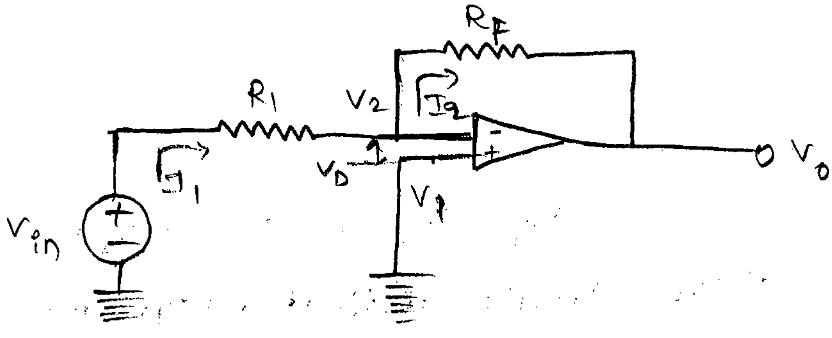
$$\therefore V_D = V_B - V_A = 0 \Rightarrow V_B = V_A$$

Note :

The Node voltage V_B at positive terminal is same as the Negitive Feed back Node point V_A

Applications of an Op Amp :—

1. Inverting Amplifier :—



The above diagram shows the Inverting Amplifier Its Non-inverting I/p terminal is grounded where has the external input signal V_{in} is applied to the Inverting I/p through Resistance R_1. A Feed back Resistance R_f connected from o/p to Inverting i/p terminal of the op Amp.

According to virtual ground concept $V_1 = V_2$

Apply KCL at Node V_2,

$$I_{in} = i_1 + i_f$$

$$I_{in} = i_f \quad (\because i_1 = 0)$$

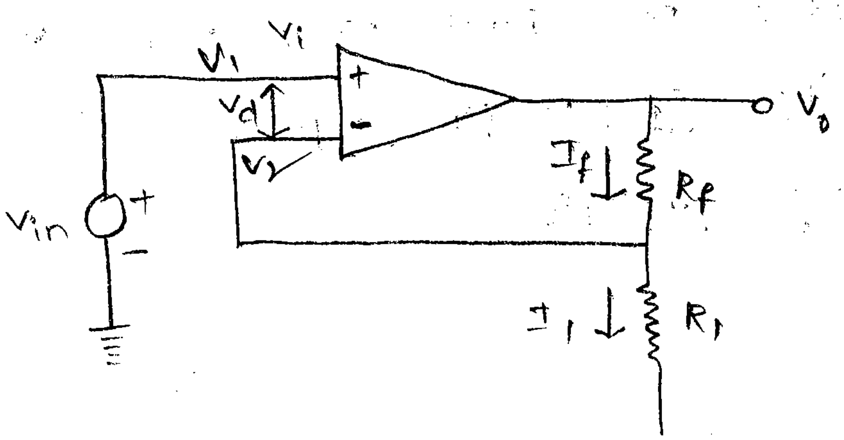
$$\frac{V_{in} - V_2}{R_1} = \frac{V_2 - V_0}{R_F}$$

As $V_1 = 0 \Rightarrow V_2 = 0$

$$\frac{V_o}{V_{in}} = -\frac{R_f}{R_1} \rightarrow \text{gain Equation}$$

Here the Negitive sign Indicates that the Input & Output voltages are out of phase by 180°

Non Inverting Amplifier :-



$$V_{in} = V_2 \quad (\because V_1 = V_2)$$

In the above circuit indicates non inverting Amplifier with feed Back (or) closed loop Non inverting Amplifier In this case inverting terminal of Amplifier is grounded through Resistance R_1 & o/p is applied to the Inverting I/p terminal through Feed Back circuit composed of a Resistors R_f & R_1 according to virtual Ground concept

$$V_{in} = V_2 \quad (\because V_1 = V_2)$$

$$I_f = I_1$$

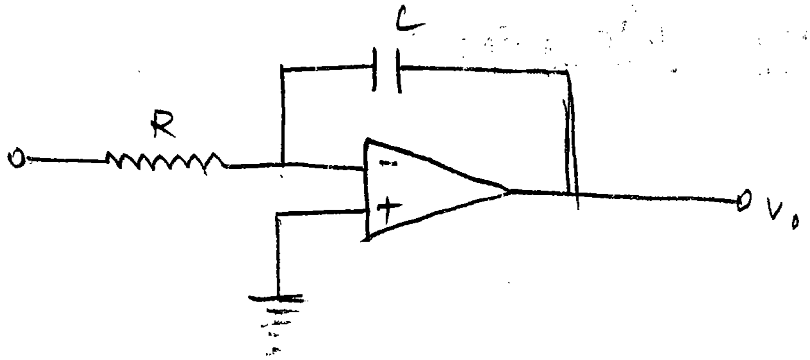
$$\frac{V_o - V_{in}}{R_f} = \frac{V_{in}}{R_1}$$

$$\frac{V_o}{R_f} = \frac{V_{in}}{R_1} + \frac{V_{in}}{R_f}$$

$$\frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_1}$$ → gain eq

In the above expression R_f & R_1 are +ve & gain eq also Positive also there is no phase Inversion.

Op Amp Integrator :—



An Integrator is a circuit that performs a mathematical operation called Integration. Integration is a process of continuous addition. The most popular application of an Integrator is to produce a ramp of o/p voltage which is a linearly increasing (or) Decreasing voltage. The Feed back is through capacitor 'c' instead of Resistor R_f. From the above dig

According to virtual ground concept

$$0 - V_o = V_C$$

$$V_o = -V_C$$

$$V_o = -\frac{1}{C}\int i\,dt = -\frac{1}{C}\int \frac{V_{in}}{R}\,dt$$

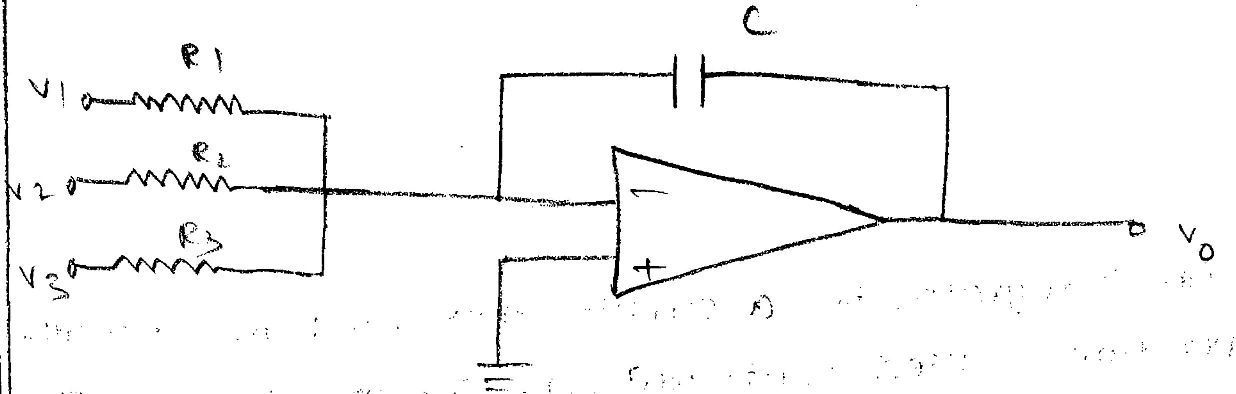
$$V_o = -\frac{1}{T}\int V_{in}\,dt$$

Where, $T = RC$ (Time constant)

Note :

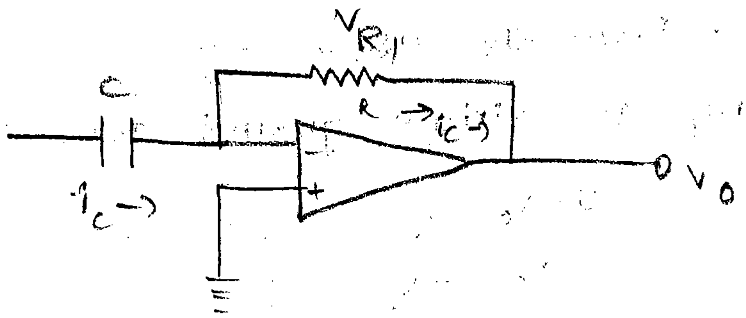
1. If the I/p voltage is step voltage the o/p voltage will be a ramp (or) linearly change in voltage
2. If the I/p voltage is square wave the o/p voltage is Triangular wave
3. If the I/p voltage is sinasoidal wave the o/p voltage will be cosine wave

Summing Integrator :—



$$V_o = -\left[\frac{1}{R_1C}\int V_1\,dt + \frac{1}{R_2C}\int V_2\,dt + \frac{1}{R_3C}\int V_3\,dt \right]$$

Op Amp Differentiator :—



Differentiator circuit can be obtained by interchanging Resistor and capacitor of Integrator circuit.

Note:

1. The common Application of op Amp Differentiator is to produce very narrow spites
2. A cosine wave i/p will generate sine wave o/p

3. A Triangular i/p will produce square wave o/p

$$i_C = C \frac{dV}{dt}$$

$$0 - V_a = V_a$$

$$V_0 = -V_a$$

$$V_0 = -i_C R = -RC \frac{dv}{dt}$$

$$V_0 = -RC \frac{dv_1}{dt}.$$

$$V_0 = -\tau \frac{dv}{dt}$$

Code No: R19ES1206 **R19** SET - 1

I B. Tech II Semester Supplementary Examinations, July/August - 2021
BASIC ELECTRICAL AND ELECTRONICS ENGINEERING
(Com. to ME, Auto E, Min E)

Time: 3 hours Max. Marks: 75

Answer any five Questions one Question from Each Unit
All Questions Carry Equal Marks

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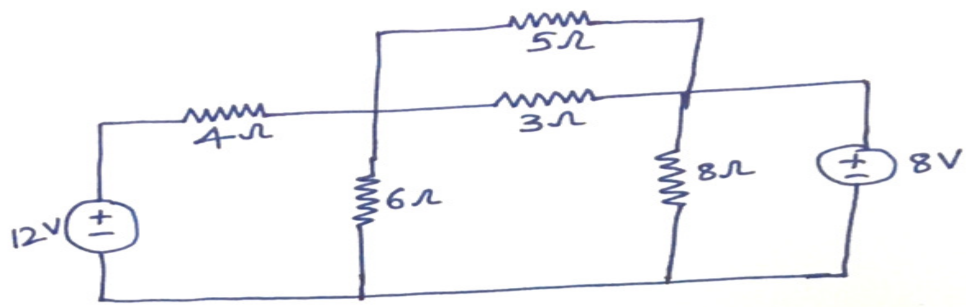
1. a) Explain the following: (8M)
(i) Ohms law (ii) Dependent and Independent sources

b) An incandescent light bulb rated at 100 W dissipates 100 W as heat and light when connected across a 220V ideal voltage source. If four such bulbs are connected in series across the same source, determine the power each bulb will dissipate. (7M)

Or

2. a) List and explain the basic types of network Elements. (8M)

b) Apply Kirchhoff's laws to determine the current through 4Ω and the power consumed in the 6Ω resistor for the circuit shown below: (7M)



3. a) Give the classification of DC Generators and explain in brief about each type. (7M)

b) A 4-pole shunt generator with lap connected armature having field and armature resistances of 50 Ω and 0.1 Ω respectively supplies sixty 100 V 40 watt lamps. Calculate the total armature current, the current per armature path and the generated emf. Allow a contact drop of 2 volts. (8M)

Or

4. a) Draw and explain the working of a Three Point Starter. (8M)

b) An 8-pole lap connected armature has 960 conductors, a flux of 40 mWb per pole and a speed of 400 rpm. Determine the emf generated. (7M)

5. a) Explain the construction and working principle of a transformer. (7M)

b) Find the primary and secondary turns of a 2200/200 V, single phase, 50 Hz, 25 KVA transformer if the flux in the core is to be about 0.08Wb. Also determine the primary and secondary currents if the losses are to be neglected. (8M)

Or

||''|''||''||''''|
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6. a) Explain the constructional features and principle of operation of a Three phase Induction motor. (8M)

   b) A three phase star connected alternator is rated at 1500 KVA, 12000 V. The armature effective resistance and synchronous reactance are 2.5Ω and 40Ω respectively per phase. Calculate the percentage regulation for a load of 1500 KW at power factor of (i) 0.85 lagging and (ii) 0.85 leading. (7M)

7. a) Sketch and explain in detail about the V – I characteristic of the p – n junction diode. (8M)

   b) Draw and explain the equivalent circuit of a Dual input operational amplifier. (7M)

Or

8. a) Distinguish between Intrinsic Semiconductors and Extrinsic Semiconductors. (8M)

   b) Explain the basic application of operational amplifier as an Integrator amplifier. (7M)

9. a) What is a Transistor and give its significance. (7M)

   b) Explain in detail about Common base circuit configuration with a neat diagram. (8M)

Or

10. a) Explain in detail about the correct biasing of a PNP Transistor with a neat connection diagram. (8M)

    b) Draw and explain in detail about the Input and output characteristics of a common Collector NPN transistor. (7M)

Code No: R201209 **R20** SET - 1

I B. Tech II Semester Regular Examinations, September- 2021

ELECTRICAL CIRCUIT ANALYSIS –I

(Only for EEE)

Time: 3 hours Max. Marks: 70

Answer any five Questions one Question from Each Unit
All Questions Carry Equal Marks

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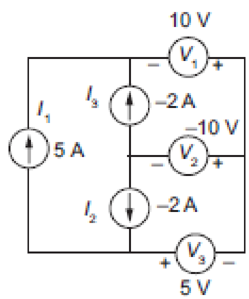
UNIT-I

1. a) Explain the following dependent sources: (7M)
   i) Voltage controlled voltage source ii) Voltage controlled current source
   iii) Current controlled current source iv) Current controlled voltage source

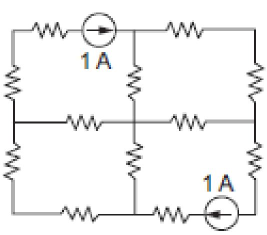
   b) Find the power delivered by all the sources in the following circuit: (7M)



Or

2. a) Three equal resistors are connected across a voltage source in series first and in parallel later. Find the ratio of power delivered by the source in the two cases. (7M)

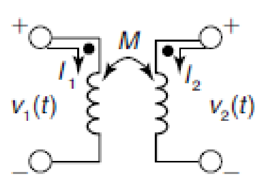
   b) All resistors in the circuit are of 4Ω. Find currents in all resistors and voltage across current sources by mesh analysis. (7M)



UNIT-II

3. a) Explain the following terms with respect to magnetic circuits: (7M)
   i) Self-inductance ii) Mutual inductance
   ii) Series and parallel magnetic circuits

   b) For the circuit shown below, if L_1 =0.4 H, L_2= 2.5 H, k =0.6, and i_1 = $4i_2$= 20cos $(500t - 20^0)$ mA. (7M)



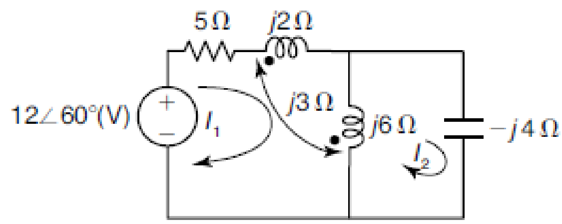
   Evaluate the following quantities at t = 0:
   (i) i_2,
   (ii) V_1, and
   (iii) the total energy stored in the system.

|''|'||||''|'''|||'|
~~~~~~

Or

4. a) Prove that when two coils of self-inductances L_1 and L_2 are connected in series aiding connection with a mutual inductance M then the total inductance is equal to $L_{eqv} = (L_1 + L_2 + 2M)$. (7M)

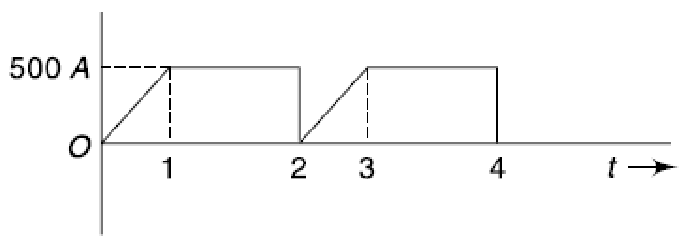
   b) For the circuit shown below, determine the phasor currents I_1 and I_2 (7M)



UNIT-III

5. a) A 200 V, 50 Hz. inductive circuit takes a current of 15 A, lagging the voltage by 45°. Calculate the resistance and inductance of the circuit. (7M)

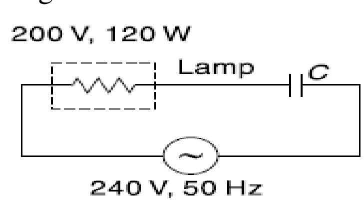
   b) Find the average and rms value for the following waveform: (7M)



Or

6. a) Prove that the active power over a complete cycle of current in a purely capacitive circuit is zero. (7M)

   b) A 200 V, 120 W lamp is to be operated on 240 V, 50 Hz. supply. Calculate the value of the capacitor that would be placed in series with the lamp in order that it may be used at its rated voltage. (7M)



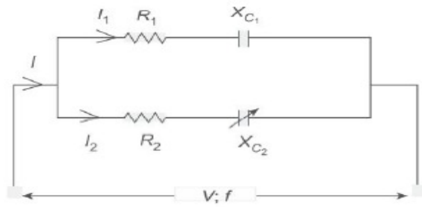
UNIT-IV

7. a) Explain the effect of band width and selectivity in series resonance circuit. (7M)

   b) A circuit consists of a coil of resistance 100 Ω and inductance 1 H in series with a capacitor of capacitance 1 μF. Calculate (i) the resonant frequency, (ii) current at resonant frequency and (iii) voltage across each element when the supply voltage is 50 V. (7M)

Or

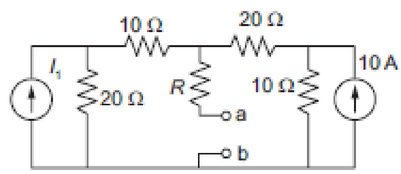
8. a) Draw the locus of I_2 and I for the parallel circuit shown below with neat step by step explanation: (7M)



b) A coil of resistance 5 Ω and inductance 0.1 H is connected in parallel with a circuit containing a coil of resistance 4 Ω and inductance 0.05 H in series with a capacitor C and a pure resistor R. Calculate the values of C and R so that currents in either branch are equal but differ in phase by 90°. (7M)

UNIT-V

9. A resistor of 20 Ω connected across a – b for the circuit shown below, draws maximum power from the circuit and the power drawn is 100W. i) Find the value of R and I_1. ii) With 20 Ω across a- b find the value of I_1 such that power transferred to it is 0 W. (14M)



Or

10. a) State and explain Thevenin's theorem. (7M)

b) Find the power dissipated in the resistor R_2 for the circuit shown below by applying superposition theorem (7M)