Sl. No.	Date	Chapter Name	Page No.	Teacher's Sign Remarks

PAGE
DATE

Chapter-1
Introduction

Role of electricity in modern society:

Electricity is the set of physical phenomena associated with presence and flow of electric charge. It gives a wide variety of well known effects such as lightening, ~~cat~~ static electricity, electromagnetic induction and the flow electrical current and creation and reception of electromagnetic radiation such as radio waves.

Today the modern society exists because of electricity, it is one of the greatest invention in the history, because of electricity many things can be possible like medical operations, production, construction & many more are likely to happen even during night time. Almost everything we use function by the help of electricity. Imagine the world without electricity, we can not watch televisio or play computer games. The essential device and a man's best friend which is the cellular or mobile phone cannot be possible without electricity. Laptops and computers is nothing without electricity and every homes are lightened with the power of this great invention.

Hence progress of human civilization has historically been in proportional to the ability of humans to use energy. The operation of our technological society depends upon the production and use of large amount of energy. The use of electrical energy has reached such a scale that it is unimaginable to live without it.

Energy source & production, generation, transmission & distribution of electrical energy:

There are some basic energy sources that can be used for production of electrical energy. To generate electricity means to convert source of energy into electrical form. The device used for production of electrical energy in large scale is known as generator which converts mechanical energy into electrical form. Electrical energy sources are divided into two types. They are:

(1) Thermal:

(i) <u>Coal</u>: Coal has been the major source of power generation in the countries around the world where its deposits are substantials. In USA about 45% of total electrical energy generation is from coal and in India it is more than 50%. However in Nepal we donot have any deposits of source and therefore there is no power stations using coal as a source.

(ii) <u>Nuclear fission</u>: Nuclear fission of atomic materials such as Uranium produces heat which is utilized to produce station steam turbines, such as power station is called nuclear power station. About 3000 metric tones of coal produces the same amount of heat as by the 1kg of nuclear fuel.

(iii) <u>Geo-Thermal</u>: Heat from the earth's interior and sub-surface water is combine to produce natural steam which can be used to run the turbines and there by produces electrical energy. California operating at a capacity of about 400 mega watt which is the biggest of this kind. It is an example of geo-thermal source.

(2) Non-Thermal:

(i) <u>Tidal</u>: There are a few sites around the world where it proves economical to convert the change in potential energy caused by tide levels into electrical form. The largest installation of this tide is in France with a rated capacity of 240 Mega watt.

(ii) <u>Wind</u>: The wind can be used to drive turbines (air turbines) that inturns drive generators to produce electricity. In certain places where the strong winds are common features, this source of energy may be attractive for the generation of electricity.

(iii) <u>Solar</u>: Semi-conductors expose to solar radiations produces electricity through the solar pannels. Because of the high cost of solar cells and low efficiency of this conversion this process be source for the commerical production of electrical energy has not been feasible.

(iv) <u>Hydropower</u>: Hydro-electricity is another term for power generated by harnessing the power of moving water. Not necessarily falling water, just moving water. There are many famous such generating stations in the world such as Niagara falls, Grand Coullee and Bullder Dam. These are just a few of the many examples of energy produced by falling water. Power is generated or manufactured in large scale at power generating stations using the same basic principle as a small grist mill yet on a most larger and vastly improved scale for better efficiency. These electrical generators are attached to turbines which spin at a great speed as a result of water rushing through them. These power stations, turbines are much more efficient at extracting the kinetic energy from the moving water and converting that energy into power through these generators.

The hydro electricity extracted from water depends not only the volume but in the difference in height between the source & the water out flow. The height difference is called head. The amount of P.E in water is directly proportional to head. To obtain very high head water ~~bye~~ for hydrolic turbine may be run through a large pipe. Hence, in this way electricity is generated in hydropower stations.

Chapter - 2
D.C circuit Analysis
[30-35 marks]

Electric Circuit :
A circuit is a closed conducting path through which an electric current flows. Circuit consist of active and passive elements.

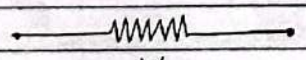
Active elements are those which have their own energy and they transfer energy to passive elements.

And passive elements are those which doesnot have their own energy. They receive energy from active elements.

Example: Active elements → Voltage, Current
passive elements → Resistor, capacitor, inductor etc

Resistor :
It is defined as the property of a substance due to which it opposses the flow of electricity.

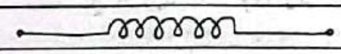
It is a dissipative element which converts electrical energy into heat energy as current flow through it at any direction.



Symbol of Resistor

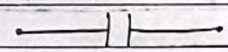
It's unit is ohm (Ω).

Inductor :
It is two terminal storage element in which energy is stored in magnetic flux field. The inductance of a circuit is measured in Henery (H).



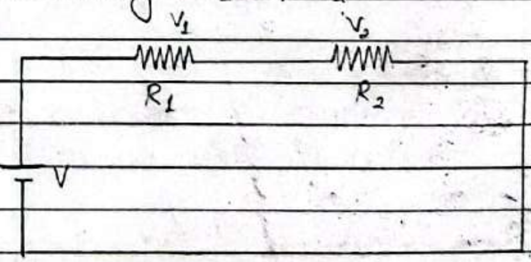
Symbol of Inductor

Capacitor :
It is a two terminal element that has the capability of energy storage in electric field. The energy stored can be fully restored. Its unit is Farad (F).



Symbol of capacitor

Series & Parallel Resistor :
(1) Series Resistor :
Let us consider a circuit having resistance R_1 & R_2 connected in series with their respective voltage V_1 & V_2.



In this case, total voltage of the circuit is :

$$V = V_1 + V_2$$

$\because V = IR$, so, we get :

$$IR_{eq} = I_1R_1 + I_2R_2$$

Again, $I_1 = I_2 = I$ [$\because$ current is same in series]

$$IR_{eq} = IR_1 + IR_2$$

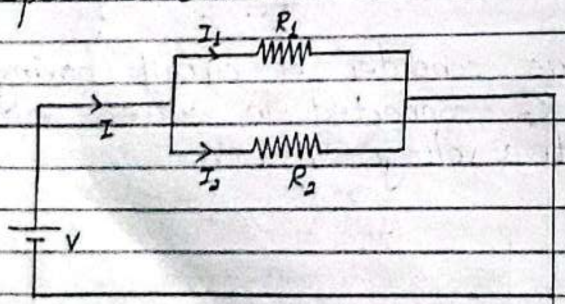
$$\boxed{R_{eq} = R_1 + R_2}$$

For 'n' number of resistors :

$$\boxed{R_{eq} = R_1 + R_2 + R_3 + \ldots\ldots R_n}$$

(2) Parallel Resistor :

let us consider a circuit having resistance R_1 & R_2 connected in parallel with their respective current I_1 & I_2.



In this case, total current is :

$$I = I_1 + I_2 \qquad [\because I = V/R]$$

$$\frac{V}{R_{eq}} = \frac{V_1}{R_1} + \frac{V_2}{R_2}$$

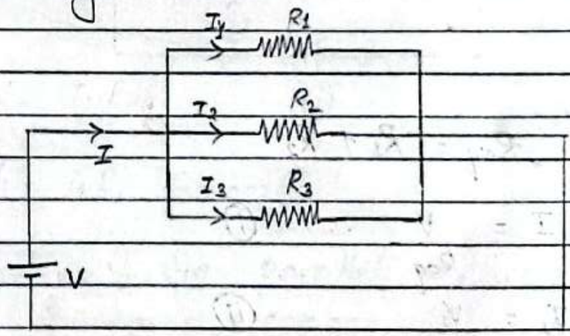
$\because$ voltage is same in parallel combination.

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

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

$$\cancel{\frac{1}{R_{eq}} \neq R_1 + R_2} \qquad \therefore \boxed{R_{eq} = \frac{R_1 \cdot R_2}{R_1 + R_2}}$$

If 3 resistors R_1, R_2 & R_3 are connected in parallel with respective current I_1, I_2 & I_3 through them.



In this case, total current is :

$$I = I_1 + I_2 + I_3$$

$$\frac{V}{R_{eq}} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

∵ Voltage is same in parallel, so we have:

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

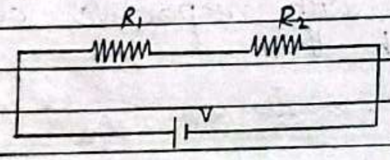
$$\frac{1}{R_{eq}} = \frac{R_2R_3 + R_1R_3 + R_1R_2}{R_1R_2R_3}$$

$$\boxed{R_{eq} = \frac{R_1R_2R_3}{R_1R_2 + R_2R_3 + R_3R_1}}$$

For n number of resistors:

$$\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \text{-------} + \frac{1}{R_n}}$$

Voltage Divider Formula:



Here,

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

$$I = \frac{V}{R_{eq}} \quad \text{-----} \ (i)$$

$$I_1 = \frac{V_1}{R_1} \quad \text{-----} \ (ii)$$

Since, current is same in series, so

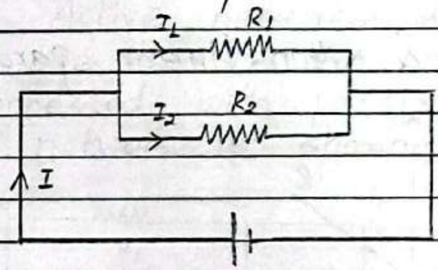
$$\frac{V}{R_{eq}} = \frac{V_1}{R_1}$$

$$V_1 = \frac{V}{R_{eq}} \times R_1$$

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

Similarly, $\boxed{V_2 = V \times \frac{R_2}{R_1 + R_2}}$

Current Divider formula:



Here,

$$R_{eq} = \frac{R_1R_2}{R_1 + R_2}$$

$$V = I \cdot R_{eq} \quad \text{-----} \ (i)$$

$$V_1 = I_1R_1 \quad \text{-----} \ (ii)$$

Since, $V = V_1$ in parallel so, we have:

$$I R_{eq} = I_1 R_1$$

$$I_1 = \frac{I R_{eq}}{R_1}$$

$$I_1 = \frac{I}{R_1} \times R_{eq}$$

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

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

Similarly, $\boxed{I_2 = I \times \frac{R_1}{R_1+R_2}}$

Linear & Non-linear parameters :

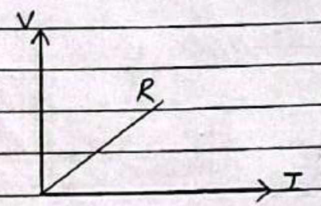


fig: Graphical representation of linear parameter or ohm's law

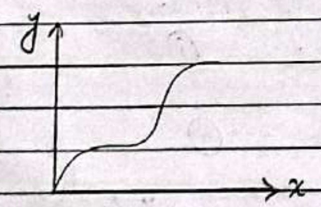


fig: o/p of non-linear parameter

A linear element shows linear characteristics of voltage and current. Simple resistors, capacitors and inductors are linear elements and their resistance, inductance and capacitance does not change with the change in applied voltage or current.

For a non-linear element the current passing through it doesnot change linearly with the linear change in applied voltage or current. Semi-conductor devices are the example of non-linear elements.

Active and Passive networks :

Active networks are those which contains one or more than one sources of emf connected with passive elements. Active network is shown below:

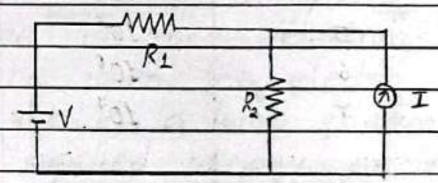


fig: Active Network

Passive networks are those which doesnot contains any active elements. Passive network is the combination of resistor, capacitor or inductor.

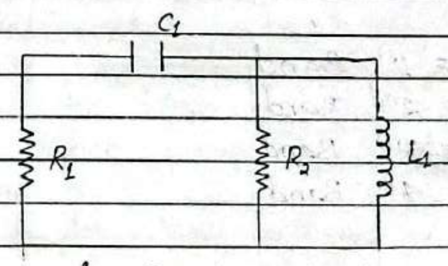


fig: Passive circuit

Resistor Colour Coding:

It is difficult to write the value of resistor on the surface of resistor because of its size. so for simplicity coloured bars are stamped on the surface of resistance or resistor.

Different coloured bar has different values as shown in table below:

colour	1st Band A	2nd Band B	3rd Band C	4th Band D
Black	0	0	10^0	
Brown	1	1	10^1	
Red	2	2	10^2	± 2 %
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
violet	7	7	10^7	
Grey				± 2 %
white				± 2 %
Gold				± 2 %
Silver				± 2 %

Then, value of resistor is given by:

$$\boxed{R = AB \times C \pm D}$$

where, A = 1st Band
B = 2nd Band
C = 3rd Band
D = 4th Band

Ohm's law:

It describes the relationship between voltage or emf and current established by it.

Ohm's law states that the voltage in the circuit is directly proportional to current provided that the temperature of the conducto remains constant.

i.e $V \propto I$

$V = RI$

$\boxed{V = IR}$ [where R is constant known as resistance]

Power:

When an electric current flows in a conductor heat is dissipated as a result of work done in moving electrons. Work is said to be done when the electric current is converte into light in a lamp filament or bulb. The power supplied in any electrical component is given by the product of voltage and current.

power = voltage × current

$P = IR \times I$

$\boxed{P = I^2R}$

Its unit is watt (ω).

Imp
Ideal and Practical Voltage Source:

An ideal voltage source is that voltage source which gives a fixed or constant load voltage.

An ideal voltage source has zero

internal resistance as shown in figure:

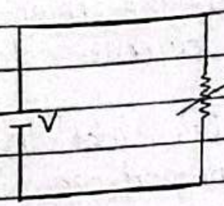


fig: Ideal voltage source

A practical voltage source is one in which there is some internal resistance or impedence which makes the load voltage vary with the load or load current due to drop in internal resistance of the source.

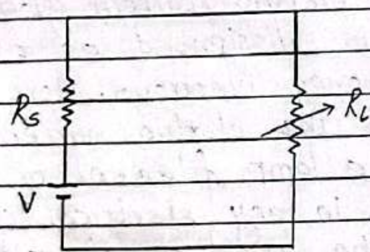
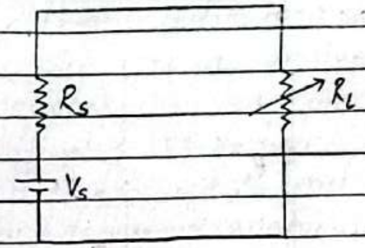


fig: practical voltage source

where, $R_s \rightarrow$ Internal resistance
$R_L \rightarrow$ load resistance

Imp # Conversion of voltage source into current source:

let us consider a circuit having source voltage 'V_s' with its internal resistance 'R_s' and load resistance 'R_L' as shown below:



If the series resistance R_s is not present in the circuit, then the voltage source cannot be converted into current source or ideal voltage source cannot be converted into current source.

After conversion of voltage source into current source, the series resistance is connected in parallel with the current source with the same value and the current is given by:

$$I_s = \frac{V_s}{R_s}$$

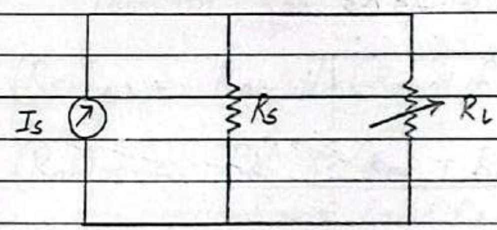
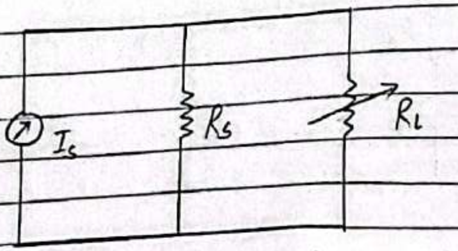


fig: Conversion of voltage into current

Imp # Conversion of current source into voltage source:

let us consider a circuit having source current 'I_s' with its internal resistance 'R_s' parallel to it and load resistance 'R_L' as shown below:



If the parallel resistance 'R_s' is not present in the circuit, then the current source can not be converted into voltage source or ideal current source can not be converted into voltage source.

After conversion of current source into voltage source, the parallel resistance is connected in series with voltage source with the same value & the voltage is given by:

$$V_S = I_S R_S$$

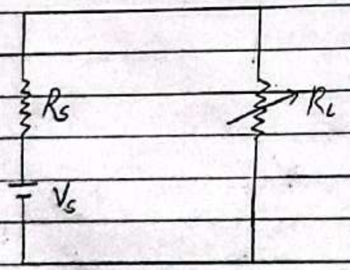
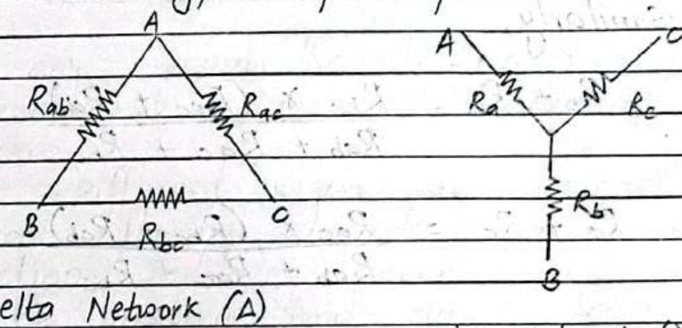


fig: Conversion of current into voltage

Star / Delta Transformation:

Imp

In circuit analysis, the topology of some network is so complicated that it is very difficult to reduce into an equivalent structure of series and parallel combination. So star/delta transformation is used to solve such types of complicated networks.



Delta Network (Δ)

Star Network (Y)

For delta network:

Here,

resistor R_{ab} is parallel with $(R_{ac} + R_{bc})$

$$(R_{ab})_\Delta = R_{ab} \parallel (R_{ac} + R_{bc})$$

$$(R_{ab})_\Delta = \frac{R_{ab} \times (R_{ac} + R_{bc})}{R_{ab} + R_{ac} + R_{bc}} \quad \text{------ (i)}$$

For star network:

Equivalent resistance across AB is:

$$(R_{ab})_Y = R_a + R_b \quad \text{------ (ii)}$$

The equivalence between these two networks for the terminal A & B is established by

equating the equation (i) & (ii):
i.e

$$(R_{ab})_Y = (R_{ab})_\Delta$$

$$R_a + R_b = \frac{R_{ab} \times (R_{ac} + R_{bc})}{R_{ab} + R_{ac} + R_{bc}} \quad \text{----(A)}$$

similarly,

$$R_b + R_c = \frac{R_{bc} \times (R_{ac} + R_{ab})}{R_{ab} + R_{ac} + R_{bc}} \quad \text{----(B)}$$

$$R_a + R_c = \frac{R_{ac} \times (R_{bc} + R_{ab})}{R_{ab} + R_{ac} + R_{bc}} \quad \text{----(C)}$$

Now, solving equation (A), (B) & (C), we get:

$$R_a = \frac{R_{ab} \times R_{ac}}{R_{ab} + R_{ac} + R_{bc}}$$

$$R_b = \frac{R_{bc} \times R_{ab}}{R_{ab} + R_{ac} + R_{bc}}$$

$$R_c = \frac{R_{ac} \times R_{bc}}{R_{ab} + R_{ac} + R_{bc}}$$

conversion of delta to star

similarly, for converting star to delta;

$$R_{ab} = \frac{R_a R_b + R_b R_c + R_a R_c}{R_c}$$

$$\& \quad R_{ac} = \frac{R_a R_b + R_b R_c + R_a R_c}{R_b}$$

$$R_{bc} = \frac{R_a R_b + R_b R_c + R_a R_c}{R_a}$$

Imp # Kirchhoff's law:

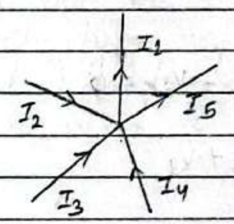
A German physicist Gustav Kirchhoff's observed two conditions for the analysis of any electrical network.

(i) Kirchhoff's Current law (KCL):

At any instant, the algebric sum of all the currents at a junction of a point is equal to zero.

Different signs are assigned to the current flowing toward or away from the junction. Incoming currents are assumed to be positive and outgoing currents are assumed to be negative.

Let us consider sources I_1, I_2, I_3, & I_4 and I_5 as shown in figure below:



Then, according KCL:

$$I_2 + I_3 + I_4 - I_1 - I_5 = 0$$

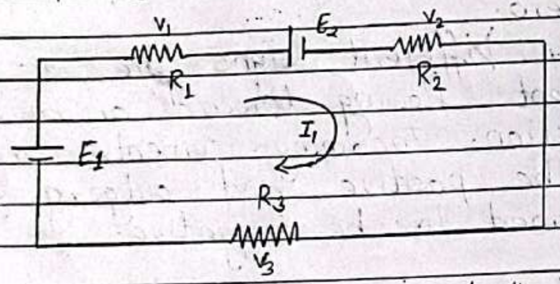
$$\boxed{I_1 + I_5 = I_2 + I_3 + I_4}$$

Incoming current = Outgoing current.

(ii) Kirchhoff's voltage law (KVL):

At any instant, in a closed loop the algebric sum of emf acting around the loop is equal to the sum of potential drop around the loop.

let us consider a circuit having sources of emf E_1 & E_2 and resistors R_1, R_2 & R_3 as shown below:



If I_1 be the current around the closed path in clockwise direction then applying KVL, we get:

$$+E_1 - V_1 - E_2 - V_2 - V_3 = 0$$

$$E_1 - E_2 = V_1 + V_2 + V_3$$

$$E_1 - E_2 = I_1R_1 + I_1R_2 + I_1R_3$$

$$\boxed{E_1 - E_2 = I_1(R_1 + R_2 + R_3)}$$

P.T.O

Mesh Analysis (Maxwell's Mesh Analysis):

A mesh is the most elementary form of a loop. It is the property of simple network and must be identical that it can not be further divided into other loops.

In this method, a different current is asumed in the loop, and the polarities of drop in each element is determined by the assumed direction (clockwise) of the loop current for that loop. KVL is than applied around each closed loop and current in each loop is determined.

Super - Mesh Analysis:

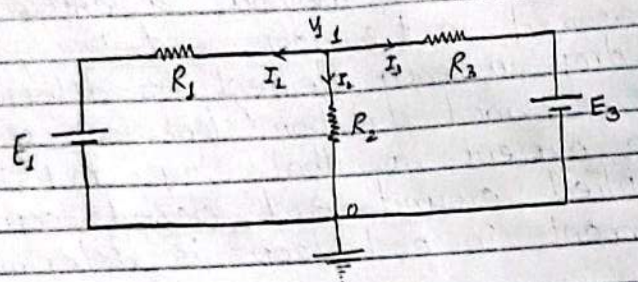
When the current source appears in between any two loops and the current source, can not be converted into voltage source such type of network is known as super mesh ~~analysis~~ and super mesh analysis is used to solve such type of network.

Nodal Analysis:

It contains a junction point and the voltage in the circuit must be measured between two terminals.

It is appropriate and usefu to assign one terminal as a reference point, this reference point or ~~&~~ reference terminal is called circuit ground.

Let us consider a circuit as shown below which contains a junction point 1 and a reference point zero.



Let V_1 be the voltage at point '1', then considering outgoing current I_1, I_2 & I_3 as shown.

Applying KCL at ~~give~~ node '1':

$$I_1 + I_2 + I_3 = 0$$

$$\therefore \frac{V_1 - E_1}{R_1} + \frac{V_1 - 0}{R_2} + \frac{V_1 - E_3}{R_3} = 0 \quad \text{---(1)}$$

Super Node:

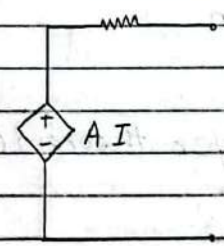
With the voltage source between two nodes a difficulty arise in applying KCL in the circuit, an easy way to solve out this difficulty is to treate nodes along with the voltage source as a supernode. Thus, KCL is applied at supernode to find the value of voltage.

Imp # Dependent and Independent Sources:

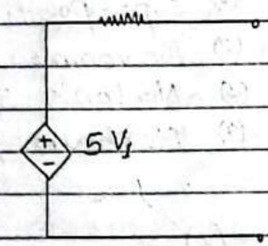
The voltage or current source which doesnot depend on any other quantity in the circuit are called independent sources.

A dependent voltage or current source is one which depends on the some other quantity in the same network which may be either voltage or current source.

Dependent Sources are represented by diamond shaped symbol.

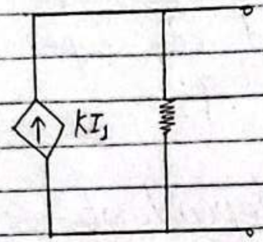


Current dependent voltage source

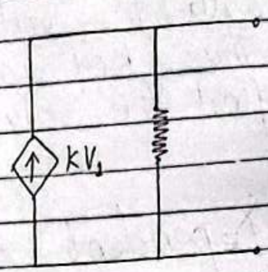


voltage dependent voltage source

P.T.O



Current dependent current source



voltage dependent current source

Network Theorems:

Network theorems are used for the solution of typical electrical networks on the basis of methods of solving the network, they are divided into following four types:

(1) Super position Theorem
(2) Thevenin's Theorem
(3) Norton's Theorem
(4) Maximum power transfer theorem (MPTT)

(1) Superposition Theorem:

The response at any point in a linear circuit (circuit having voltage, current and resistor) containing more than one independent sources can be obtained by superimposing the response caused by each source acting alone while the other source is made inactive.

A voltage source is made inactive by placing a short circuit across the terminals of voltage and making open circuit across a current source.

Note: (i) Equivalent resistance is zero with parallel to the short circuit.
(ii) equivalent resistance is zero in series with open circuit.

voltage neglect → short circuit → parallel → zero

Current neglect → open circuit → series → zero

(2) Thevenin's Theorem:

Any two terminal of a network containing linear passive and active elements can be replaced by an equivalent voltage source (V_{th} → Thevenin's equivalent voltage) and an equivalent series resistance (R_{th}).

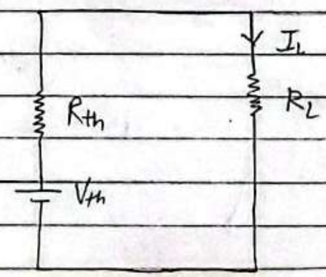


fig: Thevenin's Equivalent circuit

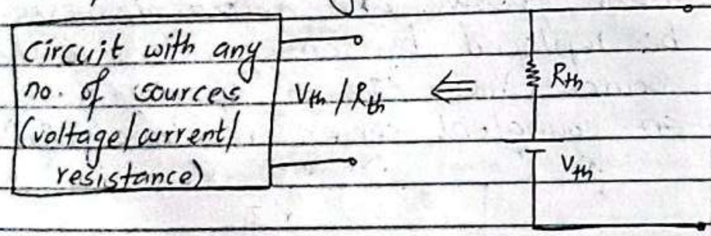
The equivalent voltage source is equal to the p.d measured between two terminals with no external sources connected to these terminals and the series resistance (R_{th}) is equivalent resistance looking into the network from these two terminals with all sources in the network made inactive.

The load current (I_L) is given by:

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

where,
$V_{th} \rightarrow$ Thevenin's equivalent voltage.
$R_{th} \rightarrow$ Thevenin's equivalent resistance
$R_L \rightarrow$ load resistance
$I_L \rightarrow$ load current

Thevenin's equivalent network can also be represented by:



P.T.O

(3) Norton's Theorem:

Any two terminal of active network containing voltage source, current source and resistance when viewed from its output terminal is equivalent to a constant current source (I_{sc} (or short circuit current) and a parallel resistance ~~(R_{sh})~~ R_o (or open ckt eq. resistance).

The constant current (I_{sc}) is equal to the current which would flow in the short circuit placed across the terminal and parallel resistance (R_o) is the equivalent resistance of the network when viewed from these open circuited terminal after all voltage and current source are removed or made inactive.

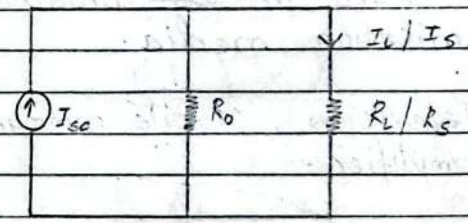
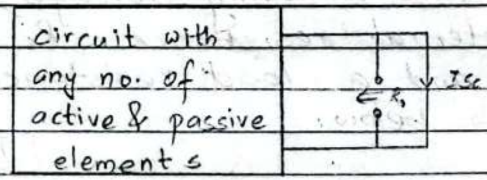


fig: Norton's Equivalent ckt



Block representation of Norton's Theorem

The current across load resistor is given by:

$$\boxed{I_L = I_{sc} \times \frac{R_o}{R_o + R_L}}$$

Imp (4) Maximum Power Transfer Theorem: [MPTT]

An independent voltage source with a series resistance R_s or an independent current source with a parallel resistance R_s delivers maximum power to the load resistor R_L when the source internal resistance is equal to the load resistance ie

$$\boxed{R_S = R_L}$$

It is used in ~~bro~~ broadcasting & communication media.

Eg: Television, Mobile communication, amplifier.

proof:

let us consider a Thevenins Equivalent ckt having voltage source 'V_s' with internal resistance 'R_s' ~~as shown below~~ and a load resistance 'R_L' as show below:

P.T.O

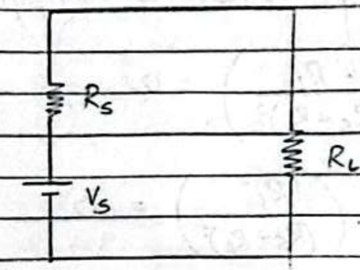


fig: Thevenin's Equivalent circuit

In this case,

Current across load resistor is:

$$I_L = \frac{V_s}{R_s + R_L} \quad \text{--- (i)}$$

Now, power across 'R_L' is given by:

$$P_L = I_L^2 R_L$$

$$= \left(\frac{V_s}{R_s + R_L}\right)^2 \times R_L$$

$$P_L = \frac{V_s^2 R_L}{(R_s + R_L)^2} \quad \text{--- (ii)}$$

The power is maximum when,

$$\frac{dP_L}{dR_L} = 0$$

P.T.O

Substituting value of P_L from equⁿ (ii):

$$\frac{d}{dR_L}\left(\frac{V_s^2 R_L}{(R_s+R_L)^2}\right)=0$$

or, $$V_s^2 \times \frac{d}{dR_L}\left(\frac{R_L}{(R_s+R_L)^2}\right)=0$$

or, $$\frac{d}{dR_L}\left(\frac{R_L}{(R_s+R_L)^2}\right)=0$$

or, $$\frac{(R_s+R_L)^2 \times \frac{d}{dR_L}(R_L) - R_L \times \frac{d}{dR_L}(R_s+R_L)^2}{[(R_s+R_L)^2]^2}=0$$

or, $$\frac{(R_s+R_L)^2 \times 1 - R_L \times 2(R_s+R_L)\times(0+1)}{(R_s+R_L)^4}=0$$

or, $$\frac{(R_s+R_L)^2 - 2R_L(R_s+R_L)}{(R_s+R_L)^4}=0$$

or, $$(R_s+R_L)^2 - 2R_L(R_s+R_L)=0$$

or, $$(R_s+R_L)\{(R_s+R_L)-2R_L\}=0$$

or, $$(R_s+R_L)-2R_L=0$$

or, $$R_s-R_L=0$$

$$\therefore \boxed{R_s=R_L}$$

This is the required condition for maximum power transfer to load resistor.

$\therefore$ Equⁿ (i) becomes:

$$I_L=\frac{V_s}{R_s+R_L}=\frac{V_s}{2R_L}$$

$\therefore$ Equⁿ (ii) becomes:

$$P_L=\frac{V_s^2 R_L}{(R_s+R_L)^2}$$

$$=\frac{V_s^2 R_L}{(R_L+R_L)^2}$$

$$=\frac{V_s^2 R_L}{4R_L^2}$$

$$=\frac{V_s^2}{4R_L}$$

$$\therefore \boxed{P_L=\frac{V_s^2}{4R_L}}=\frac{V_{th}^2}{4R_{th}}$$

Unit - 3

Single Phase AC Circuit Analysis

An alternating current or voltage is one that regularly flows in one direction and then in opposite direction. This reversible of flow of current or voltage occurs at regular interval of time. AC circuits are more common than DC circuits because they can be controlled and utilized more easily in general application.

Generation of Alternating Voltage or current :

Alternating voltage may be generated by rotating a coil in a magnetic field or by rotating a magnetic field within a stationary coil.

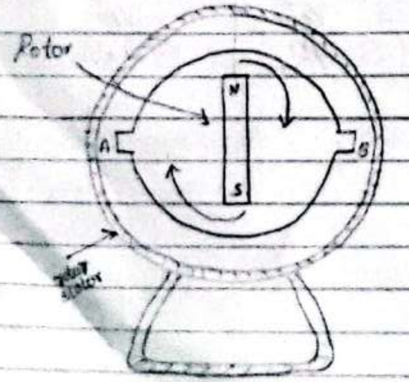
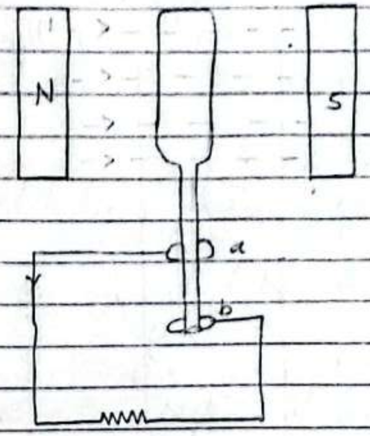


fig: rotating a magnetic field within a stationary coil.



Pro 459 (Book)

fig: Rotating a coil within a stationary magnet

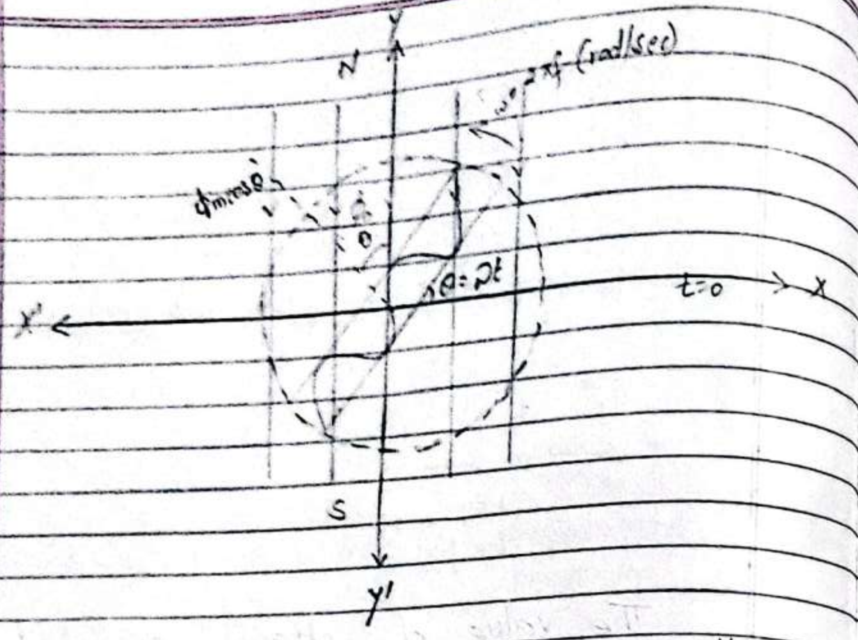
The value of voltage generated depends upon the number of turns 'N' in the coil, strength of field and the speed at which coil or magnet rotates.

Alternating voltage or current may be generated in either of two ways but rotating magnetic field within a stationary coil is one of the most widely used method.

Equation of Alternating Current :

Consider a rectangular coil having 'N' number of turns rotating in a uniform magnetic field with an angular velocity 'ω' (radian/sec) as shown in figure :

P.T.O



let, time be measured in X-axis, the maximum flux (ϕ_m) ~~lin~~ is linked in coil when its position is at X-axis at time 't sec'. The coil moves through an angle $\theta = \omega t$, in this position the component of flux which is perpendicular to plane of coil is given by:

$$\phi = \phi_m \cos\omega t \quad \text{- - - - - (i)}$$

If 'N' be the total number of turn in the coil then the maximum flux linkage of the coil at any time is given by $N \times \phi$.

According to the Faraday's law of electromagnetic induction, the induced emf is given by the rate of change flux linkage.

i.e

$$e = \frac{-d}{dt} N\phi \quad \text{- - - - (ii)}$$

Substituting the value of ϕ from equ^n (i):

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

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

$$e = -N\phi_m \cdot (-\sin\omega t) \cdot \omega$$

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

$$\therefore e = N\phi_m \omega \sin\omega t \quad \text{- - - (i)}$$

At $\theta = \omega t = 90^\circ$, $\sin\omega t = 1$

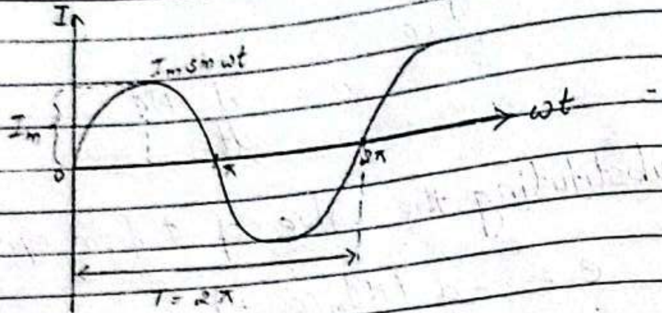
$$e = E_m = N\phi_m \omega \quad \text{(ii)}$$

$$\therefore e = E_m \sin\omega t \quad [\because \text{put } N\phi_m\omega = E_m \text{ in eq}^n \text{(i)}]$$

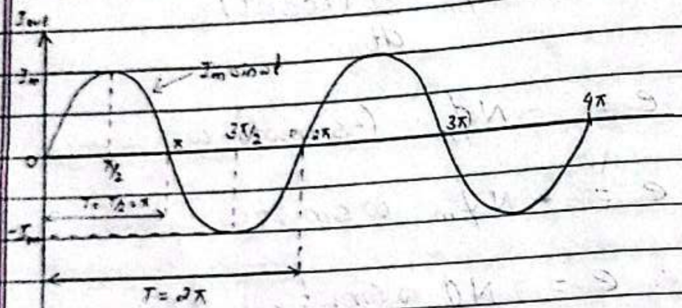
$$\boxed{E = E_m \sin\omega t}$$

$$\boxed{V = V_m \sin\omega t}$$

$$\boxed{I = I_m \sin\omega t}$$



Sinusoidal function Terminology:



Cycle:

One complete set of positive and negative values of alternating quantities (voltage or current) is known as cycle.

Time period:

The time taken by an alternating quantity to complete one cycle is known as time period.

for example: A 50Hz alternating current has a time period of $1/50$ sec

Frequency:

The numbers of cycles per second is called the frequency of the alternating quantity. Its unit is Hz (Hertz).

i.e.

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

Amplitude:

The maximum positive or negative value of alternating quantity is known as amplitude or instantaneous value of that quantity

Imp # Average value of an alternating quantity

The average value of alternating current is express by that steady current which transfer across any circuit, the same change is transfered by that alternating current during the same time.

In case of a symmetrical wave form, the average value over a complete cycle is zero. Hence in such case the average value is obtained by adding or integrating the instantaneous value of current over one half cycle ($T = T/2$) but in case of unsymmetrical wave form the average value most be taken over the complete cycle.

Let us consider an alternating current:

$$I = I_m \sin\omega t$$

where, I_m is the maximum value or amplitude of the alternating current

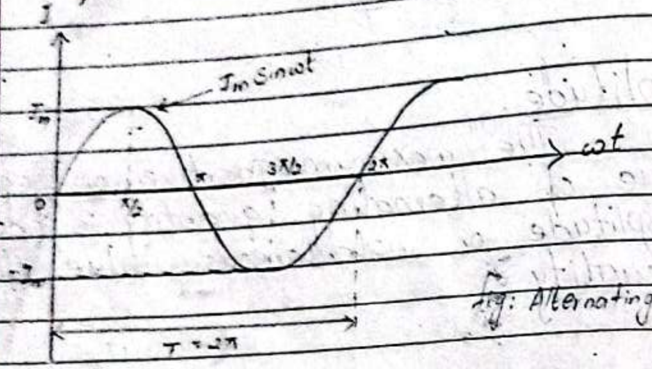


Fig: Alternating Current

Now, The average value of current is given by:

$$I_{av} = \frac{1}{T}\int_0^T I(t)\, dt \quad \text{- - - - (i)}$$

Here, from above wave form:

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

Substituting in equ^n (i), we get:

$$I_{av} = \frac{1}{2\pi}\int_0^{2\pi} I_m \sin\omega t\, d\omega t$$

$$= \frac{I_m}{2\pi}\int_0^{2\pi} \sin\omega t\, d\omega t$$

$$= \frac{I_m}{2\pi}\Big|-\cos\omega t\Big|_0^{2\pi}$$

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

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

$$\therefore I_{av} = 0$$

Therefore, the average value of symmetric wave form is zero over a complete cycle.

Now, Average value of current at: ~~$0-\pi/2$~~

$$T = \frac{T}{2}$$
$$= \frac{2\pi}{2}$$

i.e. $T = \pi$

& $I(t) = I_m \sin\omega t$

$$\therefore I_{av} = \frac{1}{\pi}\int_0^{\pi} I_m \sin\omega t\, d(\omega t)$$

$$= \frac{I_m}{\pi}\int_0^{\pi} \sin\omega t\, d(\omega t)$$

$$= \frac{I_m}{\pi}\Big|-\cos\omega t\Big|_0^{\pi}$$

$$= -\frac{I_m}{\pi}\left[\cos\pi - \cos 0\right]$$

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

$$\therefore I_{av} = \frac{2I_m}{\pi} \Rightarrow \boxed{I_{av} = 0.637\, I_m}$$

Imp # Root Mean Square (RMS) value:

The RMS value of an alternating quantity is given by that direct current which when flowing through a given circuit for a given time produces the same heat as produced by the alternating current.

The RMS value of alternating current is given by:

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T I^2(t)\,dt}$$

Squaring both sides:

$$I_{rms}^2 = \frac{1}{T}\int_0^T I^2(t)\,dt \quad \text{------(1)}$$

Here, $T = 2\pi$

$I(t) = I_m \sin\omega t$

$$\therefore I_{rms}^2 = \frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2(\omega t)\, d(\omega t)$$

$$= \frac{I_m^2}{2\pi}\int_0^{2\pi} \sin^2(\omega t)\, d(\omega t)$$

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

$$= \frac{I_m^2}{2\pi}\left[\int_0^{2\pi}\frac{1}{2}\,d(\omega t) - \int_0^{2\pi}\frac{1}{2}\cos 2\omega t\, d(\omega t)\right]$$

$$= \frac{I_m^2}{4\pi}\left[\int_0^{2\pi} d(\omega t) - \int_0^{2\pi}\cos 2\omega t\, d(\omega t)\right]$$

$$= \frac{I_m^2}{4\pi}\left[\left|\omega t\right|_0^{2\pi} - \left|\frac{\sin 2\omega t}{2}\right|_0^{2\pi}\right]$$

$$= \frac{I_m^2}{4\pi}\left[(2\pi - 0) - 0\right]$$

$$= \frac{I_m^2}{4\pi} \times 2\pi$$

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

$$\therefore \boxed{I_{rms} = \frac{I_m}{\sqrt{2}} = 0.707\, I_m}$$

$$I_{av} = \frac{2I_m}{\pi} = 0.637\,I_m$$

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

Similarly, $V_{av} = 0.637\,V_m = \frac{2V_m}{\pi}$

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

Imp # Form factor:

It is defined as the ratio of rms value to the average value.
i.e

$$\text{form factor}(k_f) = \frac{\text{Rms value}}{\text{Average value}}$$

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

$$\boxed{k_f = 1.1}$$

Imp # Peak factor:

Peak factor is the ratio of maximum value to the RMs value.
i.e

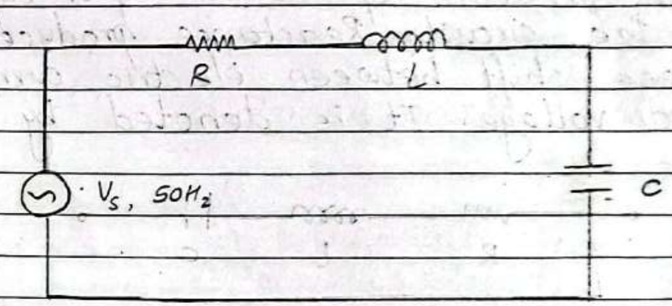
$$\text{Peak factor}(k_a) = \frac{\text{Maximum value}}{\text{RMs value}}$$

or, $k_a = \frac{I_m}{0.707\,I_m}$

$$\therefore \boxed{k_a = 1.41}$$

Impedence & Admitance:

Let us consider a series RLC circuit as shown below connected with source voltage V_s and frequency 50 Hz.



Now, Applying KVL:

$$V_s = V_R + V_L + V_C$$

$$IZ = IR + IX_L + IX_C$$

$$Z = R + X_L + X_C \ \Omega$$

where, $Z \rightarrow$ impedance

$X_L \rightarrow$ inductance $= 2\pi f L$

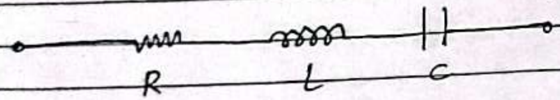
$X_C \Rightarrow$ capicatance $= \frac{1}{2\pi f C}$

Admittance is the reciprocal of impedance, it is denoted by Y and given by:

$$Y = \frac{1}{Z} \ \mho / mho / siemen$$

Reactance:

The analysis of an electric current in an electric circuit (RLC circuit) is known as reactance. It is the imaginary part of impedance which is caused by the presence of inductor ~~&~~ or capacitor in the circuit. Reactance produces a phase shift between electric current and voltage. It is denoted by 'X'.



$$Z = R + jX_L - jX_C$$

$$\boxed{Z = R + j(X_L - X_C)}$$

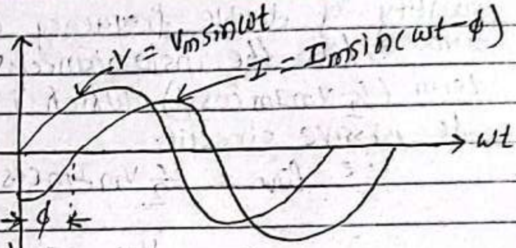
Complex / polar form

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

Phase / Angle is, $\theta = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$

now,
reactance$(X) = X_L - X_C$

Instantaneous power in AC circuit:



In a passive AC circuit, let the instantaneous voltage be $V = V_m \sin\omega t$ while the current is given by $I = I_m \sin(\omega t - \phi)$, ϕ being the phase difference between the voltage & current at any instant. ϕ is negative when voltage leads and ϕ is positive when voltage lags the current. $\phi = 0$ when the current and voltage are in same phase.

The instantaneous power 'p' is thus given by,

$$p = VI$$
$$= V_m \sin\omega t \cdot I_m \sin(\omega t - \phi)$$
$$= V_m I_m \sin\omega t \sin(\omega t - \phi)$$
$$= \frac{1}{2} V_m I_m \, 2\sin\omega t \sin(\omega t - \phi)$$
$$= \frac{1}{2} V_m I_m \left[\cos(\omega t - \omega t + \phi) - \cos(\omega t + \omega t - \phi)\right]$$
$$= \frac{1}{2} V_m I_m \left[\cos\phi - \cos(2\omega t + \phi)\right]$$

$$p = \frac{1}{2} V_m I_m \cos\phi - \frac{1}{2} V_m I_m \cos(2\omega t + \phi) \quad \text{---(i)}$$

The second term in the right hand side of eqn (i) contains a double frequency term and it is evident ~~value of this~~ that the magnitude of the average value of this term is zero since the average of a sinus quantity of double frequency over a complete cycle is zero. Thus the instantaneous power consists only term ($\frac{1}{2} V_m I_m \cos\phi$), which is the average power the passive circuit.

i.e $P_{av} = \frac{1}{2} V_m I_m \cos\phi$

$= \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} \cos\phi$

$P_{av} = V_{rms} . I_{rms} \cos\phi$

$\therefore P_{av} = VI\cos\phi$

i) If $X > 0$, then the circuit is inductive

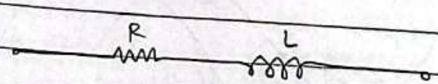
$\boxed{X = X_L}$

ii) If $X < 0$, then the circuit is capacitive

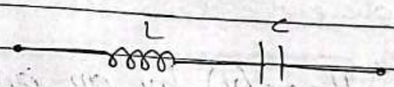
$\boxed{X = X_C}$

iii) If $X = 0$ i.e $X_L = X_C$, then the circuit is "Reactive" resistive

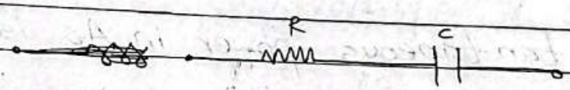
$\boxed{Z = R}$



$Z = R + jX_L$



$Z = jX_L - jX_C$



$Z = R - jX_C$

Instantaneous Power in AC circuit

In an AC circuit analysis let instantaneous voltage be:

$-\sin A \sin B = \cos(A-B) - \cos(A+B)$

$$V = V_m \sin(\omega t + \theta_v) \quad \text{-------- (i)}$$

$$I = I_m \sin(\omega t + \theta_i) \quad \text{-------- (ii)}$$

Where, $\theta_v \rightarrow$ Angle of voltage

$\theta_i \rightarrow$ Angle of current

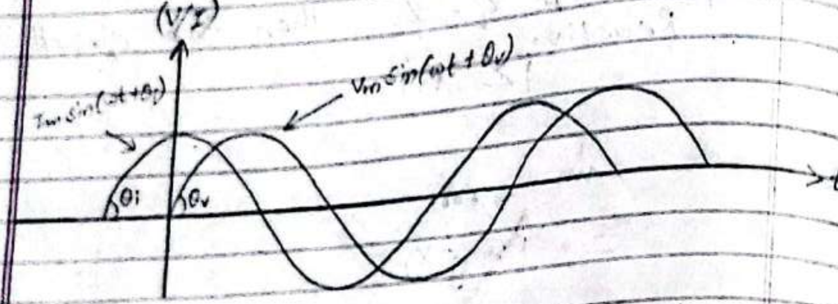


fig: Instantaneous voltage & current

Current (I) lead voltage (V) by an angle θ_i.

Voltage (V) lag current (I) by an angle θ_v.

The instantaneous power in AC is given by:

$$P = VI$$

$$= V_m \sin(\omega t + \theta_v) \times I_m \sin(\omega t + \theta_i)$$

$$= V_m I_m \times \frac{1}{2} \times 2\sin(\omega t + \theta_v) \cdot \sin(\omega t + \theta_i)$$

$$= \frac{V_m I_m}{2} \left[\cos(\theta_v - \theta_i) - \cos(2\omega t + \theta_v + \theta_i) \right]$$

$$\therefore P = \underbrace{\frac{V_m I_m}{2} \cos(\theta_v - \theta_i)}_{\text{Constant}} - \underbrace{\frac{V_m I_m}{2} \cos(2\omega t + \theta_v + \theta_i)}_{\text{sinusoidal term}}$$

The sinusoidal term contains a double frequency term (2ω), it is evident the magnitude of average value of sinusoidal term is zero over a complete cycle. Hence, instantaneous power is given by:

$$P = \frac{V_m I_m}{2} \cos(\theta_v - \theta_i)$$

$$= \frac{\sqrt{2} V_{rms} \times \sqrt{2} I_{rms}}{2} \cos(\theta_v - \theta_i)$$

$$= V_{rms} I_{rms} \cos(\theta_v - \theta_i)$$

$$\therefore \boxed{P = VI \cos\phi}$$

where, $\phi = (\theta_v - \theta_i)$ which is angle between voltage & current.

(i) Active Power: (P)

It is the power which is actually dissipated in the circuit resistance. It is given by:

$$\boxed{\text{Active power} = VI\cos\phi} = I^2R$$

$$[P = VI\cos\phi = I^2R$$

Its unit is watt.

(ii) Apparent Power: (S)

It is the product of rms value of voltage and current.

$\boxed{\text{Apparant power} = VI}$

Its unit is VA (volt Ampere), KVA

$\boxed{S = VI = IZ \cdot I = I^2 Z}$

(iii) Reactive Power : 'Q'

It is the power developed in the inductive resistance of the circuit.

$\boxed{\text{Reactive power} = VI\sin\phi}$

Its unit is VAR (volt Ampere Reactive).

$Q = I^2 X_L = I \cdot I \cdot Z\sin\phi$

$\boxed{Q = I \cdot V\sin\phi}$

Imp # Power factor:

It is the ratio of active power to the apparent power.

i.e.

$$\text{power factor (p.f)} = \frac{VI\cos\phi}{VI} = \cos\phi$$

$$\therefore \boxed{P.f = \cos\phi = \frac{R}{Z}}$$

The term $\cos\phi$ is called powerfactor. It is the cosine of angle between voltage and current ($I = \theta_v - \theta_i$) in any AC circuit analysis.

Power factor is unity in resistive circuit i.e angle between voltage and current is zero, leading in capacitive and laging in inductive circuit.

Imp # Significance of power factor:

→ With the reduction of magnitude of angle ϕ, the phase angle between voltage and current is zero. In this condition power in the circuit is maximum. But reactive factor $\sin\phi$ decreases.

→ Improvement of power factor in any AC system is highly desired.

→ when the magnitude of ϕ decreases then the value of power factor ($\cos\phi$) improves and the value of reactive factor ($\sin\phi$) decreases.

Complex Number Representation:

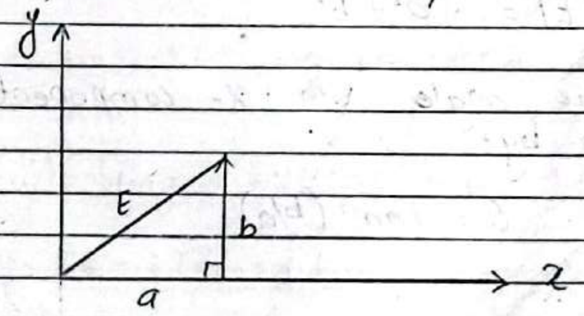


fig: vector/complex representation

In this case,

$E = a + jb$

where a is horizontal component &

b is vertical component, j is operator.

It indicates that component 'b' is perpendicular to component 'a' and the two terms 'a' and 'b' are not to be treated as like term in any algebric terms.

The vector written in this way is said to be written in complex form.

In mathematics, 'a' represents real part and 'b' represents imaginary part. But in Basic electrical engineering these terms are known as inphase (active) and quadrature (reactive) components respectively.

The numerical value of E is given by:

$$|E| = \sqrt{a^2+b^2}$$

And the angle with x- component is given by:

$$\theta = \tan^{-1}(b/a)$$

Imp # Resonance:

Resonance in electrical circuit consisting of active and passive elements represents a particular state of the circuit, when the current or voltage in the circuit is maximum or minimum with respect to the magnitude of excitation at a particular frequency, the circuit impedance become minimum or maximum at a power factor of unity.

Imp (1) Resonance of RLC Series Circuit:

let us consider RLC series circuit as shown below:

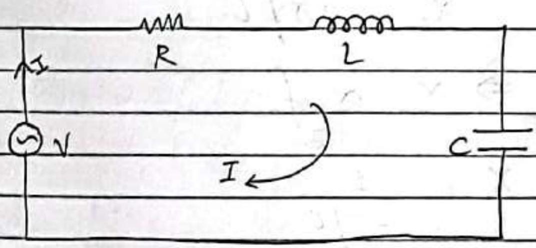


fig: RLC series circuit

Now,

Applying KVL in the ckt:

$$V - IR - jIX_L + jIX_C = 0$$

$$V = IR + jIX_L - jIX_C$$

$$V = I\{R + j(X_L - X_C)\}$$

$$I = \frac{V}{R + j(X_L - X_C)}$$

$$V = IR + jX_L + \frac{1}{jX_C}$$

$$= IR + j\omega L + \frac{1}{j\omega C}$$

$$= I(R + j\omega L - j/\omega C)$$

$$V/I = R + j(\omega L - 1/\omega C)$$

$$Z = R + j(\omega L - 1/\omega C)$$

$$I = \frac{V}{Z} \quad \text{....(i)}$$

where, Z : Impedance
X_L : Inductance
X_C : Capacitance
R = Resistance

Impedance varies as the frequency of voltage changes because X_L & X_C both changes with change in frequency.

Since, $X_L = 2\pi f L$

$\Rightarrow X_L \propto f$

And, $X_C = \frac{1}{2\pi f C}$

$\Rightarrow X_C \propto \frac{1}{f}$

But resistance is independent of frequency.

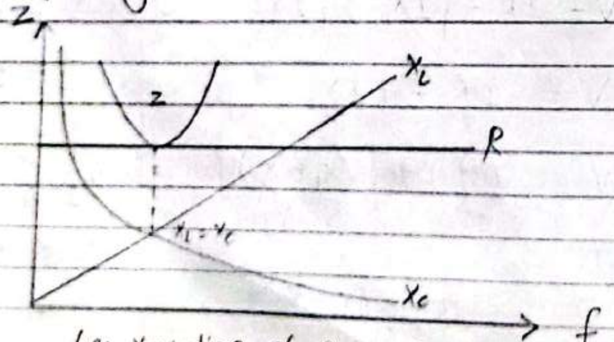


fig: Variation of R, X_L and X_C with f...

From above figure, the variation of X_L is a straight line passing through the origin, X_C with frequency is a curve approaching the two axis. And the resistance is independent of frequency. Hence it is a straight line parallel to frequency axis.

For a paticular frequency f_0 the difference of X_L & X_C is equal to zero.
i.e

$$X_L - X_C = 0$$

or, $X_L = X_C$

or, $2\pi f_0 L = \frac{1}{2\pi f_0 C}$

or, $f_0^2 = \frac{1}{4\pi^2 LC}$

$$\boxed{f_0 = \frac{1}{2\pi\sqrt{LC}}}$$

This is the required expression for Resonance RLC series circuit.

$$2\pi f_0 = \frac{1}{\sqrt{LC}}$$

$$\boxed{\omega_0 = \frac{1}{\sqrt{LC}}}$$

Imp ② Resonance for R-L-C parallel Circuit:

let us consider R-L-C parallel circuit as shown below:

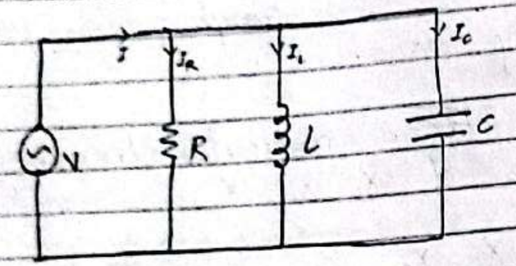


fig: RLC parallel circuit

$$I = I_R + I_L + I_C$$

$$I = \frac{V}{R} + j\frac{V}{X_L} - j\frac{V}{X_C}$$

$$I = V\left(\frac{1}{R} + \frac{j}{X_L} - \frac{j}{X_C}\right)$$

$$\frac{I}{V} = \frac{1}{R} + \frac{j}{X_L} - \frac{j}{X_C}$$

$$\frac{1}{Z} = \frac{1}{R} + j\left(\frac{1}{X_L} - \frac{1}{X_C}\right)$$

applying KCL,

$$I = I_R + I_L + I_C$$

or, $I = \frac{V}{R} + \frac{V}{jX_L} + \frac{V}{\frac{1}{j\omega C}}$

$$= \frac{V}{R} - \frac{jV}{\omega L} + V.j\omega C$$

or, $I = \frac{V}{R} + jV(\omega C - \frac{1}{\omega L})$

or, $\frac{I}{V} = \frac{1}{R} + j(\omega C - \frac{1}{\omega L})$

or, $\frac{1}{Z} = \frac{1}{R} + j(\omega C - \frac{1}{\omega L})$

At resonance,

$\omega C - \frac{1}{\omega L} = 0$

$\frac{V}{R} + \frac{V}{jX_L} + \frac{V}{jX_C}$

$\frac{V}{R} + \frac{jV}{X_L} + V.j\omega C$

At Resonance, $\frac{1}{X_L} - \frac{1}{X_C} = 0$

or, $\frac{1}{2\pi f_0 L} - 2\pi f_0 C = 0$

or, $\frac{1 - 2\pi f_0 C \times 2\pi f_0 L}{2\pi f_0 L} = 0$

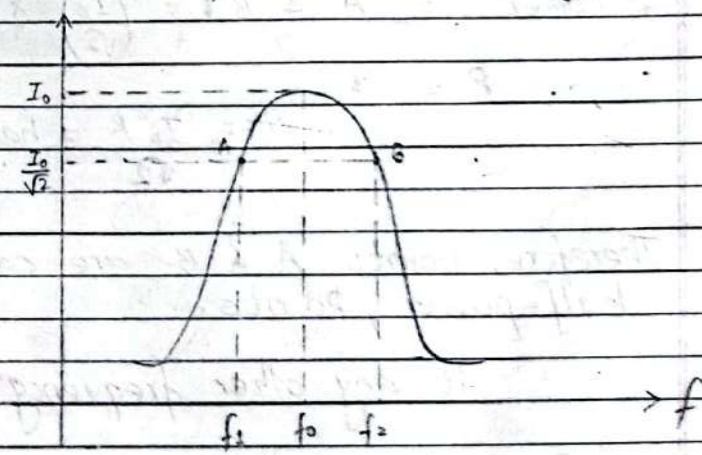
or, $1 - 4\pi^2 f_0^2 LC = 0$

or, $1 = 4\pi^2 f_0^2 LC$

or, $\frac{1}{4\pi^2 LC} = f_0^2$

or, $\boxed{f_0 = \frac{1}{2\pi\sqrt{LC}}}$

Imp # Band-width of Resonance Curve:



Band-width of a circuit is given by the band of frequency which lies between two points on either side of resonance frequency curve, where current I_0 decreased to $\frac{1}{\sqrt{2}}$ of maximum value of current at resonance.

$$\boxed{\Delta f = f_2 - f_1}$$

$$\boxed{I_0 = \frac{V}{R}}$$

Power at resonance = $I_0^2 R$

Now, At point A & B:

$$I_0 = \frac{I_0}{\sqrt{2}}$$

$\therefore$ Power at A & B = $\left(\frac{I_0}{\sqrt{2}}\right)^2 \times R$

$$= \frac{I_0^2 R}{2} = \text{half of power at Resonance}$$

Therefore, points A & B are called half-power points.

At any other frequency:

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

or, $I = \dfrac{V}{\sqrt{R^2 + (X_L - X_C)^2}}$ ------ (i)

At point A & B:

$$I = \frac{I_0}{\sqrt{2}} = \frac{V}{\sqrt{2}\,R} \quad \text{------ (ii)}$$

$\therefore \dfrac{V}{\sqrt{2}\,R} = \dfrac{V}{\sqrt{R^2 + (X_L - X_C)^2}}$ [from (i) & (ii)]

or, $\dfrac{1}{\sqrt{2}\,R} = \dfrac{1}{\sqrt{R^2 + (X_L - X_C)^2}}$

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

Squaring both sides:

$2R^2 = R^2 + (X_L - X_C)^2$

or, $R^2 = (X_L - X_C)^2$

or, $R = (X_L - X_C)$

or, $R = \omega L - \dfrac{1}{\omega C}$

or, $R - \omega L + \dfrac{1}{\omega C} = 0$

or, $R\omega C - \omega^2 LC + 1 = 0$

or, $LC\omega^2 - R\omega C - 1 = 0$

Comparing with $ax^2+bx+c=0$

$$\omega = \frac{RC \pm \sqrt{R^2C^2+4LC}}{2LC}$$

$$= \frac{R}{2L} \pm \sqrt{\frac{R^2C^2}{4L^2C^2} + \frac{4LC}{4L^2C^2}}$$

$$= \frac{R}{2L} \pm \sqrt{\frac{R^2}{4L^2} + \frac{1}{LC}}$$

If $\frac{R^2}{4L^2} << \frac{1}{LC}$ then,

$$\sqrt{\frac{R^2}{4L^2} + \frac{1}{LC}} = \frac{1}{\sqrt{LC}}$$

neglecting $\frac{R^2}{4L^2}$

$\omega_1 = -\frac{R}{2L} + \omega_0$

$\omega_2 = \frac{R}{2L} + \omega_0$

$$\therefore \omega = \frac{R}{2L} \pm \frac{1}{\sqrt{LC}}$$

Taking value of ω_0 only positive:

$$\omega = \omega_0 \pm \frac{R}{2L}$$

Now, Taking -ve sign:

$$\omega_1 = \omega_0 - \frac{R}{2L}$$

Taking +ve sign:

$$\omega_2 = \omega_0 + \frac{R}{2L}$$

$\therefore$ Bandwith $\Delta\omega = \omega_2 - \omega_1$

$$= \omega_0 + \frac{R}{2L} - \omega_0 + \frac{R}{2L}$$

$$\boxed{\Delta\omega = \frac{R}{L}}$$

Quality factor (Q-factor):

Imp

Quality factor gives the quality of resonance in accordance with selectivity of frequency. The large value of quality factor gives the sharp value of selectivity or selective frequency and it is numerically given by:

$$Q\text{-factor} = \frac{\omega_0 L}{R}$$

$$= \frac{1}{\sqrt{LC}} \times \frac{L}{R}$$

$$\therefore \boxed{Q\text{-factor} = \frac{1}{R}\sqrt{\frac{L}{C}}}$$

Imp (i) Quality factor in series RLC resonating circuit:

It is defined as the ratio of voltage across inductor to the voltage at resonance.

It is also the voltage magnification in the resonanting circuit.

$$Q\text{-factor} = \frac{V_L}{V}$$

$$= \frac{I_0 X_L}{I_0 R} \quad [\because I_0 = I]$$

$$= \frac{X_L}{R}$$

$$= \frac{\omega_0 L}{R} \quad \left[\because \omega_0 = \frac{1}{\sqrt{LC}}\right]$$

$$\therefore \boxed{Q\text{-factor} = \frac{1}{R}\sqrt{\frac{L}{C}}}$$

Imp (ii) Quality factor in parallel RLC resonating circuit:

In parallel resonating circuit, Q-factor is the current magnifaction of the circuit at resonance.

It is the ratio of current across capacitor to the applied current.

i.e

$$Q\text{-factor} = \frac{I_c}{I}$$

$$= \frac{V_c/X_c}{V/Z}$$

$$= \frac{Z}{X_c} \quad (\because V_c = V)$$

$$= \frac{L}{RC} \times \frac{1}{1/\omega_0 C} \quad \left(\because Z = \frac{L}{RC}\right)$$

$$= \frac{L}{RC} \times \omega_0 C$$

$$= \frac{L}{R} \times \omega_0$$

$$= \frac{L}{R} \times \frac{1}{\sqrt{LC}}$$

$$\therefore Q\text{-factor} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

$$\boxed{Q\text{-factor} = \frac{1}{R}\sqrt{\frac{L}{C}}}$$

P.T.O

Steady state Response :

(1) R-L Series Circuit :

Let us consider R-L series circuit with supplied AC voltage 'V', frequency f as shown in figure below:

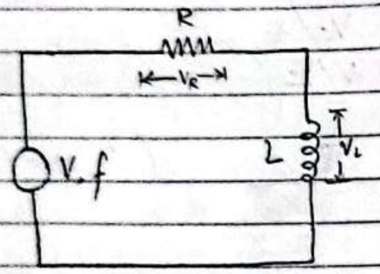
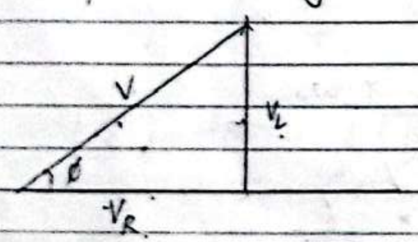


fig: R-L series circuit

The phasor diagram is,



Now, from phasor diagram:

$$V = \sqrt{V_R^2 + V_L^2}$$

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

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

or, $V = IZ$

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

$$\tan\phi = \frac{P}{b} = \frac{V_L}{V_R} = \frac{IX_L}{IR}$$

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

(2) R-C Series Circuit :

Let us consider R-C series circuit with supplied AC voltage 'V', frequency f as shown in figure below:

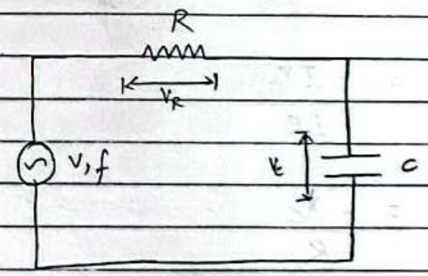
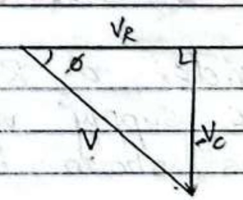


fig: R-C series circuit

The phasor/vector diagram is:



Now, from phasor diagram:

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

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

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

or, $V = IZ$

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

Now, $\tan\phi = \frac{p}{b}$

$$= \frac{-V_C}{V_R}$$

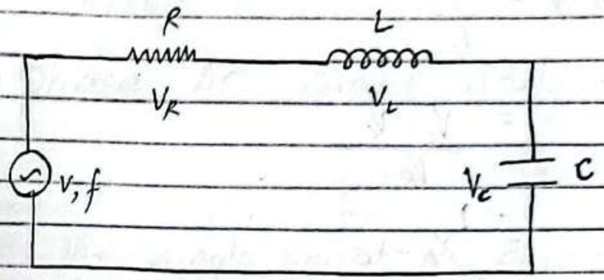
$$= \frac{-IX_C}{IR}$$

$$= \frac{-X_C}{R}$$

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

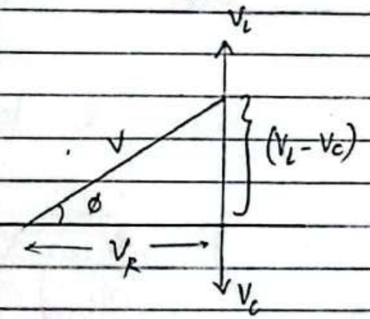
(3) R-L-C series circuit:

Let us consider a R-L-C series circuit with AC supply voltage 'V', frequency 'f' as shown in figure below:



where, $V_R \rightarrow$ voltage across resistor
$V_L \rightarrow$ voltage across inductor
$V_C \rightarrow$ voltage across capacitor

The phasor diagram of RLC series circuit is:



Now,

From the phasor diagram:

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

or, $V = \sqrt{I^2R^2 + (IX_L - IX_C)^2}$

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

or, $V = IZ$

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

PAGE DATE

$$\tan\phi = \frac{P}{b}$$

$$= \frac{V_L - V_C}{V_R}$$

$$= \frac{X_L - X_C}{R}$$

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

PAGE DATE

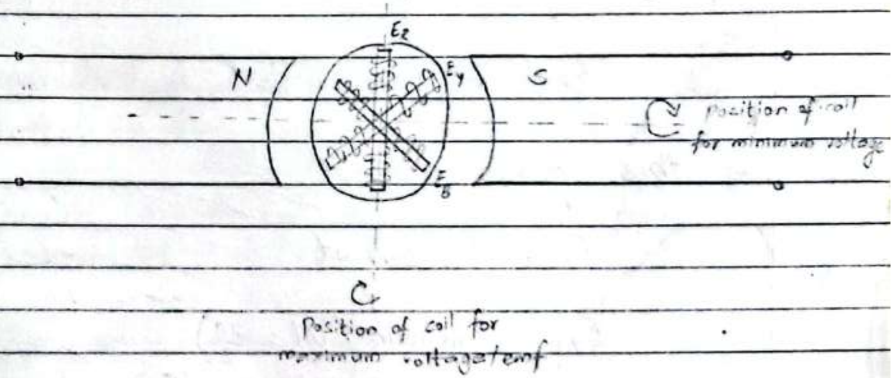
Unit - 4

Poly phase AC Circuit Analysis (3-ϕ)

[6 hrs]

The single phase AC circuit is suitable for most of the domestic applications but in the field of electrical Engineering such as power transmission, electrochemical energy, large industrial areas where power consumption is high, single phase is not applicable. So to overcome this limitation, three phase system is ~~built~~ used.

Generation of 3-phase voltage/current:



In three phase system, three coils are mounted or ~~located~~ rotated in the armature which is displaced by $2\pi/3$ radian (120°). These coils have sinusoidally varying electromagnetic force or emf induced in them.
The three phase may be

$0, \pi, 2\pi, 3\pi$
120, 300, 480, 660
60, 240, 420, 600

numbered 1, 2 & 3 or a, b & c or they are given three colours. The commerically used colours are Red, Yellow or white & blue, this is called RYB sequence.

The figure above shows the generation of three phase voltage. The graphical representation of three phase voltage is as shown below:

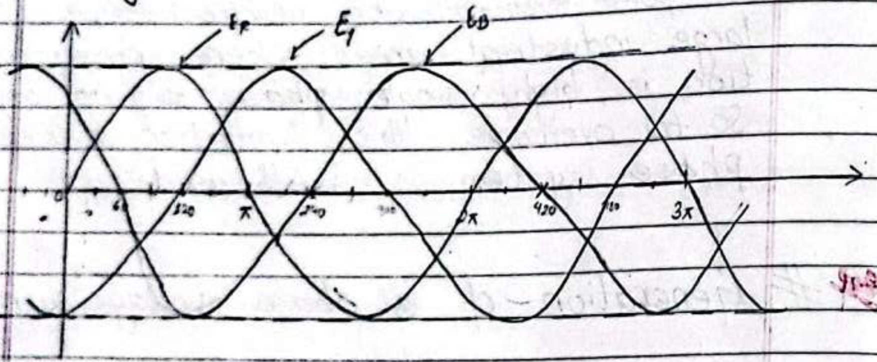


fig: Graphical representation of 3-ϕ voltage

In this case,

$$E_R = E_m \sin\omega t$$

$$E_Y = E_m \sin\left(\omega t - \frac{2\pi}{3}\right)$$

$$E_B = E_m \sin\left(\omega t - \frac{4\pi}{3}\right)$$

$$= E_m \sin\left(\omega t + \frac{2\pi}{3}\right)$$

Phasor diagram of 3-ϕ system is given below:

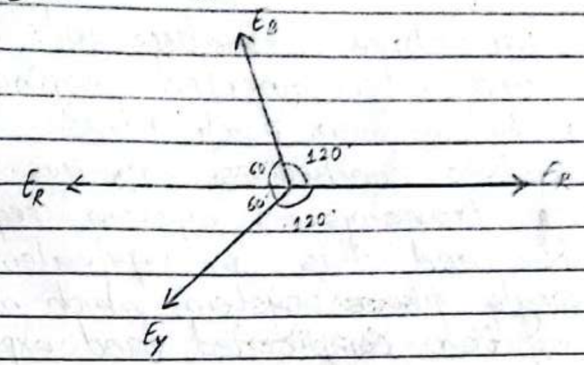


fig: phasor diagram of 3-ϕ system

Imp

Advantages of 3-ϕ system:

(i) Domestic and industrial power can be provided from same source.

(ii) Voltage regulation of 3-ϕ system is better than single phase system.

(iii) Torque produced by 3-ϕ voltage is maximum.

(iv) The ~~at~~ amount of conductor wire needed to transfer same amount of power is less for three phase system. Thus it is more economical.

(v) For a given size of frame 3-ϕ generator provides more output.

Interconnection of 3-ϕ system :

If the three armature coils of 3-ϕ system are interconnected separately as shown below then each phase of circuit requires two conductors or wires. The resulting transmission system requires six wires and this is equivalent to three single phase system which makes the whole system complicated and expensive.

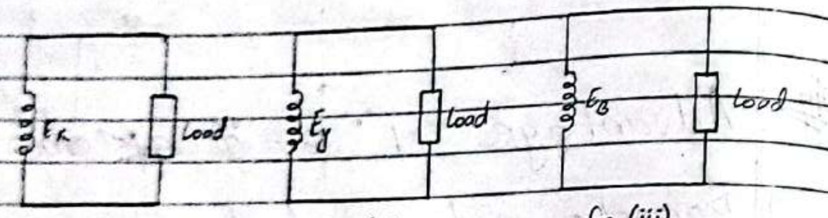


fig (i) fig (ii) fig (iii)

Hence, a 3-ϕ system are generally inter connected which results in the saving of copper wire. The general method of inter connection are :

(i) Balanced star or Wye (Y) Connected system.
(ii) Balanced Delta or mesh(Δ) connected system.

Balanced System :

A balanced system is one in which

(i) The voltage in all phase are equal in magnitude and offer a phase difference of 120° or $\frac{2\pi}{3}$ radian.

(ii) The current in the three phase are equal in magnitude and offer a phase difference 120° or $\left(\frac{2\pi}{3}\right)^c$.

(iii) A three phase balance load is one in which load connected across three phases are identical or equal

(1) Balanced star or Wye (Y) connected system:

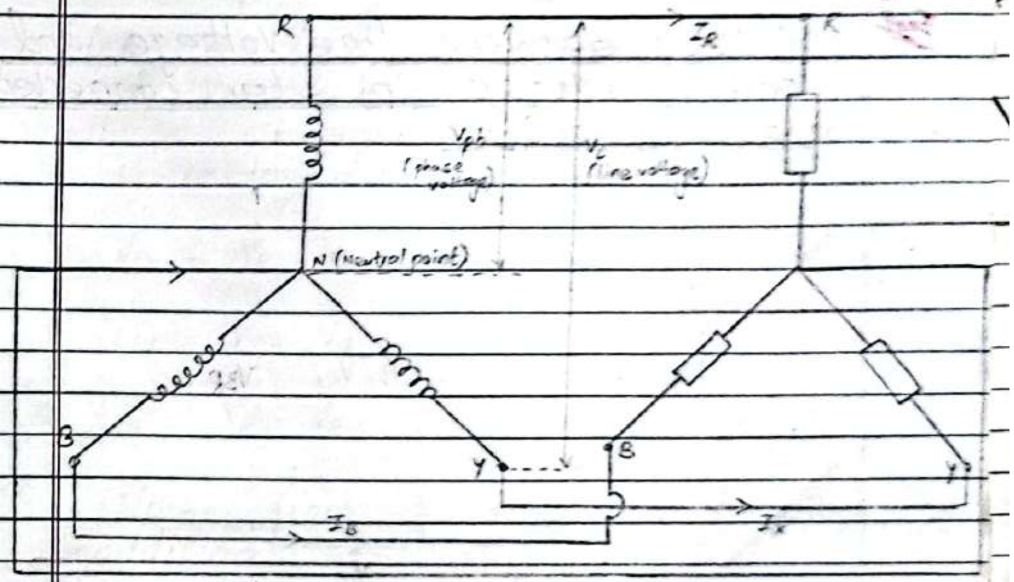


fig : 4-wire 3-ϕ star (Y) connected system

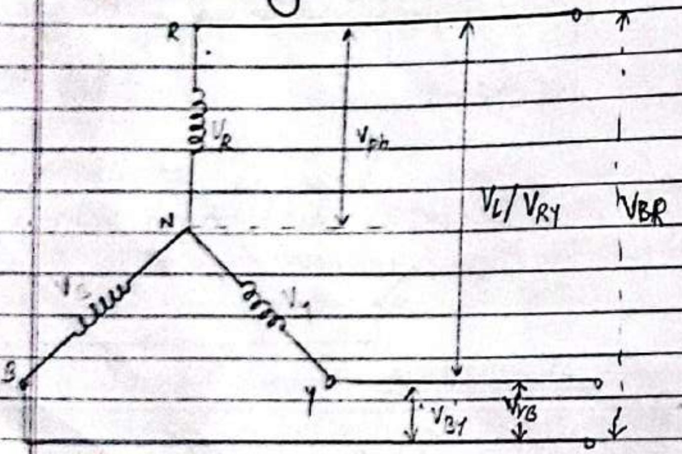
The star connected sytem is inter-connected as shown in figure above, the end of three coils are connected at a point which is known as neutral point. Such an inter connected system is known as 4-wire 3-ϕ star (Y) connected system.

At neutral point,

$$\boxed{I_N = I_R + I_B + I_Y}$$

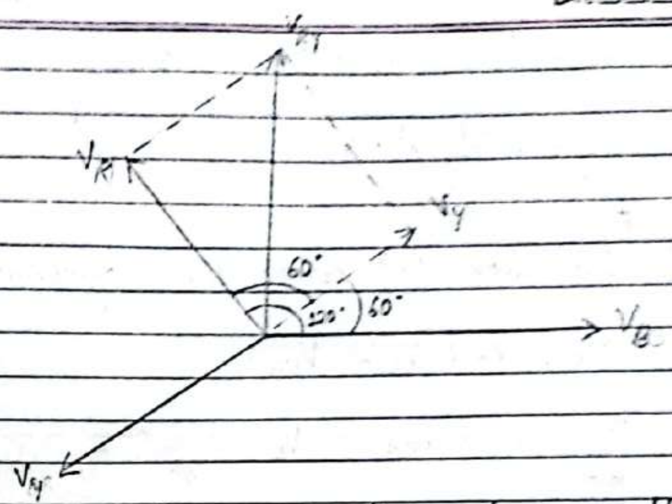
The emf between any line and neutral point is called phase emf or voltage and the emf between any two lines gives the line-to-line emf or simply line emf. It is denoted by E_L or V_L.

Relation Between line Voltage and phase voltage in star connected 3-ϕ system:



The phasor diagram of 3-ϕ Y-connected system is:

P.T.O



Let V_R, V_Y & V_B be the phase voltage and V_{RY}, V_{YB} & V_{RB} be the line voltage then it is observed that the line voltage V_{RY} is vector difference of V_R & V_Y.

$$V_{RY} = V_R - V_Y$$

$$V_{YB} = V_Y - V_B$$

$$V_{RB} = V_R - V_B$$

Now, from parallelogram law of vector addition:

$$\therefore V_{RY} = \sqrt{V_R^2 + V_Y^2 + 2 V_R V_Y \cos\theta}$$

$$\cancel{V_{YB} = \sqrt{V_Y^2 + V_B^2 + 2 V_Y V_B \cos\theta}}$$

$$\cancel{V_{RB} = \sqrt{V_R^2 + V_B^2 + 2 V_R V_B \cos\theta}}$$

or, $V_{RY} = \sqrt{V_R^2 + V_Y^2 + 2 V_R V_Y \cos 60}$

or, $V_{RY} = \sqrt{V_R^2 + V_Y^2 + 2V_R V_Y \times 1/2}$

$$V_{RY} = \sqrt{V_R^2 + V_Y^2 + V_R V_Y} \quad \text{- - - - (1)}$$

In star (Y) connected system:

$$V_R = V_Y = V_B = V_{ph}$$

$$V_{RY} = V_{YB} = V_{RB} = V_L$$

∴ Equ^n (1) becomes:

$$V_L = \sqrt{V_{ph}^2 + V_{ph}^2 + V_{ph}^2}$$

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

$$\boxed{I_L = I_{ph}}$$

This the required relationship between line voltage and phase voltage, line current and phase current in Stare connected three phase system.

(2) Balanced Delta (Δ) connected System:

P.T.O

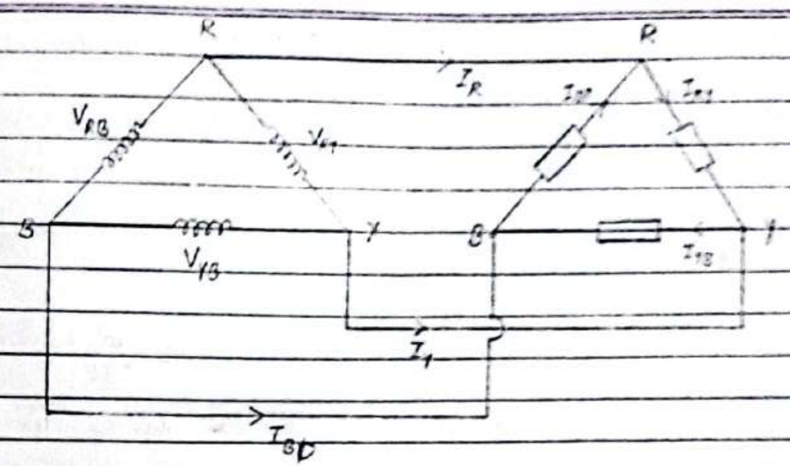


fig: 3-φ 3-wire delta connected system

The figure above shows the delta connected generator supplying a delta connected load. The current in each line is the phasor difference between the phase current.

Now, from figure:

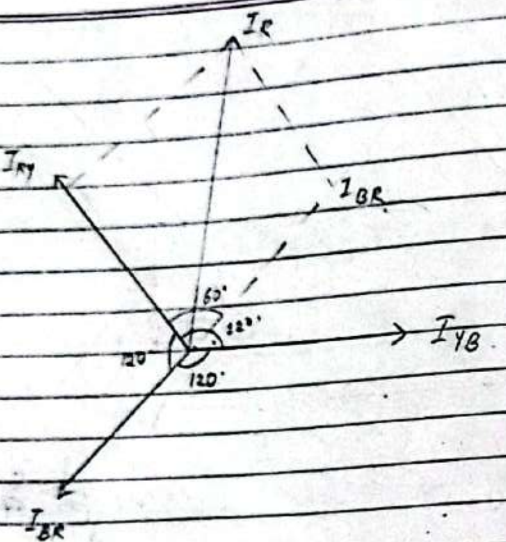
$$I_R = I_{RY} - I_{BR}$$

$$I_Y = I_{YB} - I_{RY}$$

$$I_B = I_{BR} - I_{YB}$$

The phasor diagram of delta connected 3-φ system is shown below:

P.T.O



Applying parallelogram of vector addition:

$$I_R = \sqrt{I_{RY}^2 + I_{BR}^2 + 2 I_{RY} I_{BR} \cos 60°}$$

$$= \sqrt{I_{RY}^2 + I_{BR}^2 + I_{RY} \cdot I_{BR}}$$

In Δ (delta) connected system:

$$I_R = I_B = I_Y = I_L$$

$$I_{RY} = I_{BR} = I_{YB} = I_{ph}$$

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

$$\boxed{I_L = \sqrt{3}\, I_{ph}}$$

And, $\boxed{V_L = V_{ph}}$

This is the required relationship between line current and phase current in balanced delta connected 3-ϕ system.

Difference between star (Y) & Delta (Δ) connected system:

	Star		Delta
(1)	$I_L = I_{ph}$	(1)	$I_L = \sqrt{3}\, I_{ph}$
(2)	$V_L = \sqrt{3}\, V_{ph}$	(2)	$V_L = V_{ph}$
(3)	Resultant potential difference at a neutral point is zero.	(3)	Resultant current at loop is zero.
(4)	KCL	(4)	KVL
(5)	Power (P) = $\sqrt{3}\, V_L I_L \cos\phi$	(5)	Power (P) = $\sqrt{3}\, V_L I_L \cos\phi$

Three Phase Power Measurement:

"Since the phase impedance of a balanced ~~or~~ star or delta connected load contains equal phase ~~current~~, the phase power is 1/3rd of total power. As from the defination of power the voltage across load impedance and current in the impedance can be used to calculate the power for phase."

In the 3-ϕ power system

one, two or three wattmeters can be used to measure the total power. A wattmeter may be considered to be a voltmeter and an ammeter connected in the same box which has a deflection proportional to the $V_{rms} I_{rms} \cos\phi$ which is equal to $VI\cos\phi$, where ϕ is the angle between voltage and current.

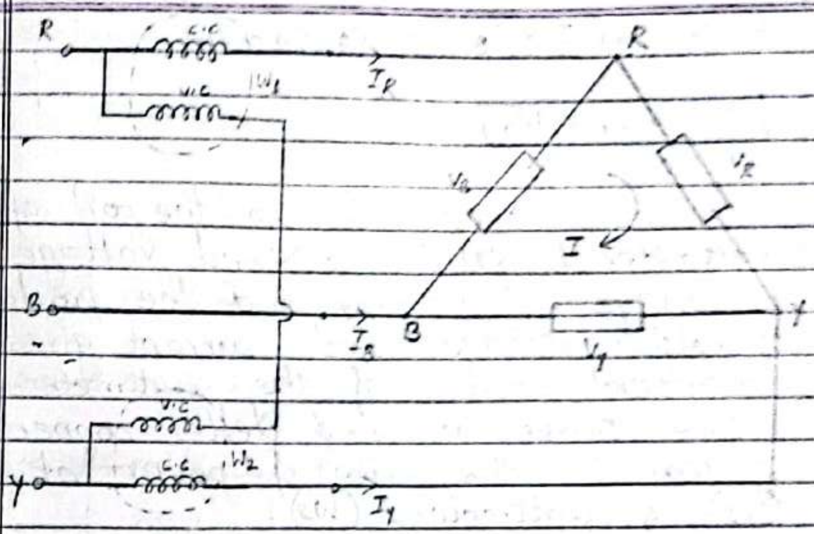
Hence, a wattmeter has two voltage terminals and two current terminals, it can be used for the power measurement in balanced or unbalanced star and delta connected system.

Imp # Three phase power measurement by two wattmeter methods:

Several methods are available for measuring the power delivered to the 3-ϕ load. The most commonly used technique is two wattmeter method.

(i) Delta Connected system:

P.T.O



c.c → Current coil
v.c → Voltage coil
W_1, W_2 → Wattmeter 1 & 2

Now, Applying KVL in the loop:

$$V_R + V_Y + V_B = 0$$

$$V_B = -(V_R + V_Y) \quad \text{-----(i)}$$

Instantenous Power is:

$$P = VI$$

or, $P = V_R I_R + V_Y I_Y + V_B I_B$

or, $P = V_R I_R + V_Y I_Y + I_B(-V_R - V_Y)$

or, $P = V_R I_R + V_Y I_Y - V_R I_B - V_Y I_B$

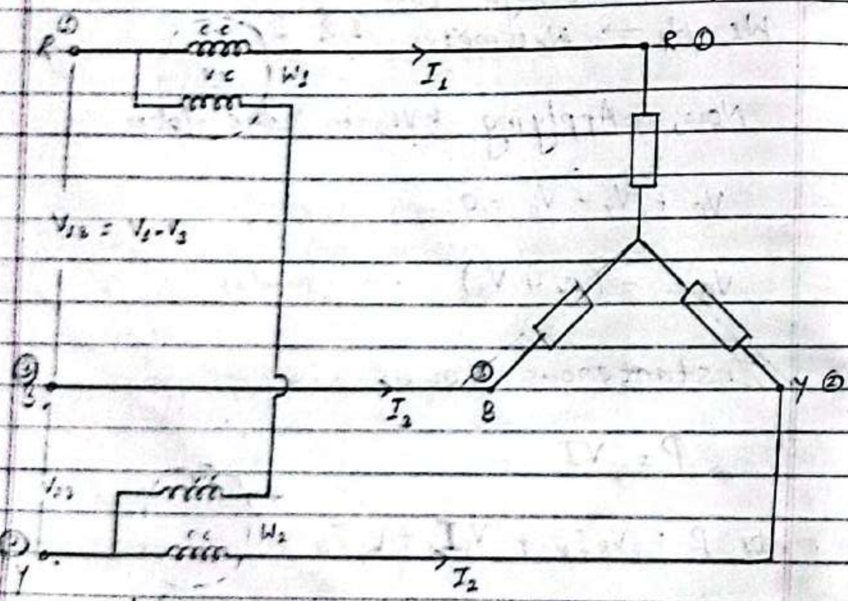
or, $P = V_Y I_Y - V_Y I_B + V_R I_R - V_R I_B$

or, $P = V_Y(I_Y - I_B) + V_R(I_R - I_B)$

$$\boxed{P = W_1 + W_2}$$

The current through the coil of wattmeter 1 (W1) is I_R and voltage across its voltage coil is V_{RY} and the product of ~~vol~~ this voltage and current gives the resultant power of the wattmeter 1. Hence, power in 3-ϕ delta connected system is the sum of power at wattmeter (W1) & wattmeter 2 (W2).

(ii) Star Connected System:



Applying KCl at netural point:

$I_1 + I_2 + I_3 = 0$

$I_3 = -(I_1 + I_2)$ . . . . . (i)

Instantaneous power is:

$P = VI$

or, $P = V_1 I_1 + V_2 I_2 + V_3 I_3$

or, $P = V_1 I_1 + V_2 I_2 - V_3(I_1 + I_2)$

or, $P = V_1 I_1 + V_2 I_2 - V_3 I_1 - V_3 I_2$

or, $P = I_1(V_1 - V_3) + I_2(V_2 - V_3)$

or, $P = I_1 V_{13} + I_2 V_{23}$

$$\boxed{P = W_1 + W_2}$$

Power In star connection:	Power in delta connection
The total active or real power in the circuit is the sum of the individual 3-ϕ powers.	we know, the power per phase i.e active power/phase = $V_{ph} I_{ph} \cos\phi$
$\therefore$ Total active power = 3 × Individual phase power	$\therefore$ Total active power
$= 3 \times V_{ph} I_{ph} \cos\phi$	$P = 3 V_{ph} I_{ph} \cos\phi$
$= \sqrt{3} V_{ph} \sqrt{3} I_{ph} \cos\phi$	$= \sqrt{3} V_{ph} \cdot \sqrt{3} I_{ph} \cos\phi$
$\therefore P = \sqrt{3} V_L I_L \cos\phi$	$= \sqrt{3} \cdot V_L I_L \cos\phi$
$[\because V_L = \sqrt{3} V_{ph} \; \& \; I_L = I_{ph}]$	$[\because I_L = \sqrt{3} I_{ph}, \; \& \; V_L = V_{ph}]$
	$\therefore P = \sqrt{3} V_L I_L \cos\phi$ watt
11y, ② Total reactive power $(Q) = \sqrt{3} V_L I_L \sin\phi$ (VAR)	11y, Total reactive power (Q) $Q = \sqrt{3} V_L I_L \sin\phi$ VAR
and ③ total apparent power $(S) = \sqrt{3} V_L I_L$ VA	Total apparent power (S) $S = \sqrt{3} V_L I_L$

Chapter-5

Electric Machines

Review of magnetic circuit:

A magnetic circuit is made up of one or more closed loop paths containing a magnetic flux. The flux is usually generated by permanent magnets or electromagnets and confined to the path by magnetic cores consisting of feromagnetic materials like iron, although there may be air gaps or other materials in the path. Magnetic circuits are employed to efficiently channel magnetic fields in many devices such as electric motors, generators, transformers, relays etc.

Terminologies:

(1) Magnetic flux (ϕ):

The number of magnetic ~~field~~ lines of force created in a magnetic field is known as magnetic flux.

Its unit is Weber (Wb).

(2) Flux Density (B):

The number of magnetic lines of force created in a magnetic circuit per unit area normal to the direction of flux line is known as flux density.

i.e

$$\boxed{B = \phi/A}$$

Its unit is Weber/sq.m (Tesla).

(3) Magneto motive force (F):

Force which drives or tends to drive the magnetic flux through a magnetic circuit is magneto motive force.

i.e

$$\boxed{MMF = \text{No. of turns} \times \text{current} = NI}$$

Its unit is AT (ampere turns).

(4) Magnetic field strength (H):

The magneto motive force per meter length of the magnetic circuit is known as magnetic field strength (H).

i.e

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

Its unit is AT/meter.

(5) Permeability (μ):

A property of a magnetic material which indicates the ability of magnetic circuit to carry electromagnetic flux is known as permeability.

It is also ratio of flux density to the magnetizing force.

$$\boxed{\mu = \frac{B}{H}}$$

It unit is henry/meter.

Permeability of free space or air or non-magnetic material is:

$$\mu_0 = 4\pi \times 10^{-7}\ H/m$$

(6) Relative Permability (μ_r):

The ratio of the flux density produced by a given MMF in a magnetic material to the flux density produced in a non magnetic material.

$$\mu_r = \frac{B}{B_0} = \frac{\mu H}{\mu_0 H} = \frac{\mu}{\mu_0}$$

$$\therefore \mu = \mu_0 \mu_r$$

(7) Reductance (S):

It is the opposition of a magnetic circuit to setting up of a magnetic flux in it.

$$\text{Flux} = \phi = BA$$

$$F = mmf = H \cdot l \quad \left[\because H = \frac{NI}{l}\right]$$

$$B = \mu H$$

$$\frac{\phi}{F} = \frac{BA}{Hl} = \frac{\mu_0 \mu_r A}{l}$$

$$\phi = \left(\frac{\mu_0 \mu_r A}{l}\right) F$$

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

$$\text{Reluctance(S)} = \frac{MMF}{\phi} = \frac{Hl}{BA} = \frac{Hl}{\mu H \cdot A} = \frac{l}{\mu_0 \mu_r A}$$

$$\boxed{S = \frac{l}{\mu_0 \mu_r A}}$$

$$\therefore \phi = \frac{F}{S} \quad \text{where } S = \frac{l}{\mu_0 \mu_r A}$$

'S' is called reluctance of the magnetic circuit.

~~Reck~~

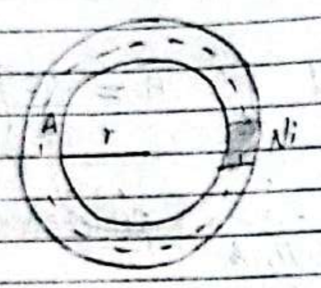
$$\boxed{\text{Reluctance} = \text{MMF} / \text{Magnetic flux}}$$

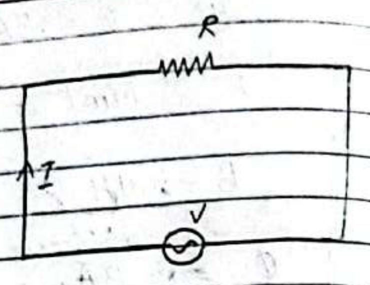
Its unit is AT/Wb.

Magnetic Circuit:

The complete closed path followed by any group of magnetic lines of flux is referred to a magnetic circuit.

Left page



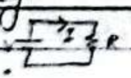


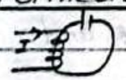
Equivalent electrical circuit

Imp # Analogy with Electric ~~Ec~~ Circuits:

Similarities:

	Electric Circuit		Magnetic Circuit
(1)	Electromotive force (EMF) EMF, volt (V)	(1)	Magnetomotive force (MMF) MMF, ampere turn (AT)
(2)	Current, ampere (A)	(2)	flux, weber
(3)	Resistance, ohm (Ω)	(3)	Reluctance, A/wb
(4)	Current density, A/m^2	(4)	flux density, T or wb/m^2
(5)	Conductivity	(5)	Permeability





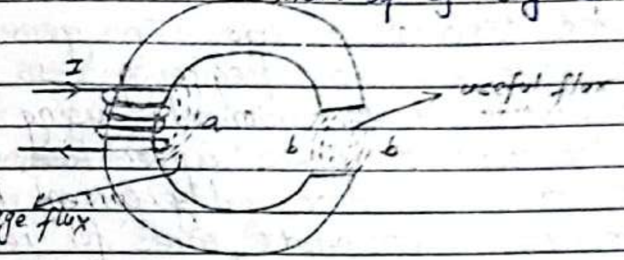
Difference:

	Electric circuit		Magnetic circuit
(1)	Current actually flows	(1)	flux is created but does not flow
(2)	Circuit may be open or closed	(2)	Circuit is always closed.

Right page

leakage Flux:

Eddy current loses can be reduced by using magnetic core made up of very thin lamination



The flux that does not follow the intended path in the magnetic circuit is know as leakage flux.

Magnetic Circuits loses:

There are following two types of circuit losses:

(1) Eddy Current losses:

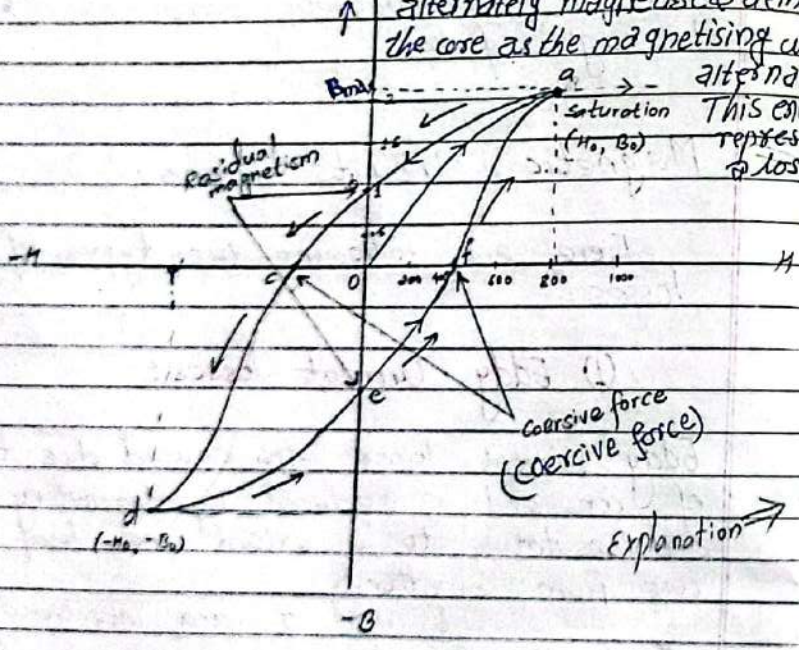
Eddy current losses are caused due to conduction of core and is reduced by laminating the core, and insulating to an extent, one leaf of the core from another.

E and I are interleaved to form the final core. I^2R losses are due to finite resistances of the wires used in primary and secondary. [The unnecessary current of the magnetic circuit is called eddy current. Eddy current loses is due to the fluctation of magnetic field. Due to which temp of the core is increased and heat is transferred to outside and then energy is lost of the magnetic circuit.

CamScanner

(2) Hysteresis losses:

Hysteresis loss is due to residual magnetization of and depends on core. In general this loss increases as frequency is increased. The losses are minimized using copper wire for the coils, to reduce copper loss, laminating the core to reduce eddy current losses and selecting appropriate cores for reduction of hysteresis loss. [Hysteresis losses are due to the energy required to alternately magnetised & demagnetised the core as the magnetising current alternates. This energy represents loss.



Explanation

Magnetic Hysteresis:

① The lag or delay of a magnetic material is known commonly known as Magnetic Hysteresis, relates to the magnetisation properties of a material by which it firstly becomes magnetised and then de-magnetised. We know that, the magnetic flux generated by an electromagnetic coil is the amount of magnetic field or lines of force produced within a given area and that it is more commonly called "Flux Density".

Given the symbol B with the unit of flux density being the Telsa (T).

$B = \frac{\phi}{A}$ and $\frac{B}{H} = \mu_0$

figure of Hysteresis loss

The Magnetic Hysteresis loop above, shows the behavior of a ferromagnetic core graphically as the relationship between B and H is non-linear. Starting with an unmagnetised core both B and H will be at zero, point 0 on the magnetisation curve.

If the magnetisation current I is increased in a positive direction to some value the magnetic field strength H increases linearly with I and the flux density B will also increase as shown by the curve from point 0 to point a as it ~~heads~~ helds towards saturation. ~~Now~~

Now if the magnetising current in the coil is reduced to zero the magnetic field around the core reduces to zero but the

~~magnetic field around the flux arour~~ magnetic flux does not reach zero due to the residual magnetism present within the core and this is shown on the curve from point a to point b.

To reduce the flux density at point b to zero we need to reverse the current flowing through the coil. The magnetising force which must to applied to null the residual flux density is called a 'Coercive force'. This coercive force revers the magnetic field re-arranging the molecular magnets until the core becomes unmagnetised at point c.

An increase in the reverse current causes the core to be magnetised in the opposite direction and increasing this magnetisation current will cause the core to reach saturation but in the opposite direction, point d on the curve which is symmetrical to point a. If the magnetising current is reduced again to zero the residual magnetism present in the core will be equal to the previous value but in reverse at point e.

Again, reversing the magnetising current flowing through the coil, this time into a positive direction will cause the magnetic flux to reach zero, (point f) on the curve and as before increasing the magnetisation current further in a positive direction will cause the core to reach saturation at point a.

Then the B-H curve follows the path of a-b-c-d-e-f-a as the magnetising current flowing through the coil alternates between a positive and negative value such as the cycle of an AC voltage. This path is called Magnetic Hysteresis loop.

Transformer:

"The transformer is very simple static (or stationary) electromagnetic passive electrical device that works on the principle of Faraday's law of induction.

It does this by linking together two or more electrical circuits using a common oscillating magnetic circuit which is produced by the transformer itself. A transformer operates on the principle of 'electromagnetic induction' in the form of mutual induction."

A transformer is a device that converts one AC voltage to another AC voltage at the same frequency.

It consists of one or more coil(s) of wire wrapped around a common ferromagnetic core. These coils are usually not connected electrically together. However, they are connected through the common magnetic flux confined to the core.

Working Principle:

A Single phase voltage transformer basically consist of two electrical coils of wire, one called the 'Primary Winding' and another called the 'secondary Winding' that are wrapped together around a closed magnetic iron circuit called a 'core'.

This soft iron core is not solid but made up of individual laminations connected together to help reduce the core's losses. These two windings are electrically isolated from each other but are magnetically linked through the common core allowing electrical power to be transformed from one coil to the other.

In other words, for a transformer there is no direct electrical connection between the two coil windings, thereby giving it the name also of an Isolation transformer.

Generally, the primary winding of a transformer is connected to the input voltage supply and coverts or transforms the electrical power into a magnetic field. ~~into electric~~ While the secondary winding converts this magnetic field into electrical power producing the required output voltage as shown below:

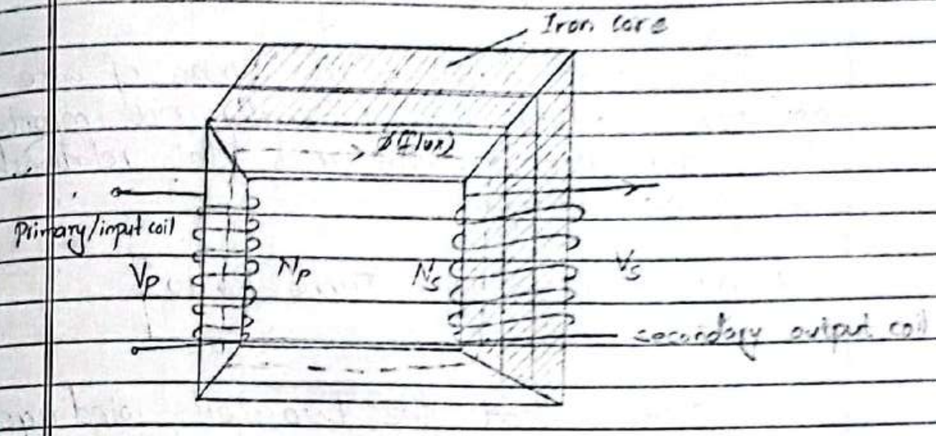


fig: Transformer Construction

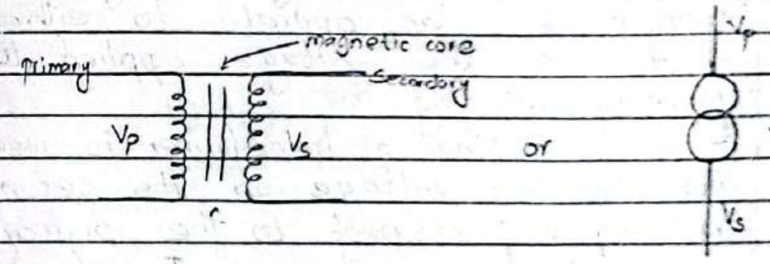


fig: Transformer Symbols

Where,

V_p = Primary voltage
V_s = Secondary voltage
N_p = No. of Primary Windings
N_s = No. of secondary Windings
ϕ = flux linkage

A transformer is all about 'ratios', and the turns ratio of a given transformer will be the same as its voltage ratio. In other words for a transformer: ~~turns ratio~~

turns ratio = voltage ratio

The actual number of turns of wire of any winding is generally not important, just the turns ratio and this relationship is given as:

$$\boxed{\frac{N_P}{N_S} = \frac{V_P}{V_S} = n = \text{Turns Ratio}}$$

Note that the two coil windings are not electrically connected but are only linked magnetically. A single phase transformer can operate to either increase or decrease the voltage applied to the primary winding.

When a transformer is used to increase the voltage on its secondary winding with respect to the primary, it is called a Step-Up Transformer.

When it is used to decrease the voltage on the secondary winding with respect to the primary it is called Step-Down Transformer.

Imp: EMF equation of transformer:

P.T.O

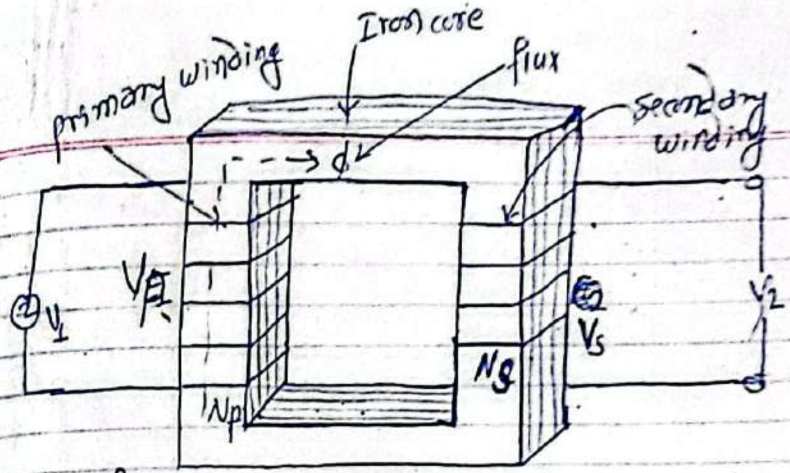


fig: construction of transformer.

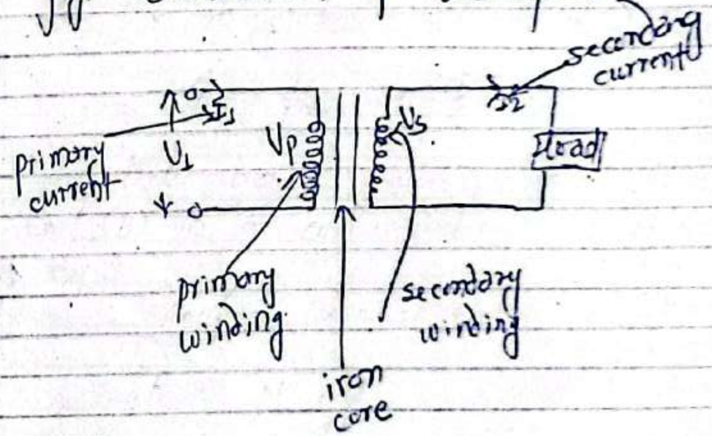


fig: Transformer circuit symbol with load

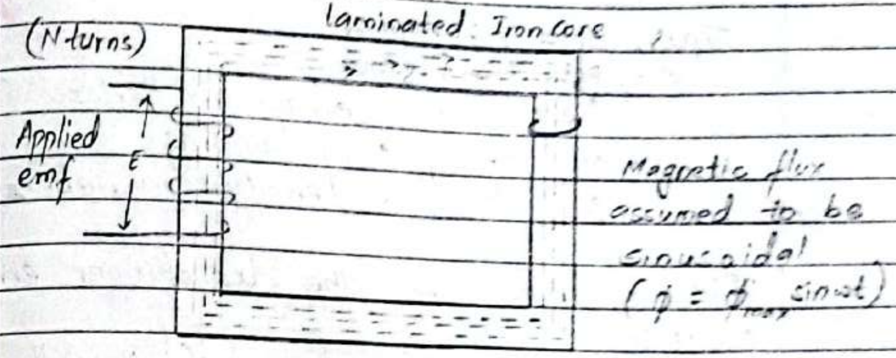


fig:

As the magnetic flux varies sinusoidally,

$$\phi = \phi_{max} \sin\omega t$$

then the basic relationship between induced emf (E) in a coil winding of N turns is given by:

emf = turns × rate of change of flux

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

$$E = N \times \omega \times \phi_{max} \times \cos(\omega t)$$

$\cos(\omega t) = \sin(\omega t + \pi/2)$
$= \sin\pi/2$
$= \sin 90 = 1$

Now, for maximum emf $\cos(\omega t) = 1$, so we have:

$$E_{max} = N\omega\phi_{max}$$

$$E_{rms} = \frac{N\omega}{\sqrt{2}} \times \phi_{max} \quad \left[\because E_{rms} = \frac{E_{max}}{\sqrt{2}}\right]$$

$$= \frac{2\pi}{\sqrt{2}} f \times N \times \phi_{max}$$

$\therefore E_{rms} = 4.44 f N \phi_{max}$

Thus, $E_p = 4.44 f N_p \phi_{max}$

where, $E_s = 4.44 f N_s \phi_{max}$

f = flux frequency in Hertz

N = no. of coil windings

ϕ = the flux density in webers

This is known as the transformer emf equation.

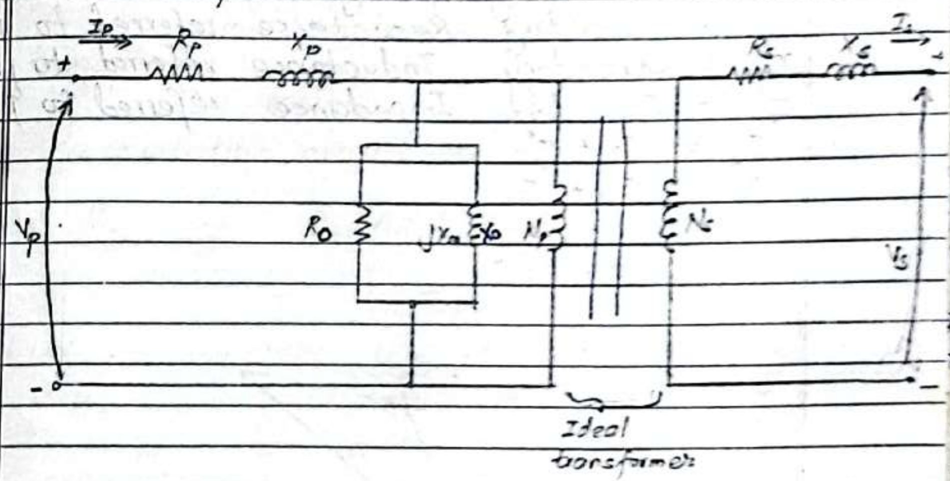
For primary winding emf, N will be the number of primary turns (N_p) & for the secondary winding emf, N will be the number of secondary turns (N_s).

Transformers require an alternating magnetic flux to operate correctly, transformers cannot therefore be used to transform DC voltages or currents, since the magnetic field must be changing to induce a voltage in the secondary winding. In other words, transformer do not operate on DC voltages.

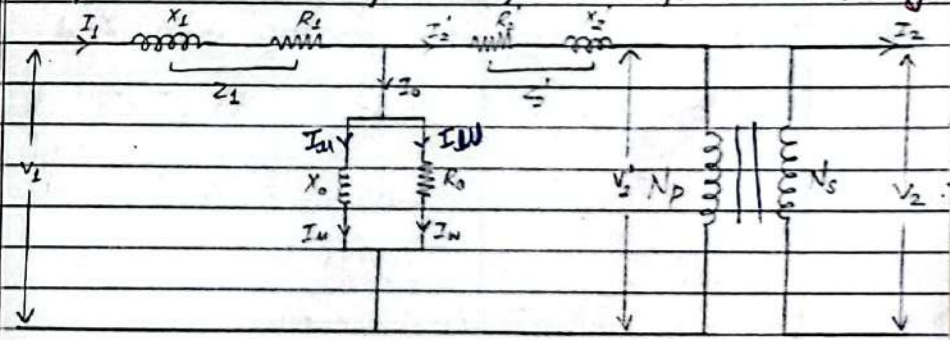
Imp # Equivalent Circuit of Transformer:

Equivalent impedance of transformer is essential for estimating different parameters of electrical power system, so it may be required to calculate total internal impedance of an electrical power transformer viewing ~~prin~~ from primary side or secondary side as per requirement. This calculation requires equivalent circuit of transformer referred to primary or equivalent circuit of transformer referred to secondary sides respectively.

The exact circuit diagram of real transformer:



Equivalent circuit of Transformer reffered to Primary:



where, V_1 = Primary voltage, I_0 = no-load primary current

I_1 = Primary Current, R_0 = core loss resistance

X_0 = magneting reactance

X_1 = Primary Inductance
R_1 = Primary Resistance
Z_1 = Primary Impedance
I_μ = Magnitizing component of current
I_w = ~~$\boxtimes$~~ Core loss component of current
I_2' = Secondary current referred to primary
V_2' = Secondary voltage referred to primary
R_2' = Secondary Resistance referred to primary
X_2' = Secondary Inductance referred to primary
Z_2' = Secondary Impedance referred to primary
$I_1 = I_0 + I_2'$
$I_0 = I_\mu + I_w$

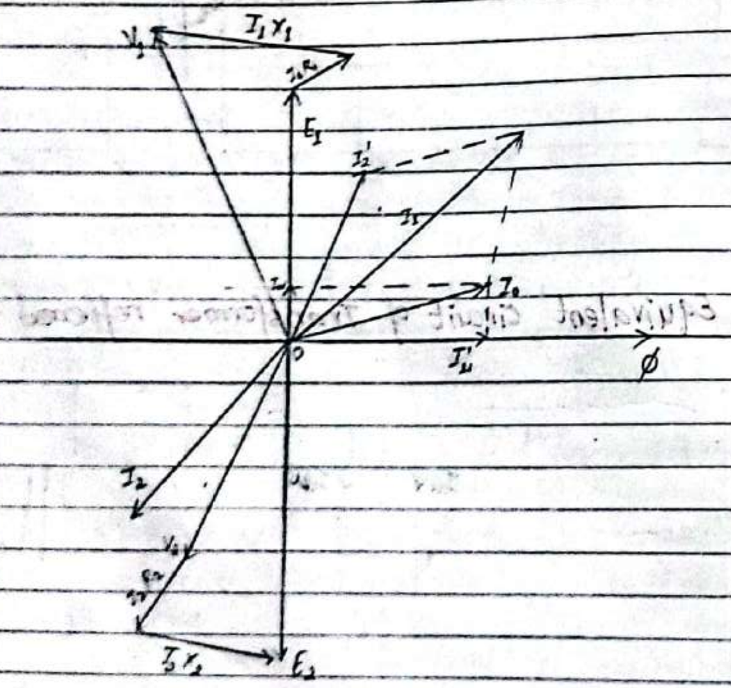


fig: Vector diagram of Transformer on load

~~tet~~ Now it is found that total primary current I_1 has two components one is no load component I_0 and other is load component I_2'. As this primary current has two components or branches so there must be a parallel path with primary winding of transformer. This parallel path of electric current is known as excitation branch of equivalent circuit of transformer.

The resistive and reactive branches of the excitation circuit can be represented as:

$$R_0 = \frac{E_1}{I_w} \quad \text{and} \quad X_0 = \frac{E_1}{I_\mu}$$

Let us consider the transformation ratio be:

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

Now, if we see the voltage drop in secondary from primary side then it would be $1/K^2$ times greater and would be written as:

$$Z_2 \cdot I_2 / K$$

Again,
$$I_2' \cdot N_1 = I_2 \cdot N_2$$

$$\Rightarrow I_2 = \frac{I_2' \cdot N_1}{N_2}$$

$$\Rightarrow I_2 = I_2'/K$$

Therefore, $Z_2 \cdot I_2/K = Z_2 \cdot I_2'/K^2 = Z_2 I_2'/K^2 = I_2' \frac{Z_2}{K^2}$
$= I_2' Z_2'$

From above equation,
Secondary impedance of transformer referred to primary is :

$$Z_2' = Z_2/K^2$$

Hence, $R_2' = \dfrac{R_2}{K^2}$

And, $X_2' = \dfrac{X_2}{K^2}$

So, the complete equivalent circuit of transformer referred to primary is shown in the figure above.

Approximate Equivalent Circuit of Transformer:

Since I_0 is very small compared to I_1, it is less than 5% of full load primary current, I_0 changes the voltage drop insignificantly. Hence, it is good approximation to ignore the excitation circuit in approximate equivalent circuit of transformer.

The winding resistance and reactance being in series can now be combined into equivalent resistance and reactance of transformer ~~reff~~ referred to any particular side. In this case it is side.

Here, $V_2' = \dfrac{V_2}{K}$

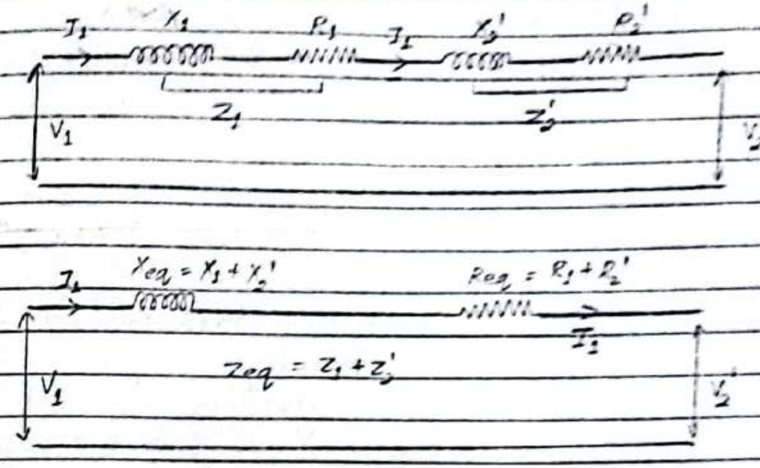


fig : Approximate equivalent circuit of transformer referred to primary

Equivalent Circuit of Transformer referred to Secondary:

In similar way approximate equivalent circuit of transformer referred to secondary can be drawn. Where, equivalent impedance of transformer referred to secondary, can be derived as :

$$Z_1' = Z_1 . K^2$$

Therefore, $R_1' = R_1 . K^2$

and, $X_1' = X_1 . K^2$

Here, $V_1' = V_1 . K$

P.T.O

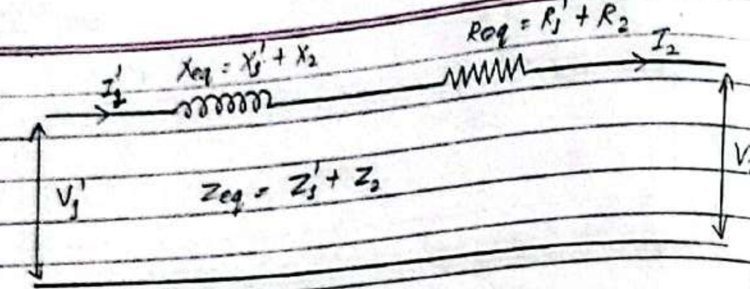


fig: Approximate equivalent circuit of transformer referred to secondary

Imp Short Q.

Open Circuit Test:

The open circuit test, or no-load test is one of the methods used in electrical engineering to determine the no load impedance in the excitation branch of a transformer.

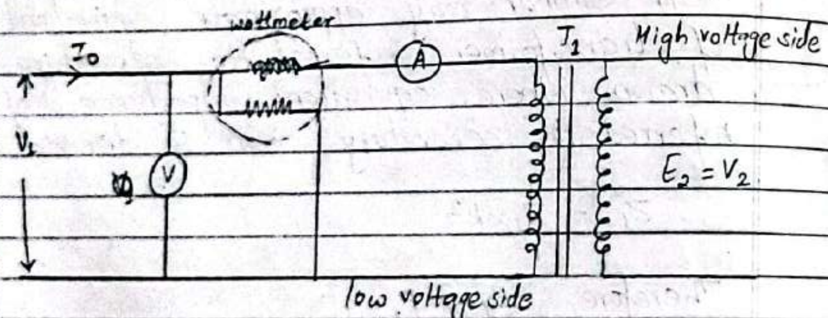


fig. circuit diagram for open circuit test

The secondary of the transformer is left open-circuited. A wattmeter is connected to the primary. An ammeter is connected in series with the primary winding. A voltmeter is optional since the applied voltage is the same as the voltmeter reading. Rated voltage is applied at primary.

No load

open ckt → core loss – varying of magnetic field & no heat produced across copper wire → neglect copper loss.

Since, the secondary of the transformer is open, the primary draws only no-load current, which will have some copper loss. This no-load current is very small and because the copper loss in the primary is proportional to the square of this current, it is negligible. There is no copper loss in the secondary because there is no secondary current.

Now, the components of no-load circuit

$W = VI\cos\phi$

$I_\mu / I_m = I_0 \sin\phi$ $\qquad I_0 = \sqrt{I_\mu^2 + I_w^2}$

$I_w = I_0 \cos\phi$

$R_0 = V_1 / I_w$

$X_0 = V_1 / I_m$

These values are referred to LV side of the transformer.

Hence it is seen that open circuit test gives core losses of transformer and shunt parameters of the equivalent ckt.

where, W is the wattmeter reading.

V_1 is the applied rated voltage.

I_0 is the no-load voltage.

I_m is the magnetizing component of no load current.

I_w is the core loss component of no load current.

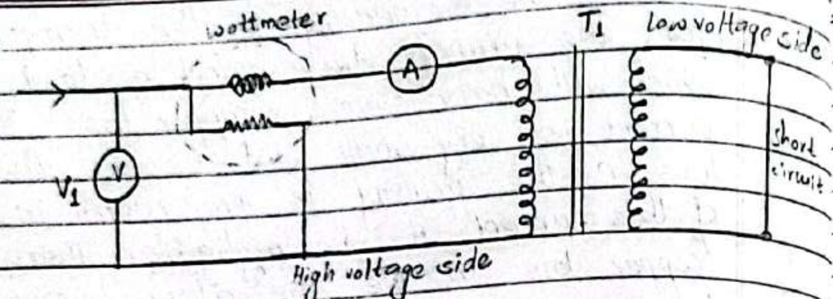
Imp Short Q.

Short circuit test:

The purpose of short circuit test is to determine the series branch parameters of the equivalent circuit of a real transformer.

P.T.O

Load ⇒ S/C ckt → copper loss → heat produced ...
core loss.



The test is conducted on the high voltage (HV) side of the transformer where the low voltage (LV) side or the secondary is short circuited. The supply voltage required to circulate rated current through the transformer is usually very small and is of the order of a few percent of the nominal voltage and this voltage is applied across primary. Thus the wattmeter reading measures only the full load copper loss.

short ckt test gives copper losses of transformer and approximate equivalent resistance and reactance of the transformer.

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

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

$$Z_{01} = \frac{V_1}{I_1} \quad \& \quad R_{01} = \frac{W}{I_1^2}$$

These values are referred to the H.V side of transformer where,

W is the full load copper loss.
V_1 is the applied voltage.
I_1 is the rated current
R_{01} is the resistance as viewed from the primary.
Z_{01} is the total impedance as viewed from the primary.
X_{01} is the reactance as viewed from the primary.

DC Machines:

A dc machine is a device which converts mechanical energy into electrical energy and vice-versa.

When the device converts mechanical energy into electrical form then it is called generator and if it converts electrical energy into mechanical energy then it is known as motor. Thus electrical machines can be made to work either a generator or motor.

Generators and motors are very similar to each other in essential parts and construction.

An electric motor is an electric machine that converts electrical energy into mechanical energy.

In normal motoring mode, most electric motors operate through the interaction between ~~the~~ an electric motor's magnetic field and winding currents to generate force within the motor.

Motor Construction:

→

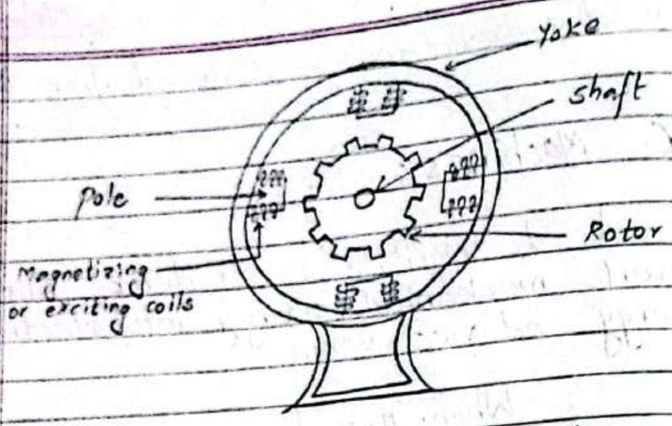


fig: construction of motor

① **Rotor:**
In an electric motor the moving part is the rotor which turns the shaft to deliver the mechanical power. The rotor usually has conductors laid into it which carry currents that interact with the magnetic field of the stator to generate the forces that turn the shaft. However, some rotors carry permanent magnets, and the stator holds the conductors.

② **stator:**
The stationary part is the stator, usually has either windings or permanent magnets.

③ **Air gap:**
In between the rotor and stator is the air gap. The air gap has important effects, and is generally as small as possible, as a large gap has a strong

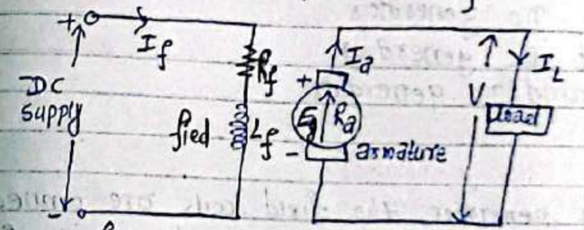
①

Types of DC Generators:

The device which converts mechanical energy into electrical energy is known as generator. There are two types of DC generators: Ac generator & DC generator. There are two types of DC generators
① separately excited DC generator.
(2) Self excited DC generator

(1) separately Excited DC generator:

A DC generator whose field winding (or coil) is energized by a separate or external DC source is called a separately excited DC generator. The flux produced by the poles depends upon the field current with the unsaturated region of magnetic material of the poles i.e flux is directly proportional to the field current but in the saturated region, the flux remains constant. separately excited DC generators are rarely used in practice.



Here, fig: separately excited DC generator

From above circuit,

terminal voltage(V) $= E_g - I_a R_a$

E_g induced/back emf of motor.

$I_a R_a$ drop voltage across armature resistance(R_a).

If the contact brush drop is considered, then terminal voltage becomes,

$$V = E_g - I_a R_a - 2V_b$$

power developed across armature = $E_g \cdot I_a$

Where,

E_g = back emf

I_a = armature current

output power = $V \cdot I_L$

$= V \cdot I_a$ [$\because I_a = I_L$]

or

output power =

$= E_g I_a - I_a^2 R_a$

$= I_a(E_g - I_a R_a)$

$= I_a(V)$

$= I_a V_a$

(2) Self excited DC generator:

Self excited DC generator is a device in which the current to the field winding is supplied by the generator itself. The self excited DC generator is further classified as:

(a) Series DC generator
(b) Shunt DC generator
(c) compound DC generator

(a) Series DC generator:

In series DC generator, the field coils are connected in series with the armature winding. The series field winding carries the armature current. The series field winding consists of a few turns of wire of thick wire of larger cross-sectional area and having low resistance usually of the order of less than 1Ω because the armature current has a very large value. Such types of series DC generator is also rarely used in practice.

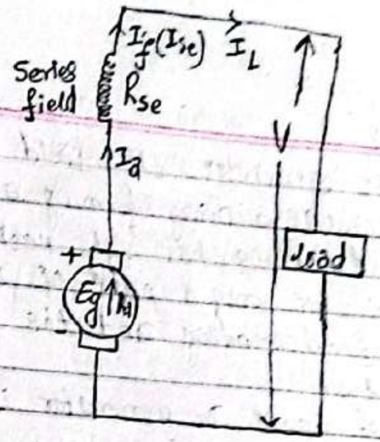


fig: Series DC generator

From figure,

Terminal voltage is given by,

$$V = E_g - \underbrace{I_a R_a}_{\text{drop V}} - \underbrace{I_{se} R_{se}}_{\text{drop V}}$$

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

$$\therefore V = E_g - I_a R_a - I_a R_{se}$$ [R_{se} = series field resistance]

$$\text{or, } V = E_g - I_a(R_a + R_{se})$$

If the brush contact drop is included, then terminal voltage becomes,

$$V = E_g - I_a(R_a + R_{se}) - 2V_b$$

power developed = $E_g \cdot I_a$

output power = $V \cdot I_a$

Note: The flux developed by the series field winding is directly proportional to the current flowing through it.

(b) shunt DC generators

In a shunt DC generator, the field winding is connected across the armature winding forming a parallel or shunt circuit. The field winding has high resistance and more number of turns so that only a part of armature current passes through field winding and the rest of current passes through load.
The connection diagram of shunt DC generator is shown below.

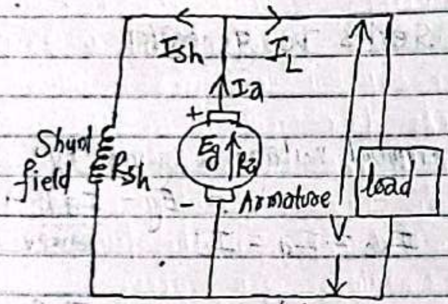


fig: Shunt DC generator

From circuit diagram,

$$I_{sh} \text{ (shunt current)} = \frac{V}{R_{sh}}$$

where, V = terminal voltage, R_{sh} = shunt field res.

The armature current $(I_a) = I_{sh} + I_L$

Terminal voltage $(V) = E_g - I_a R_a$

If the brush contact is included then V becomes as,

$$V = E_g - I_a R_a - 2V_b$$

developed power $= E_g I_a$

output power $= V \cdot I_L$

(c) compound DC generator:

Compound DC generator has two field windings; one is connected in series and another is connected in parallel with the armature windings. There are two types of compound DC generator.

(i) short shunt compound DC generator
(ii) Long shunt compound DC generator

(i) Short shunt compound DC generator:

In short shunt compound DC generator, the shunt field winding is connected in parallel with the armature and series field winding is connected in series with the load as shown in figure below.

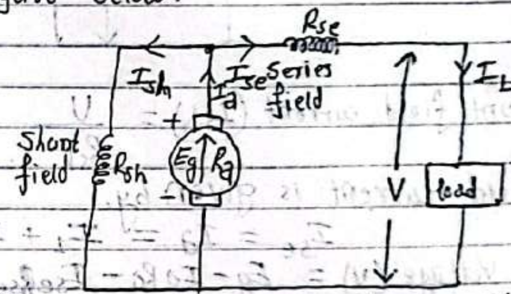


fig: Short shunt compound generator

From figure,

$$I_L = I_{se}$$

&

$$I_{sh} = \frac{V + I_L R_{se}}{R_{sh}} = \frac{E_a - I_a R_a}{R_{sh}}$$

Armature current $(I_a) = I_L + I_{sh}$

Terminal voltage $(V) = E_g - I_a R_a - I_L R_{se}$

developed/generated power $= E_g \cdot I_a$

output power $= V \cdot I_L$

If the brush contact drop is included then,

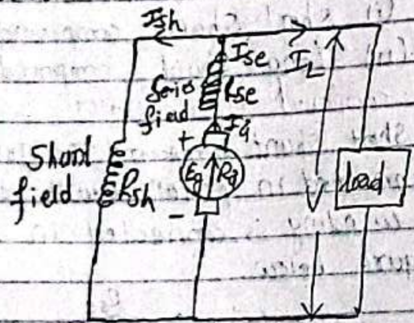
$$V = E_g - I_a R_a - I_L R_{se} - 2$$

possible, as a large gap has a ...

water turbines, steam turbines, internal

(ii) Long Shunt compound Dc generator:

In long shunt compound Dc generator, the shunt field winding is parallel with both armature and series field winding. The connection diagram of long shunt compound Dc generator is shown below.



From figure,

Shunt field current $(I_{sh}) = \frac{V}{R_{sh}}$

Series field current is given by,

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

Terminal Voltage $(V) = E_g - I_a R_a - I_{se} R_{se}$

$$= E_g - I_a R_a - I_a R_{se}$$

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

If the brush contact drop is included then

$$V = E_g - I_a(R_a + R_{se}) - 2V_b$$

developed power $= E_g I_a$

o/p power $= I_L \cdot V$

PAGE
DATE

PAGE
DATE

EMF equation of DC machine:

The emf developed by a DC machine may be determined as follows:

Let us define the following symbols.

ϕ = magnetic flux per pole.
P = number of magnetic poles
N = speed of armature in rpm (rotation per minute)
Z = Total number of armature conductors.
A = Number of parallel paths in the armature winding.

Then,

Flux cut by one conductor in one rotation $= \phi P$
Flux cut by one conductor in N rotations $= \phi NP$
Flux cut per second by one conductor in N rotations $= \frac{\phi NP}{60}$
Number of conductors in series $= Z/A$
$\therefore$ Flux cut per second by Z/A conductors $= \frac{\phi NP}{60} \times Z/A$

Hence, emf induced in the armature winding.

$$E = E_b = \frac{\phi NP}{60} \times \frac{Z}{A} = \frac{Z\phi N}{60} \times P/A$$

Torque equation of DC machine:

We know that, the generated electric power is equal to the generated mechanical power in DC machine like motor & not generator.

i.e $E_b \cdot I_a = T_a \times 2\pi N$ .. (i)

Where,

E_b = back emf, I_a = A.C
T_a = A.T
N = speed in rpm.

possible, as a large gap has a ...

water turbines, steam turbines, internal since, emf equation of DC machine is given by,

$$E_b = E = \frac{Z\phi N}{60} \times \frac{P}{A} \quad \text{---(ii)}$$

From eqn (i) & (ii) we get,

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

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

$$T_a = \frac{1}{120\pi} \frac{Z\phi P I_a}{A}$$

From this equation we can say that

$$T_a \propto \phi I_a$$

i.e Torque is directly proportional to the product of armature current and magnetic flux per pole.

Speed control of DC motor by armature control method:

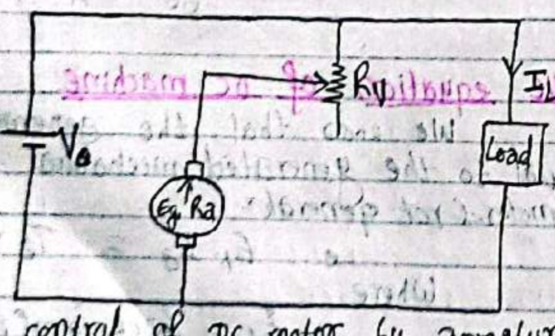


fig: speed control of DC motor by armature control method.

The armature torque method depends upon magnetic flux per and armature current.

i.e torque $\propto \phi I_a$

If the variable resistance (R_V) is increased keeping the load current torque constant then armature current remains constant but potential difference across the armature will decrease and hence speed of armature will decrease.

When R_V is zero then

$$E_{b_1} = V - I_{a_1} R_a \text{ (having } N_1 \text{ speed)}$$

When R_V is connected with armature, then

$$E_{b_2} = V - I_{a_2} R_a - I_{a_2} R_V$$

$$E_{b_2} = V - I_{a_2}(R_a + R_V) \text{ (having } N_2 \text{ speed)}$$

Now, we know,

$$\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}}$$

$$\boxed{\frac{N_2}{N_1} = \frac{V - I_{a_2}(R_a + R_V)}{V - I_{a_1} R_a}}$$

We know,

$$N \propto E_b$$

So, when R_V is not connected then voltage drop is less and back emf is larger and hence speed is increased. Illy, when R_V is connected with armature then there is more voltage drop and generated emf is less and hence speed is decreased.

AC machines: Two types of AC motors: ① Induction (Asynchronous motors) ② synchronous motor.

① Induction motor:

Induction motor is also known as asynchronous motor. It is an electric motor which operates from AC voltage source under the principle of electromagnetic induction. Stator windings of induction motor carry three-phase windings. When three phase stator windings are supplied by three phase balanced voltage then three phase current will flow through stator windings. This three phase supply produces the rotating magnetic field. The synchronous speed (stator's speed) is given by

$$N_s = \frac{120f}{P} \text{ RPM} \quad \text{or,} \quad N_s = \frac{2f}{P} \text{ RPS}$$

where,

N_s = synchronous speed

f = frequency of applied voltage

P = Number of poles on stator

The rotor always rotates at the speed less than the synchronous speed

i.e. $N_r < N_s$

we know the slip of the motor is

$$\text{slip} = s = \frac{N_s - N_r}{N_s}$$

per phase equivalent circuit of inductor motor is given by

(2)

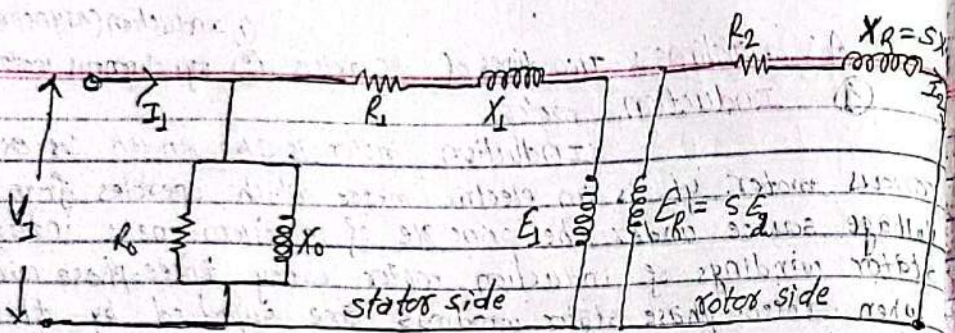


fig: Equivalent circuit of induction motor at running condition.

The difference between the stator (synchronous) speed and rotor speed is simply called the slip of the motor.

3-ϕ induction motors are mostly used for various industrial applications because of their following advantages:

→ They are easy to construct the motor system.
→ They are very reliable and having low cost.
→ They have high efficiency and good power factor.
→ 3-ϕ induction motor is self starting hence extra starting motor or any special starting arrangement is not required.
→ such motors are easier for maintenance.

Synchronous motor:

Synchronous motor operates on synchronous (constant) speed, hence this motor develops a constant torque in the direction of rotation.

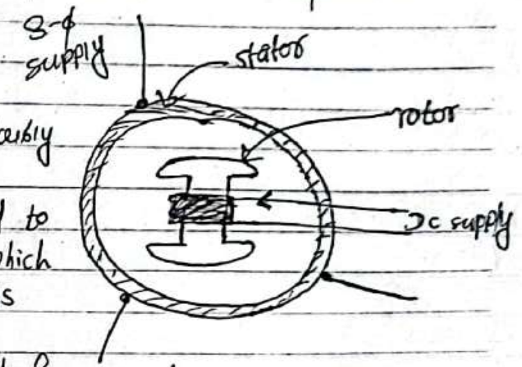


fig: synchronous motor

Synchronous motor is a doubly excited ~~motor~~ machine i.e two electrical inputs are provided to it. It's stator winding which consists of a 3-ϕ winding is provided with three phase supply and rotor is provided with DC supply. The 3-ϕ stator winding carrying 3-ϕ currents due to which produces 3-ϕ rotating magnetic flux. The rotor carrying DC supply and also produces a constant flux.

Synchronous motors are not self starting. such motors require some external trigger signal and bring their speed close to the synchronous speed. "The speed of operation of is in ~~synchronized~~ synchronism with the supply frequency and hence for constant supply frequency they behave as constant speed motor." It is capable of being operated under a wide range of power factors both lagging and leading.

Synchronous motor having no-load connected to its shaft is used for power factor improvement. Synchronous motor finds application where operating speed is less than (around 500 rpm) and high power is required.

① Applications of 1-ϕ synchronous motor
② " " Induction "
③ Differences between synchronous & induction motor

negative effect on the performace of an electric motor.

Winding :

Windings are wires that are laid in coils, usually wrapped around a laminated soft iron magnetic core so as to form magnetic poles when energized with current.

Some motors have conductors which consist of thicker metal, such as bars or sheets of metal, usually copper, although sometimes aluminum is used. These are usually powered by electromagnetic induction.

Commutator:

A commutator is a mechanism used to switch the input of certain AC and DC machnines consisting of slip ring segments insulated from each other and from the electric motor's shaft.

Types of DC Generators :

Energy can be converted from one form to other form.

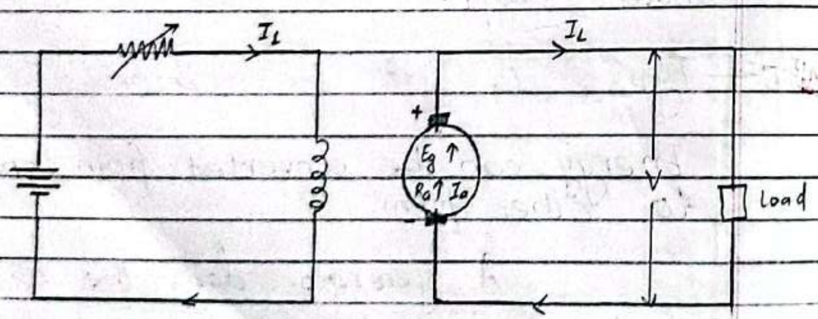
A generator does the same- It converts mechanical energy to electrical energy. Mechanical energy can be created by using water turbines, steam turbines, internal combustion engines etc. And a generator converts this mechanical energy to electrical energy. Generators can be broadly classified as AC generators and DC generators.

DC generators are classified based on their method of excitation. So on this basis there are two types of DC generators:

(1) Separately Excited DC Generator:

As we can guess from the name itself, this dc generator has a field magnet winding which is excited using a separate voltage source (like battery). The output voltage depends on the speed of rotation of armature and field current. The higher the speed of rotation and current, higher is the output emf.

Note: Separately excited DC generators are rarely used in practice.



Armature current, $I_a = I_L$

Terminal voltage, $V = E_g - I_a R_a$

Electric Power developed $= E_g I_a$

Power delivered to load $= E_g I_a - I_a^2 R_a$

$= I_a (E_g - I_a R_a)$

$= V I_a$

(2) Self Excited DC Generator:

These are generators in which the field winding is excited by the output of the generator itself. Self excited DC generator can again be classified as:

(a) Series DC Generator
(b) Shunt DC Generator
(c) Compound DC Generator

(a) Series DC Generator:

A series DC generator is shown in figure below in which the armature winding is connected in series with the field winding so that the field current flows through the load as well as the field winding.

Field winding is a low resistance, thick wire of few turns. Series generators are also rarely used.

Armature current, $I_a = I_{se} = I_L = I$ (say)

Terminal voltage, $V = E_g - I(R_a + R_{se})$

Power developed in armature = $E_g I_a$

Power delivered to load = $E_g I_a - I_a^2 (R_a + R_{se})$

$= I_a [E_g - I_a (R_a - R_{se})]$

$= V I_a$ or $V I_L$

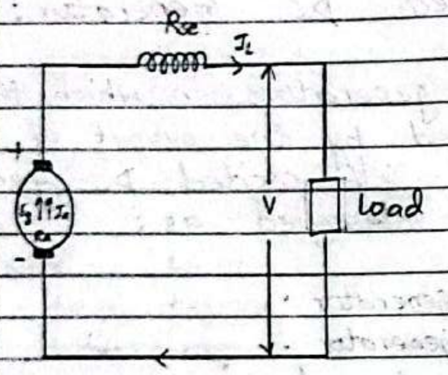


fig: Series DC Generator

(b) Shunt DC Generator:

A shunt DC Generator is shown in figure below, in which the field winding is parallel to armature winding so that the voltage across both are same.

The field winding has high resistance and more number of turns so that only a part of armature current passes through field winding and the rest passes through load.

Shunt field current, $I_{sh} = \frac{V}{R_{sh}}$

Armature current, $I_a = I_L + I_{sh}$

Terminal voltage, $V = E_g - I_a R_a$

Power developed in armature = $E_g I_a$

Power delivered to load = $V I_L$

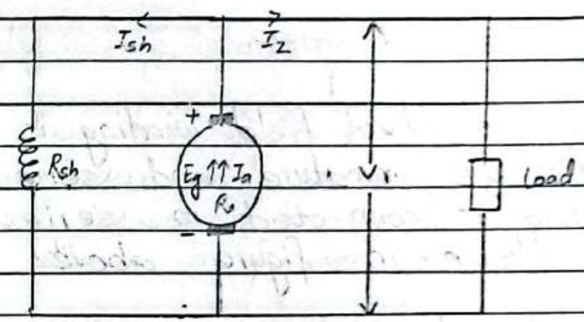


fig: Shunt DC generator

(c) Compound DC Generator:

A compound DC generator is shown below. It has two field windings namely R_{sh} and R_{se}. They are basically shunt winding (R_{sh}) and series winding (R_{se}).

Compound generators are of following two types:

(i) Short shunt:

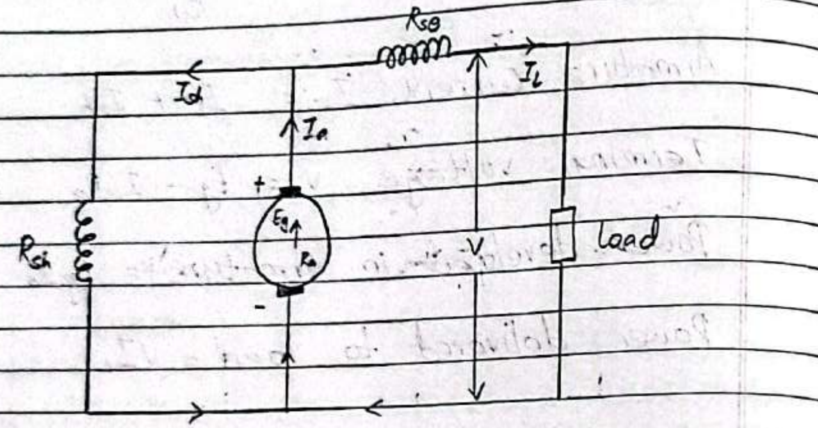


fig: Short shunt

Here, the shunt field winding is wired parallel to armature and series field winding is connected in series to the load as shown in figure above.

for short shunt:

Series field current, $I_{se} = I_L$

Shunt field current, $I_{sh} = \frac{V + I_{se}R_{se}}{R_{sh}}$

Terminal voltage, $V = E_g - I_aR_a - I_{se}R_{se}$

Power developed in armature $= E_g I_a$

Power delivered to load $= VI_L$

(ii) Long shunt:

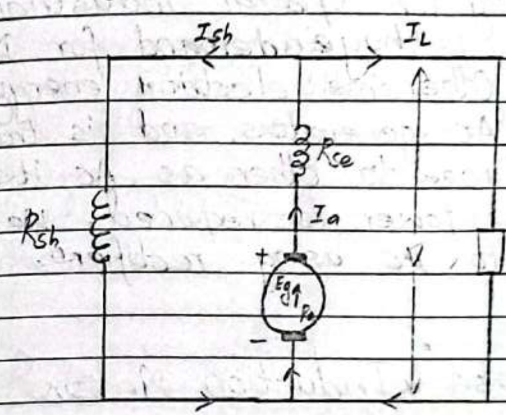


fig: long shunt

Here, the shunt field winding is parallel to both armature and series field winding (R_{se} is wired in series to the armature). It is shown ~~above~~ in figure above.

For long shunt,

Series field current, $I_{se} = I_a = I_L + I_{sh}$

Shunt field current, $I_{sh} = \frac{V}{R_{sh}}$

Terminal voltage, $V = E_g - I_a(R_a + R_{se})$

Power developed in armature $= E_g I_a$

Power delivered to load $= VI_L$

Now, we can say that these generators are used only for special industrial purposes where there is huge demand for DC production. Otherwise electrical energy is produced by AC generators and is transmitted from one place to other as AC itself. When a DC power is required, we usually convert AC to DC using rectifiers.

Imp # Three Phase Induction Motor:

An electric motor is such an electromechanical device which converts electrical energy into a mechanical energy.

In case of three phase AC operation, most widely used motor is Three phase induction motor as this type of motor doesnot require any starting device or we can say they are self starting induction motor.

The basic constructional feature of this motor consist of two major parts:

(i) Stator:

Stator of the three phase induction motor is made up of numbers of slots to construct a 3 phase winding circuit which is connected to 3 phase AC source.

The three phase windings are arranged in such a manner in the slots that they produce a rotating magnetic field after AC is given to them.

The stator of the motor consists of overlapping windings offset by an electrical angle of 120°. When the primary winding or the stator is connected to a 3-ϕ AC source, it establishes a rotating magnetic field which rotates at the synchronous speed.

(ii) Rotor:

Rotor of three phase induction motor consists of cylindrical laminated core with parallel slots that can carry conductors. Conductors are heavy copper or aluminium bars which fits in each slots & they are short circuited by the end rings.

The number of magnetic poles of the revolving field will be same as the number of poles for which each phase of primary or stator winding is wound or wrapped. The speed at which the field produced by the primary current will revolve is called synchronous speed of motor and is given by:

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

where N_s is the synchronous speed
f is the frequency
P is the no. of poles on stator.

The difference between the stator (synchronous speed) and rotor speeds is called the slip. The rotation of the magnetic field of an induction motor has the advantage that no electrical connections need to be made to the rotor.

Thus, the Three phase Induction Motor is:

- Self-starting
- Robust in construction
- Economical
- Easier to maintain

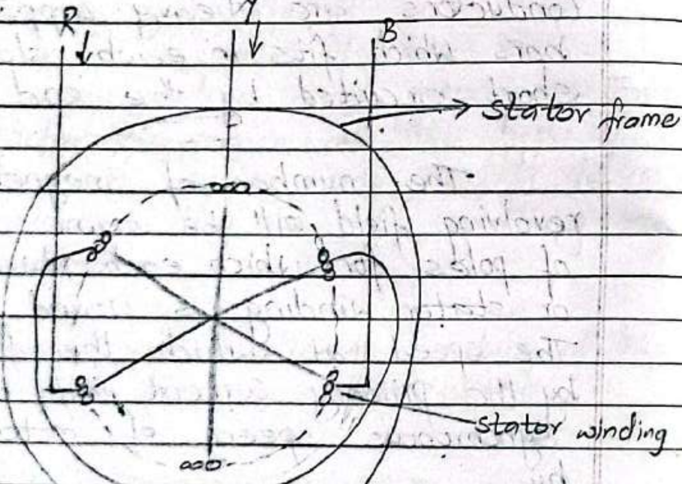


fig: 3-ϕ Induction motor

Imp # Synchronous Motor:

A Synchronous motor operates on synchronous (constant) speed, hence the motor develop a constant torque in the direction of rotation.

It is electrically identical with an alternator or Ac generator. It runs either at synchronous speed or not at all ie while running it maintains constant speed. It is capable of being operated under a wide range of power factors both lagging and leading. It can be used for power correction purpose in addition to supplying torque to drive loads.

Imp # Uses of 1-ϕ Synchronous Motor:

(1) They are small, constant speed motors.

(2) Built for the wide range of output and speed.

(3) Its power is on the range of 0.0001 kW and are used in clocks, control apparatus timing devices etc.

Imp # Emf Equation of dc machine:

let us define,

$\phi \rightarrow$ magnetic flux per pole

$P \rightarrow$ No. of magnetic pole

$Z \rightarrow$ Total no. of armature conductors
$N \rightarrow$ speed of armature rpm (rotation per minute)

Now,
Average emf generated per conductor $= \frac{d\phi}{dt}$

The Magnetic flux cut by one conductor in one revolution $= \phi \times P$
Time for one revolution $(dt) = \frac{60}{N}$

let, A be the number of parallel path in armature winding then number of conductor in series is $= \frac{Z}{A}$

$\therefore$ Average emf generated per pole $= \frac{d\phi}{dt}$

$$= \frac{\phi \times P}{\frac{60}{N}}$$

$$= \frac{\phi \times P \times N}{60} \quad \text{---(i)}$$

Now,
total emf $=$ Average emf $\times$ no. of conductor in series

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

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

Note: $A = P$ for lap winding
$A = 2$ for wave winding

Imp # Torque Equation of dc machine :

We known in electric field,

Electric power generated = Mechanical power developed

i.e

$$E_b I_a = T_a \times 2\pi N \quad \text{---(i)}$$

Where,
$E_b \rightarrow$ back emf or generated emf (E_g)
$I_a \rightarrow$ Armature current
$T_a \rightarrow$ Torque
$N \rightarrow$ Speed in rpm

Since, emf equation of d.c machine is given by:

$$E_b = E = \frac{Z\phi N}{60} \times \frac{P}{A} \quad \text{rpm} \quad \text{---(ii)}$$

$$E = Z\phi N \times \frac{P}{A} \quad \text{rps}$$

From eqn (i) & (ii) :

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

or, $\frac{Z\phi N P I_a}{60 \times A} \times \frac{1}{2\pi N} = T_a$

or, $T_a = \frac{Z\phi P I_a}{120\pi \times A}$

$$\boxed{T_a = \frac{1}{120\pi} \times \frac{Z\phi I_a P}{A}}$$

From this eqn we can say that:

$T_a \propto \phi I_a$

ie Torque is directly proportional to the product of armature current and magnetic flux per pole.

Speed control of DC motor by armature control method:

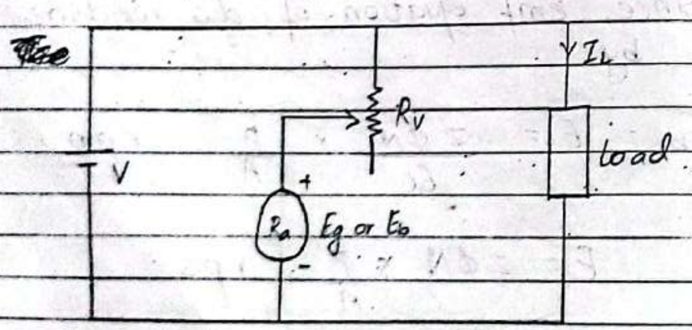


fig: speed control of d.c motor by armature control method

The armature torque method depends upon magnetic flux per pole and armature current.

i.e torque $\propto \phi I_a$

If the controller resistance or variable resistance (R_V) is increased keeping the load torque constant, the armature current remains constant but potential difference across the armature will decrease. Hence speed of armature will decrease.

let, N_1 be the speed of motor at R_V = constant > 0

Then, back or generated emf is given by:

$E_{b1} = V - I_{a_1} R_a$

$E_{b_2} = V - I_{a_2} (R_a + R_V)$

Now, we have:

$\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}}$

$$\boxed{\frac{N_2}{N_1} = \frac{V - I_{a_2}(R_a + R_V)}{V - I_{a_1} R_a}}$$

If $R_V = 0$, speed is maximum (full load)

If R_V = constant, speed is minimum (no load)

Characteristics of DC Generators:

(A) Load Characteristics:

(i) Series DC generator:

Let us consider a series DC generator as shown in figure below in which the armature winding is connected in series with field winding so that same field current flows through the load as well as the field winding.

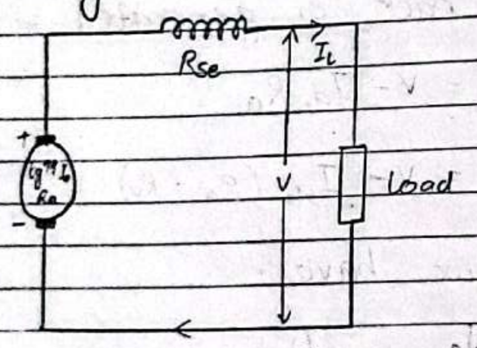


fig: series DC generator

When the load current increases, the armature current as well as field current also increases. Therefore, the voltage drop in armature resistance (I_aR_a) will also increase and other hand the flux per pole also increase. Therefore, the emf will also increases. Hence, a series DC generator have a raising voltage characteristics as shown in figure below:

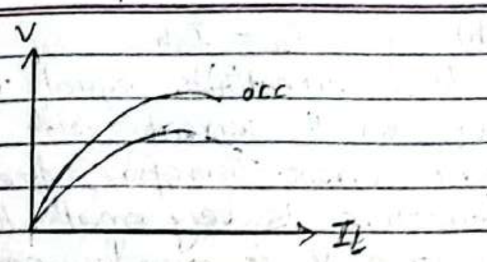
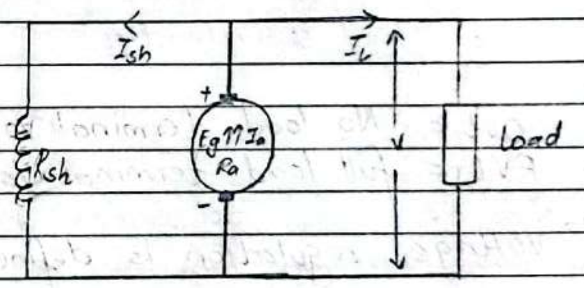


fig: Load characteristics

"But at over loaded condition, the voltage starts decreasing due to excessive demagnetizing effect of armature reaction and saturation flux effect."

(ii) Shunt DC generator:

Let us consider a shunt DC generator as shown in figure below in which the field winding is connected in parallel to armature winding so that the voltage across both are same.



∴ fig: Shunt DC generator

When there is no load current, the armature current (I_a) is equal to the field

Current (I_{sh}) ie $I_a = I_{sh}$.

Since, load current(I_L) is equal to zero, which is very small current with compare to full load current. Therefore, the voltage drop in armature is very small. Hence, the terminal voltage V is nearly equal to E_g.

When the generator is loaded than the armature current ($I_a = I_{sh} + I_L$) will increase. Now the terminal voltage is given by:

$V = E_g - I_a R_a$

Therefore, the terminal voltage V will decrease with increase in load current (I_L) as shown in figure below:

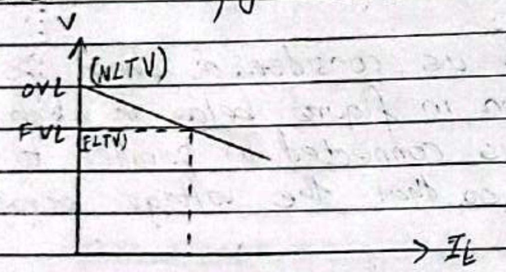


fig: load characteristics

let, OVL = No load terminal voltage
FVL = full load terminal voltage

Then, voltage regulation is defined as follows:

$$\boxed{\text{Voltage regulation} = \frac{OVL - FVL}{OVL} \times 100\%}$$

Hence, shunt DC generator have a dropping voltage characteristics.

(iii) Compound DC Generator:

We have seen that, a series DC generator has a raising voltage characteristics and a shunt DC generator has a dropping voltage characteristics. A compound DC generator has a characteristics lying between shunt and series DC generator. A shunt DC generator can be modified into a compound generator to supply constant voltage by adding few turns of field winding in series with load or armature. as show below:

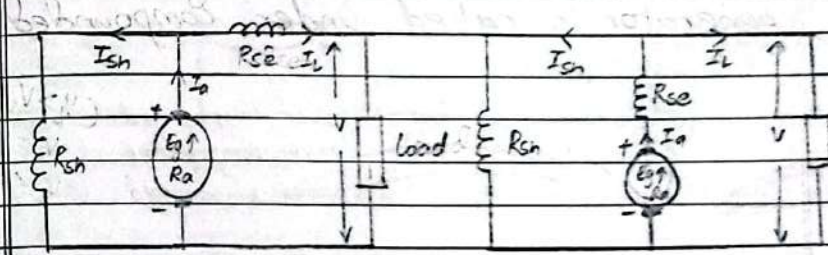


fig: short shunt (field winding series with load)

fig: long shunt (field winding series with armature)

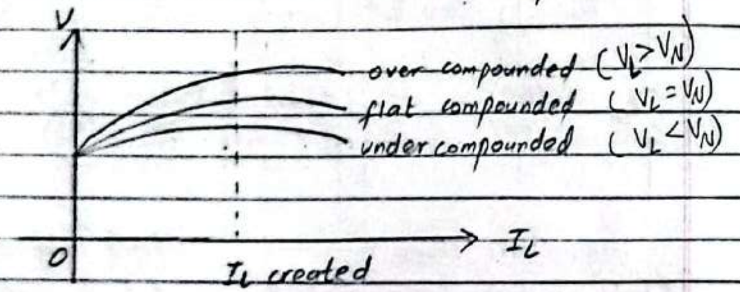
As the load current increases, the current through the series field winding also increases thereby increasing flux per pole. Due to increase in flux per pole, the emf also increases.

By adjusting the number of series turn the terminal voltage 'V' can be controlled in different ways.

If the series field ampere turns are such that the voltage at rated load and no load voltage are same then the generator is called flat compounded.

If the series field ampere turns are such that the voltage at rated load is greater than no load voltage then the generator is called over compounded.

If the series field ampere turns are such that the voltage at rated load is less than the no load voltage then the generator is called under compounded.



(2008, spring) (B) No-load characteristics:

It is a curve showing the values of emf generated across the armature at differen no load for different values of field current at constant speed.

"The load characteristics of separately excited shunt and series generator can be partially obtained in a similar way." The circuit arrangement for obtaining the data for no load characteristic curve as shown below:

fig: Circuit Diagram

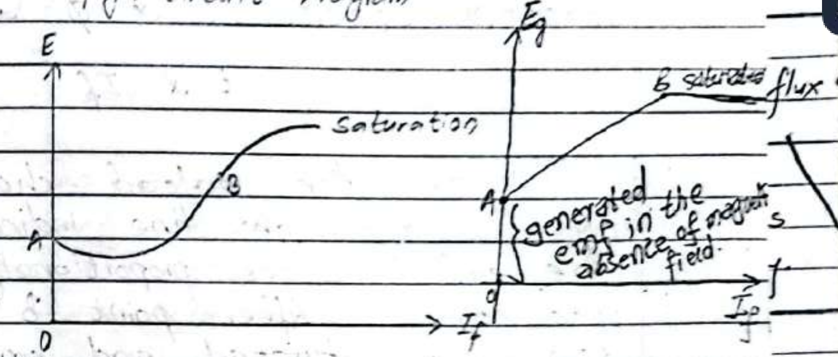


fig: open circuit curve

In case of shunt and series generator, the field windings has to be disconnected temporarily and connected them as shown above.

The armature of the generator is rotated at constant speed by prime movier and emf induced across the armature at different value of field current are measured. The resulting curve as shown in above figure where OA is the emf generated across the armature due to residual flux in the pole even in absence of field current.

"We know that:"

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

we know,

$\phi \propto I_f$ and $E \propto \phi$ so $E \propto I_f$

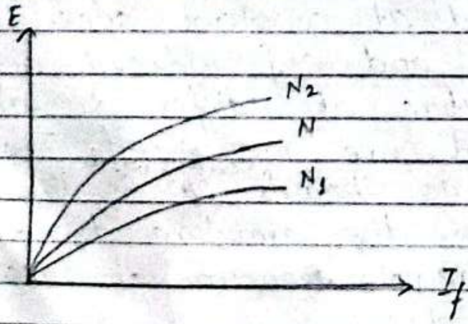
Since, armature current is driven at constant speed, $E \propto \phi$ At constant speed we can write

$$E \propto I_f$$

Therefore, the noload characteristic curve is a straight line indicating that the emf increases proportionally with I upto point B. After point B the magnetic poles get saturated and emf does not increases even if the I is increased.

Note:

No-load characteristic curve for higher speed will be above this curve and for the lower speed it will be below this can shown as:



$N_2 > N > N_1$

(ii) Characteristics of DC Shunt motor:

(i) Torque Armature Current characteristics: (T_a-I_a)

It is the curve showing the relationship betⁿ armature's torque developed at different values of armature current.

We know that, torque equation of DC machine is, $T_a \propto \phi I_a$

And, $\phi \propto I_f$

In a dc shunt motor the field current is constant provided that the applied voltage is constant.

$\therefore T_a \propto I_a$

Hence, T_a-I_a characteristics of DC shunt motor is a straight line which indicate that the armature's torque increases proportionally with the armature current. The net shaft torque is always less than the armature torque because of loss of torque due to friction loss.

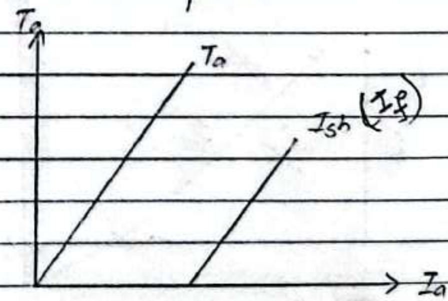


fig: T_a- I_a characteristics

(ii) Speed Torque characteristics:

It is a curve showing the speed of the motor at different values of armature torque developed by the motor.

We know, that,

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

where, N is speed of DC shunt motor and ϕ is constant for DC shunt motor.

When the speed of motor decreases the back emf E_b will also decrease.

Then, Armature current $(I_a = V - E_b/R_a)$ will increase as the armature torque (T_a) will also increase but the speed of motor is inversely proportional to the torque of the motor.

Hence, $N - T_a$ characteristics of DC shunt motor will be as follow:

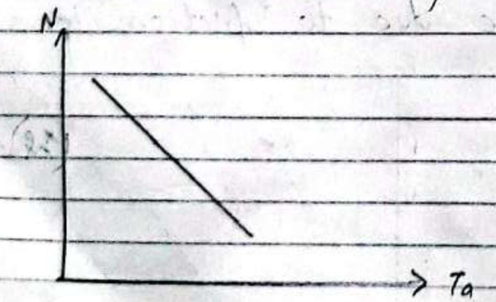


fig: $N - T_a$ characteristics

(b) Characteristics of DC series motor:

(i) Torque Armature Current Characteristics:

In a DC series motor, the armature winding and field winding are connected in series. Therefore, the flux per pole is not constant but it varies with the armature current.

We know that,

$$T_a \propto \phi I_a$$

But, $\phi \propto I_a$

$$\therefore T_a \propto I_a^2$$

Hence, $T_a - I_a$ (Torque - Armature current) characteristic of DC series motor is parabolic as shown in figure below.

After saturation the flux per pole is almost independent of I_a and hence $T_a \propto I_a$ only. Therefore, the characteristic becomes a straight line after saturation.

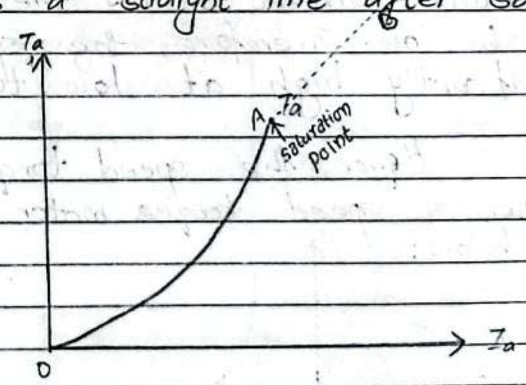


fig: $T_a - I_a$ characteristic

(ii) Speed Torque characteristics :

We know that :

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

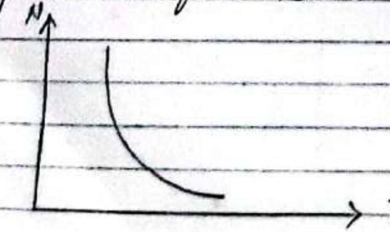
And, $E_b = V_s - I_a R_a$

and, $T_a \propto \phi I_a$

At Heavy load (ie at high T_a), the armature current is high. Therefore, the back emf E_b will reduce to allow high armature current. But flux per pole (ϕ) is proportional to series I_a in series motor. Hence, the speed will be significantly low at high torque.

At no load (ie at low T_a), the armature current is low. Therefore, the back emf E_b will be comparatively high to allow low armature current. Since the armature current is low the flux per pole will be low. Therefore, the speed will be significantly high at low torque.

Hence, the speed torque characteristic of series ~~speed torque~~ motor will be shown as below :



"From this characteristics it is clear that at the starting where the speed is very low, DC series motor develops a high torque. ~~on~~ On the other hand at no load the speed will be very high. Hence a DC series motor should not be started at no load otherwise it may develop excess speed and mechanical failure may occur due to heavy centrifugal force."

Difference between Generator & Motor:

Generator	Motor
(1) It converts mechanical energy into electrical energy.	(1) It converts electrical energy into mechanical energy.
(2) It generates an emf or voltage when conductor (or moving coils) are moved in a magnetic field.	(2) It develops a twisting effort or torque when a current is passed across the moving coil held in a magnetic field.
(3) It is generally employed to get a variable dc voltage.	(3) It is usually employed at a place where wide range of speed control is required.

Armature Reaction:

The interaction between the fluxes produced by the field windings and by the current carrying armature windings is known as armature reaction.

It is a term used to describe the effect of armature, magnetomotive force (mmf) on the operation of dc machine. It affects both the flux distribution and flux magnitude in the machine.

In generator, the effect of armature reaction is to twist or distort the flux in the direction of rotation, whereas in the case of motors it shifts the magnetic neutral plane backwards opposing the direction of rotation.

$$\eta = \frac{\text{Output power}}{\text{input Power}}$$

$$= \frac{\text{Output power}}{\text{output power + Copper loss + iron loss}}$$

E_1 / E_2 *

A 20 KVA, 2200/220 V, 50 Hz
O.C Test: 220V, 4.2A, 148W
S.C Test: 10.5A, 86V, 360W

(a) Regulation at 0.8 pf lagging

+ for lag
− for lead

$$\text{Voltage Regulation / Regulation} = \frac{I_{sc}R_{sc}\cos\theta \pm I_{sc}X_{sc}\sin\theta}{E_2}$$

$\because I_{sc} = 10.5\,A$, $\boxed{E_2 = 220}$ *

$$R_{sc} = \frac{W_{sc}}{I_{sc}^2} = \frac{360}{10.5^2} =$$

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} = \frac{86}{10.5} =$$

$$X_{sc} = \sqrt{Z_{02}^2 - R_{02}^2} = \sqrt{}$$

$$=$$

$$\therefore V.R = \frac{10.5 \times R_{sc} \times 0.8 + 10.5 \times X_{sc} \times \sin(\cos^{-1}(0.8))}{220}$$

$$=$$

(iii) $$\text{Efficiency} = \frac{x \times \boxed{KVA \times 10^3} \times \text{Power factor}}{x \times KVA \times 10^3 + x^2 P_c + P_i}$$ *

$$\text{or } \eta = \frac{x \times \boxed{V_2 I_2} \cos\theta}{x \times V_2 I_2 \cos\theta + x^2 P_c + P_i}$$

For Full load $x = 1$
" half load $x = \frac{1}{2}$

$P_c \rightarrow$ Copper loss = Short Circuit Power = 360 W
$P_i \rightarrow$ iron loss = Open Circuit Power = 148 W

(1) BCA
- Digital logic system. — 1st sem →GRAINC. (1)
- Microprocessor — 3rd sem → Er. Ashok. (2)
-

(2) BE (Computer)
- BEE — 1st sem — Er. Ganesh. (1)
- N/W theory. — 3rd sem — " " (2)
- Material — " → Er. Ashok (3)
- logic circuit — " → " " (5)
- Electronics Device Fed. — " (4)

5th sem — RAM Sir.

:- MSI

7th. sem. → Er. (5)

- DSP

(3) BE Civil — 1st sem. — Er. Ganesh (4)
- BEE

Transformer	Induction Machine
(1) It is stationary	(1) It is moving equipment.
(2) Primary and secondary frequencies are same.	(2) Primary and secondary frequencies are different
(3) It does not have any air gap between primary & secondary.	(3) There is air gap between rotor and stator.
(4) Magnetic flux is not rotating.	(4) Rotating magnetic flux (ϕ) is induced.
(5) Energy received is electrical energy.	(5) Energy received is mechanical energy.

PAGE
DATE

Imp # Active Elements:
Active elements are those which have their own energy and they transfer energy to the passive elements.

Eg: Voltage, current.

Imp # Passive Elements:
Passive elements are those which donot have their own energy and they receive energy from active elements.

Eg: Resistor, capacitor.