ELECTRICAL MACHINES I (EE401)

Online Courseware (OCW)

B.TECH (2^{nd} YEAR – 4^{th} SEM)

(2020-21)

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Department of Electrical Engineering

Guru Nanak Institute of Technology

(Affiliated to MAKUT, West Bengal , Approved by AICTE - Accredited by NAAC – ‘A+’ Grade)

157/F Nilgunj road, Panihati, Kolkata-700114, West Bengal

Course Code: EE 401
Contact:3L:0T:0P
Total Contact Hours: 36
Credit: 3

Prerequisites: Knowledge of Physics up to B. Tech. 1st year Physics-I course.

Course Outcome:

CO1. Describe the concept of magnetic circuits.

CO2. Demonstrate the operation of different types of dc machines and its applications.

CO3. Understand the equivalent circuit of Transformers, D.C. Machines, and Three-Phase Induction Motor.

CO4. Analyse the connections of transformers and its operations.

Course Content

MODULE – I: General Introduction to Electrical Machines (3L)

Faraday's laws of electromagnetic induction, Fleming's rule and Lenz's Law. 1L
Concept of Electrical and Mechanical degree. 2L

MODULE – II: D.C. Machine (9L)

EMF generation in armature, Characteristics of D.C. Machines. 1L
Methods of building up of e.m.f., Significance of Critical resistance and Critical speed. 1L
Armature reaction and its effect, Function of Interpole and Compensating winding. 2L
Commutation method, Concept of reactance voltage. 1L
Power flow diagram, Losses and efficiency, Solution of problems. 1L
Testing of D.C. machines – Hopkinson's, Swinburne's test, Brake test (Tests specified as per standards). 1L
Starting and Speed Control of D.C. Motors. 2L

MODULE – III: Single-Phase Transformers (5L)

Core construction and different parts of transformer and their function, Materials used for core, winding and insulation, Transformer oil, Different types of cooling methods (in brief), Name plate rating. 1L
Equivalent circuit and per unit representation and its importance, Regulation, Efficiency and All day efficiency, Solution of problems. 2L
Single-phase Auto transformer – Comparison of weight, copper loss with 2-winding transformer. 1L
Sumpner Test, Applications of 2-winding transformer and Auto transformer. 1L

MODULE – IV: Three-Phase Transformers (9L)

Types of three-phase transformer. Construction and Different types of windings. 1L
Polarity of transformer, Vector groups for various connections. 1L
Parallel operation and load sharing, Solution of problems. 2L
Effect of unbalanced loading and neutral shifting, Tertiary windings. 1L
Scott-connected transformer and open-delta connection – working principle, connection diagram,

practical application. 1L

Tap-changing methods, Tap changers – Off load and On-load type. 1L

Special Transformer: Pulse transformer, Grounding transformer. 1L

Testing of Three-phase Transformers. 1L

MODULE – V: Three-Phase Induction Motor (10L)

Induction motor as a transformer, Concept of rotating magnetic field, Power stages in 3-phase induction motor and their relation, power-slip characteristics. 3L

Determination of equivalent circuit parameters, Separation of losses, Efficiency, Solution of problems. 2L

Concept of Deep bar and Double cage rotor. 1L

Starting and speed control of three phase induction motor. 1L

Space harmonics: Crawling and Cogging, Brief idea of braking of induction motor. 2L

Testing and Industrial applications of 3-phase induction motor. 1L

Text Books:

1. Electrical Machinery, P.S. Bhimra, 6th Edition, Khanna Publishers.
2. Electric machines, D.P. Kothari & I.J Nagrath, 3rd Edition, Tata Mc Graw-Hill Publishing Company Limited.
3. Electrical Machines, P.K. Mukherjee & S. Chakrabarty, Dhanpat Rai Publication.

Reference Books:

1. Electric Machinery & Transformers, Bhag S. Guru and H.R. Hiziroglu, 3rd Edition, Oxford University press.
2. Electrical Machines, R.K. Srivastava, Cengage Learning
3. Theory of Alternating Current Machinery, Alexander S Langsdorf, Tata Mc Graw Hill Edition.
4. The performance and Design of Alternating Current Machines, M.G.Say, CBS Publishers & Distributors.
5. Electric Machinery & transformer, Irving L Koskow, 2nd Edition, Prentice Hall India.

CO-PO-PSO Mapping:

	POs												PSO		
CO	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
CO1	3	2	-	-	-	1	-	-	-	1	-	3	2	2	1
CO2	3	3	2	1	1	-	-	-	-	1	1	3	1	3	1
CO3	3	2	3	3	1	1	-	-	1	1	-	3	2	3	1
CO4	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg	**3**	**2**	**2.5**	**2**	**1**	**1**	**-**	**-**	**1**	**1**	**1**	**3**	**1.6**	**2.6**	**1**

Topic:

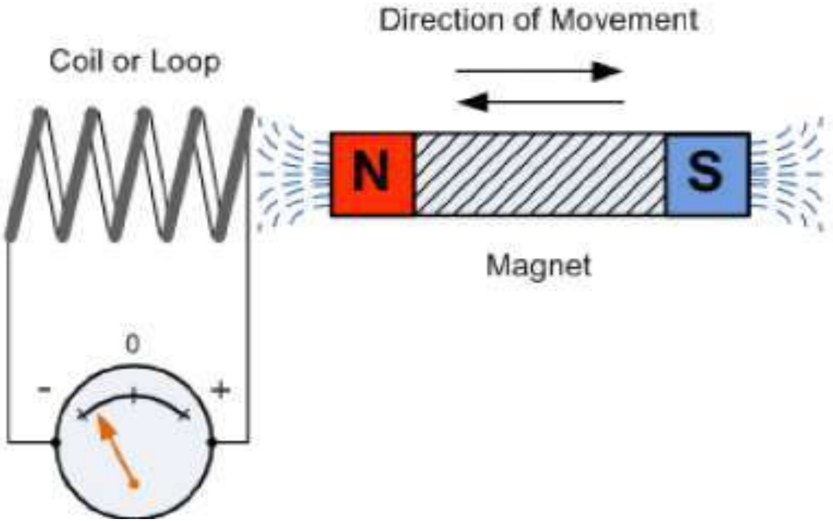
- **FARADAY’S LAWS OF ELECTROMAGNETIC INDUCTION**

- **LENZ'S LAW**

GENERAL INTRODUCTION OF ROTATING MACHINE

Faraday's Laws of Electromagnetic Induction

Faraday's law of electromagnetic induction (referred to as Faraday's law) is a basic law of electromagnetism predicting how a magnetic field will interact with an electric circuit to produce an electromotive force (EMF). This phenomenon is known as electromagnetic induction.

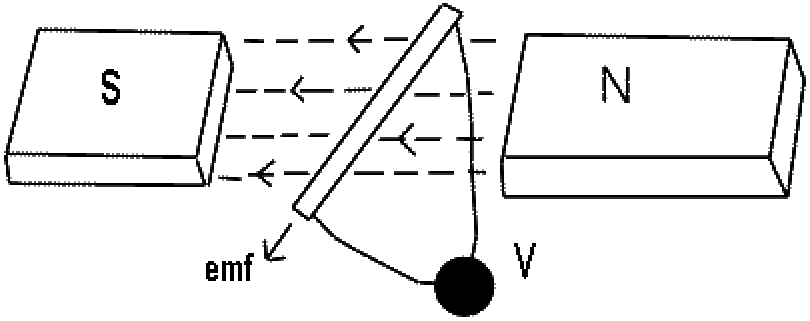


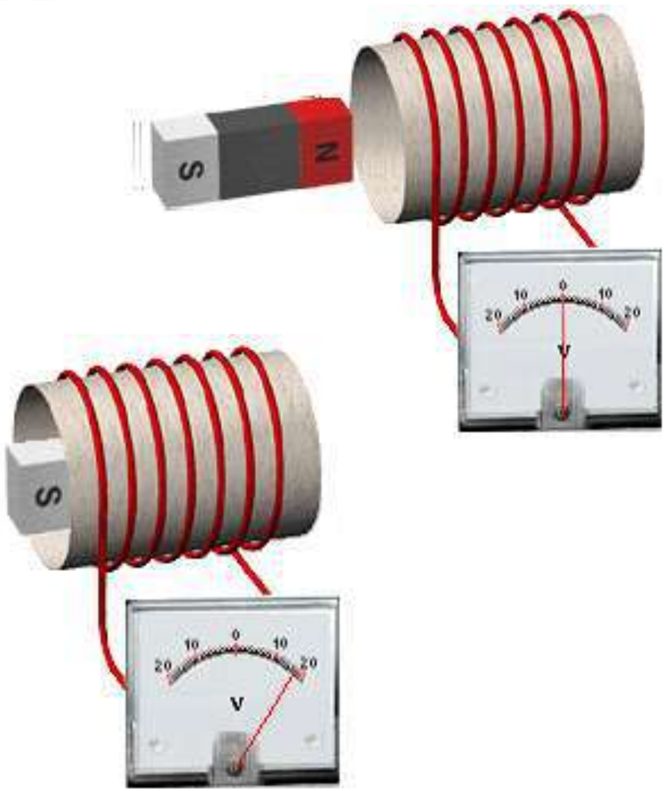
Faraday's law states that a current will be induced in a conductor which is exposed to a changing magnetic field. Lenz's law of electromagnetic induction states that the direction of this induced current will be such that the magnetic field created by the induced current ***opposes*** the initial changing magnetic field which produced it. The direction of this current flow can be determined using Fleming's right-hand rule.

GENERAL INTRODUCTION OF ROTATING MACHINE

Faraday’s Laws of Electromagnetic Induction

Faraday’s law of induction explains the working principle of transformers, motors, generators, and inductors. The law is named after Michael Faraday, who performed an experiment with a magnet and a coil. During Faraday’s experiment, he discovered how EMF is induced in a coil when the flux passing through the coil changes.





GENERAL INTRODUCTION OF ROTATING MACHINE

Faraday's Laws of Electromagnetic Induction

Faraday's law of electromagnetic induction, also known as Faraday's law is the basic law of electromagnetism which helps us to predict how a magnetic field would interact with an electric circuit to produce an electromotive force (EMF). This phenomenon is known as electromagnetic induction.

The law was proposed in the year 1831 by an experimental physicist and chemist named Michael Faraday. So you can see where the name of the law comes from. That being said, the Faraday's law or the law of electromagnetic induction is basically the results or the observations of the experiments that Faraday conducted. He performed three main experiments to discover the phenomenon of electromagnetic induction.

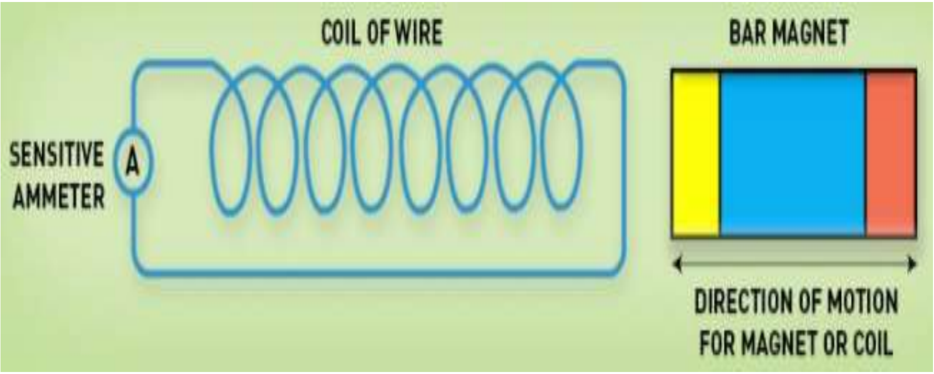
GENERAL INTRODUCTION OF ROTATING MACHINE

Faraday's Laws of Electromagnetic Induction

Faraday's Laws of Electromagnetic Induction consists of two laws. The first law describes the induction of emf in a conductor and the second law quantifies the emf produced in the conductor.

Faraday's First Law of Electromagnetic Induction

The discovery and understanding of electromagnetic induction are based on a long series of experiments carried out by Faraday and Henry. From the experimental observations, Faraday arrived at a conclusion that an emf is induced in the coil when the magnetic flux across the coil changes with time. With this in mind, Faraday formulated his first law of electromagnetic induction as,



Whenever a conductor is placed in a varying magnetic field, an electromotive force is induced. If the conductor circuit is closed, a current is induced which is called induced current.

GENERAL INTRODUCTION OF ROTATING MACHINE

Faraday's Laws of Electromagnetic Induction

Faraday's Second Law of Electromagnetic Induction

Faraday's second law of electromagnetic induction states that

The induced emf in a coil is equal to the rate of change of flux linkage.

The flux is the product of the number of turns in the coil and the flux associated with the coil. The formula of Faraday's law is given below:

$$\varepsilon = -N \frac{\Delta \phi}{\Delta t}$$

Where,
ε is the electromotive force
Φ is the magnetic flux
N is the number of turns

The negative sign indicates that the direction of the induced emf and change in the direction of magnetic fields have opposite signs.

GENERAL INTRODUCTION OF ROTATING MACHINE

Faraday's Laws of Electromagnetic Induction

Faraday's Law Formula

Consider a magnet approaching towards a coil.
Consider two-time instances T_1 and T_2.

Flux linkage with the coil at the time T_1 is given by
$\mathbf{T_1 = N\Phi_1}$

Flux linkage with the coil at the time T_2 is given by
$\mathbf{T_1 = N\Phi_2}$

Change in the flux linkage is given by
$\mathbf{N(\Phi_2 - \Phi_1)}$

Let us consider this change in flux linkage as
$\mathbf{\Phi = \Phi_2 - \Phi_1}$

Hence, the change in flux linkage is given by
$\mathbf{N\Phi}$

The rate of change of flux linkage is given by
$\mathbf{N\Phi/t}$
Taking the derivative of the above equation, we get
$\mathbf{N\, d\Phi/dt}$

According to Faraday's second law of electromagnetic induction, we know that the induced emf in a coil is equal to the rate of change of flux linkage. Therefore,

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

Considering Lenz's law,

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

GENERAL INTRODUCTION OF ROTATING MACHINE

Faraday's Laws of Electromagnetic Induction

Faraday's Experiment: Relationship Between Induced EMF and Flux

In the first experiment, he proved that when the strength of the magnetic field is varied, only then-current is induced. An ammeter was connected to a loop of wire; the ammeter deflected when a magnet was moved towards the wire.

In the second experiment, he proved that passing a current through an iron rod would make it electromagnetic. He observed that when a relative motion exists between the magnet and the coil, an electromotive force will be induced. When the magnet was rotated about its axis, no electromotive force was observed, but when the magnet was rotated about its own axis then the induced electromotive force was produced. Thus, there was no deflection in the ammeter when the magnet was held stationary.

While conducting the third experiment, he recorded that Galvanometer did not show any deflection and no induced current was produced in the coil when the coil was moved in a stationary magnetic field. The ammeter deflected in the opposite direction when the magnet was moved away from the loop.

GENERAL INTRODUCTION OF ROTATING MACHINE

Faraday's Laws of Electromagnetic Induction

Following are the fields where Faraday's law find applications:

1. Electrical equipment like transformers works on the basis of Faraday's law.

2. Induction cooker works on the basis of mutual induction which is the principle of Faraday's law.

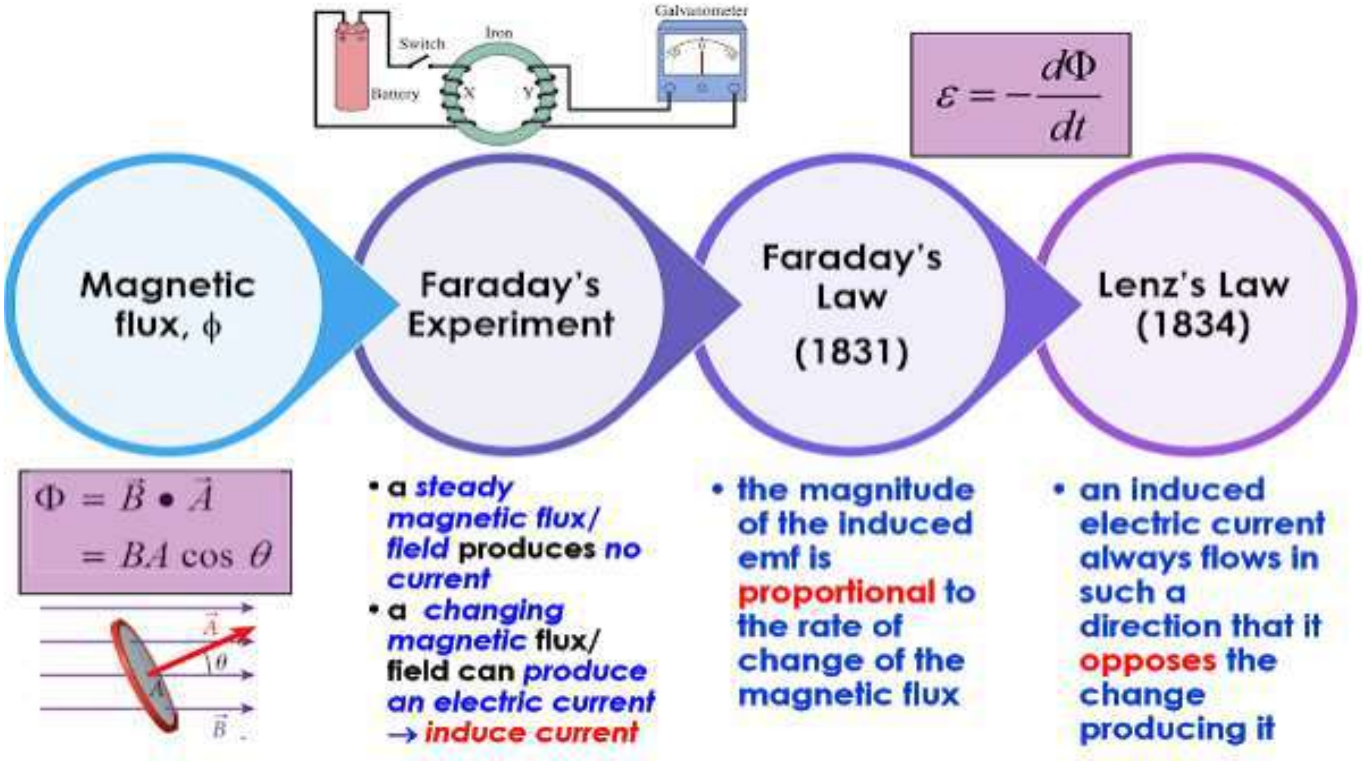
3. By inducing an electromotive force into an electromagnetic flow meter, the velocity of the fluids is recorded.

4. Electric guitar and electric violin are the musical instruments that find an application of Faraday's law.

5. Maxwell's equation is based on the converse of Faraday's laws which states that change in the magnetic field brings a change in the electric field.

GENERAL INTRODUCTION OF ROTATING MACHINE

ELECTROMAGNETIC INDUCTION 3/ FARADAY'S LAW & LENZ'S LAW



Topic:

- **ELECTROMECHANICAL ENERGY CONVERSION**

- **FLEMING'S RIGHT & LEFT HAND RULE**

GENERAL INTRODUCTION OF ROTATING MACHINE

ELECTROMECHANICAL ENERGY CONVERSION

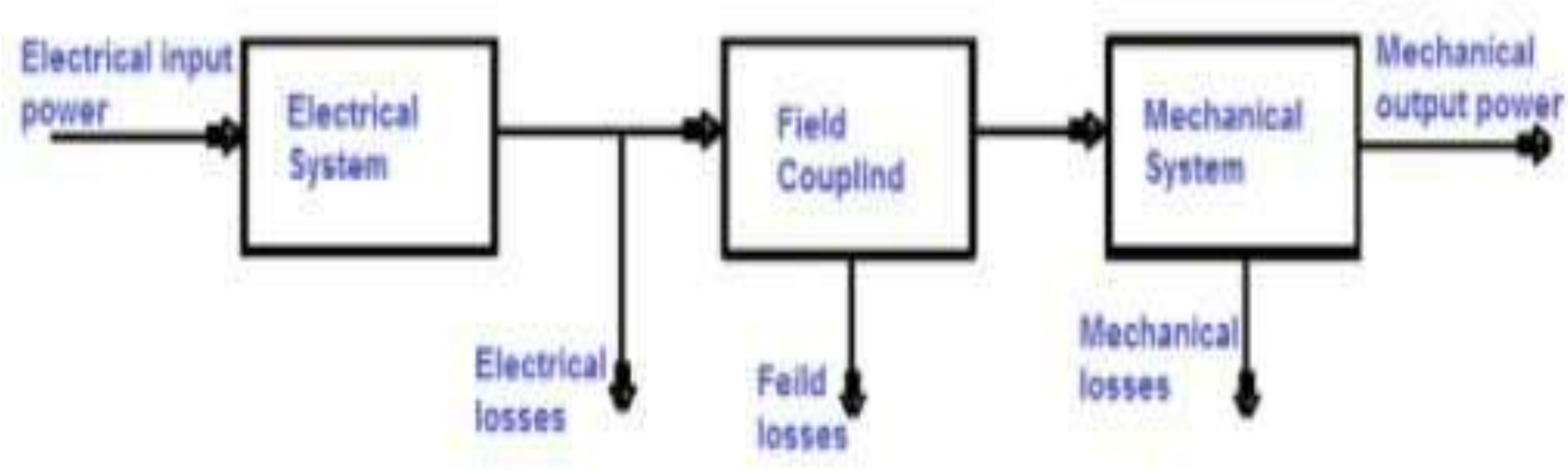
Electromechanical energy conversion is one device which is convert energy one form to another form. electromechanical device converts electrical energy into mechanical energy and vice versa. Energy conversation take place through the medium of electric field or magnetic field.

Electromechanical energy conversion devices with magnetic field as the coupling medium between electrical and mechanical systems are more common in commercial application. the energy storing capacity of the magnetic field is much greater about 25,000 greater than the electric field.

electromechanical energy conversion is a reversible process except for the losses in the system. Here we use word reversible that means the energy can be transfer back and forward between mechanical and electrical system. during the process of energy conversion, some of the energy is converted into heat and it lost from the system.

GENERAL INTRODUCTION OF ROTATING MACHINE

ELECTROMECHANICAL ENERGY CONVERSION



GENERAL INTRODUCTION OF ROTATING MACHINE

ELECTROMECHANICAL ENERGY CONVERSION

Electromechanical energy conversion devices may categorized in Various parts as under:-
The first category of devices, involving small motion, processes only low-energy signals from electrical to mechanical or vice versa. These are microphones, gramophone pick-ups, loud speakers and low-signal transducers.

The second category consists of force or torque-producing devices with limited mechanical motion. These are electromagnets , relays, moving-iron instruments etc.

The third category includes continuous energy conversion devices like motors and generators these are used for bulk energy conversion and utilization.

GENERAL INTRODUCTION OF ROTATING MACHINE

ELECTROMECHANICAL ENERGY CONVERSION

Principal of energy conversion

Its state that the energy cannot be created or destroyed. it can only be converted from one form to the another form of energy.

If we consider electric Generator then its convert mechanical energy into electrical energy
If we consider electric Motor then its convert electrical energy into mechanical energy.
Electromechanical energy conversion system has basically divided in three parts,

1. Mechanical system
2. Field coupling system
3. Electrical system

GENERAL INTRODUCTION OF ROTATING MACHINE

ELECTROMECHANICAL ENERGY CONVERSION

Principal of energy conversion

Principal of energy conversion is based on below equations.

Energy transfer equation for generator action can be written as,

Mechanical energy input = electrical energy output + losses in field + total energy losses

Energy transfer equation for motoring action can be written as,

Electrical energy input = mechanical energy output + stored energy by filed + total energy losses

During the energy conversation there are occur some **Losses**, which are following as,

Core losses or iron losses

Electrical losses or copper losses

Mechanical losses

This all losses are called energy losses

GENERAL INTRODUCTION OF ROTATING MACHINE

ELECTROMECHANICAL ENERGY CONVERSION

Principal of energy conversion

Energy losses equation can be written as,

Electrical energy input – copper loss = (mechanical energy output + mechanical losses) + (core losses + energy stored in core)

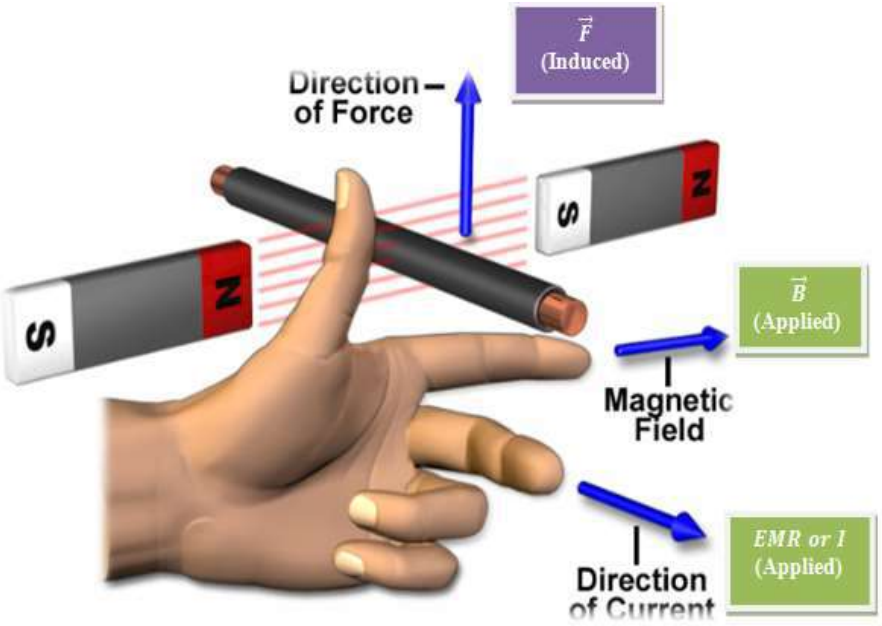
Wie – Wle = (Wom + Wlm) + (Wfd + Wlf)

Where, Wie = input electrical energy
Wle=copper losse
Wom = output mechanical energy
Wlm = mechanical losses
Wfd = stored energy by core
Wlf = core losses.

GENERAL INTRODUCTION OF ROTATING MACHINE

ELECTROMECHANICAL ENERGY CONVERSION

FLEMING'S LEFT HAND RULE



Relate the thumb with thrust, fore finger with field and center-finger with current as explained below.

1. The *Thumb* represents the direction of *Thrust* on the conductor (force on the conductor).

2. The *Fore finger* represents the direction of the *magnetic* ***Field***.

3. The *Center finger* (middle finger) the direction of the *Current*.

GENERAL INTRODUCTION OF ROTATING MACHINE

ELECTROMECHANICAL ENERGY CONVERSION

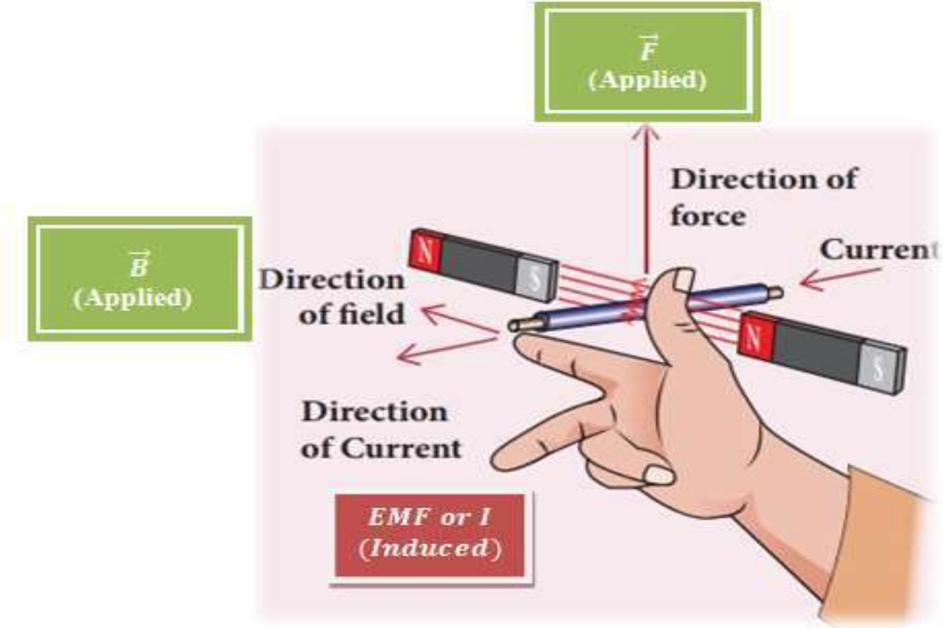
FLEMING'S RIGHT HAND RULE

The thumb, fore finger and middle finger of the right hand are stretched to be perpendicular to each other

1. The *thumb* represents the direction of the movement of conductor

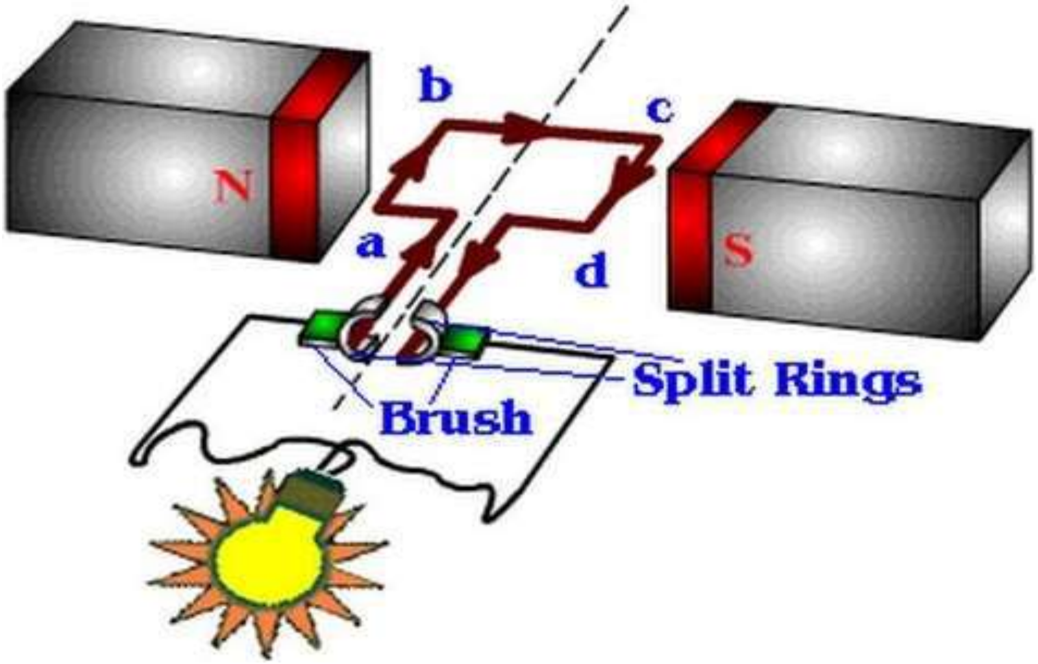
2. The *fore-finger* represents direction of the magnetic field.

3. The *middle finger* represents direction of the induced current.



Module:2

DC GENERATOR



Topic:

- **CONCEPT OF DC MACHINE**
- **APPLICATION OF DC MACHINE**
  - **DC GENERATOR**
  - **DC MOTOR**
- **TYPES OF DC MACHINE**
- **BASIC CONSTRUCTION OF DC MACHINE**
- **NAME PLATE DETAILS OF DC MACHINE**

DC MACHINES

- A DC machine is an electromechanical energy alteration device.

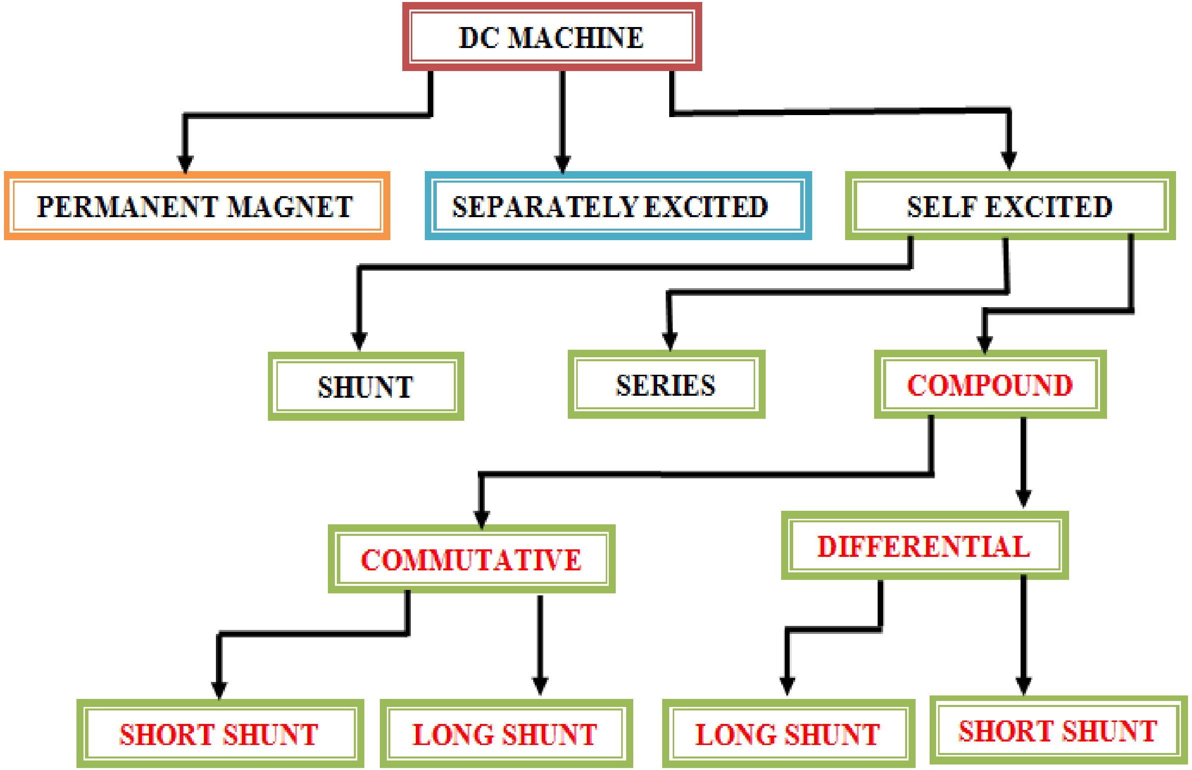
- The DC machines are classified into two types such as DC generator as well as DC motor.

- The main function of the DC generator is to convert mechanical power to DC electrical power, whereas a DC motor converts DC power to mechanical power.

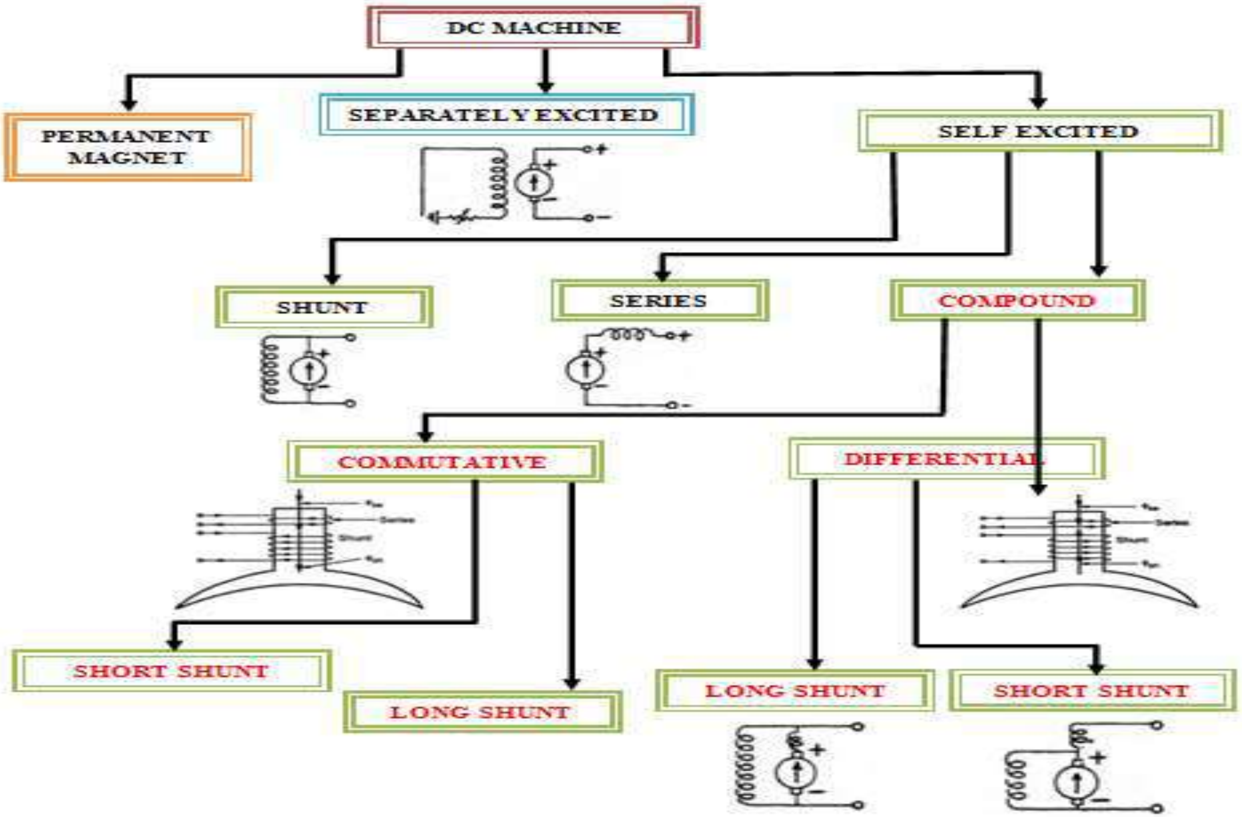
- When a conductor moves in a magnetic field it cuts magnetic lines of force, which induces an electromagnetic force (EMF) in the conductor. The magnitude of this induced EMF depends upon the rate of change of flux (magnetic line force) linkage with the conductor. This EMF will cause a current to flow if the conductor circuit is closed.

- The working principle of a DC machine is when electric current flows through a coil within a magnetic field, and then the magnetic force generates a torque which rotates the dc motor.

TYPES OF DC MACHINES



TYPES OF DC MACHINES



APPLICATIONS DC MACHINES

DC MOTOR

SERIES MOTORS

The series DC motors are used where high starting torque is required, and variations in speed are possible. For example – the series motors are used in **Traction system, Cranes, air compressors, Vacuum Cleaner, Sewing machine**, etc.

SHUNT MOTORS

The shunt motors are used where constant speed is required and starting conditions are not severe. The various applications of DC shunt motor are in **Lathe Machines, Centrifugal Pumps, Fans, Blowers, Conveyors, Lifts, Weaving Machine, Spinning machines**, etc.

COMPOUND MOTORS

The compound motors are used where higher starting torque and fairly constant speed is required. The examples of usage of compound motors are in **Presses, Shears, Conveyors, Elevators, Rolling Mills, Heavy Planners**, etc.

The small DC machines whose ratings are in fractional kilowatt are mainly used as control device such in Techno generators for speed sensing and in Servo motors for positioning and tracking.

APPLICATIONS DC MACHINES

DC GENERATOR

SEPARATELY EXCITED DC GENERATORS

Separately excited DC Generators are used in **laboratories** for testing as they have a wide range of voltage output.
Used as a supply source of DC motors.

SHUNT WOUND GENERATORS

DC shunt wound generators are used for **lighting purposes**.
Used to **charge the battery**.
Providing **excitation to the alternators.**

SERIES WOUND GENERATORS

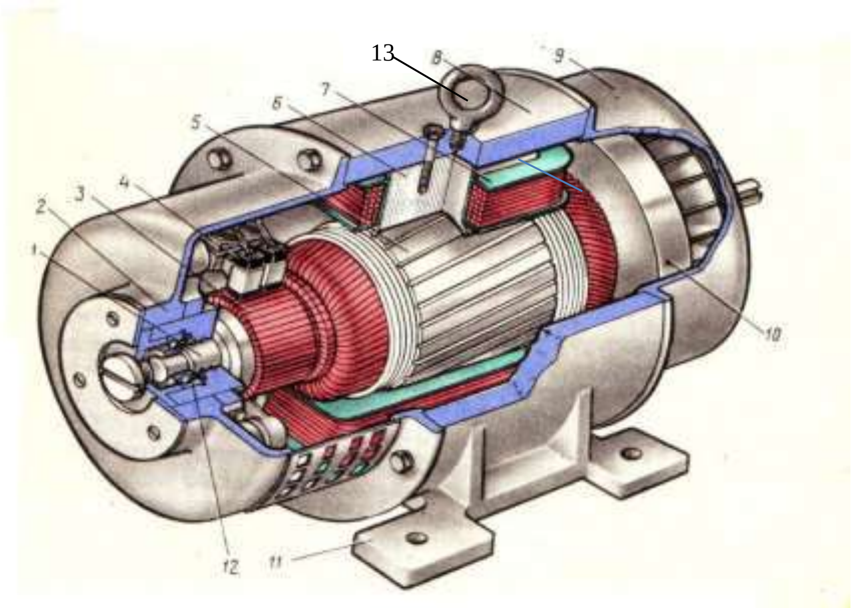
DC series wound generators are used in DC locomotives for regenerative braking for providing field excitation current.
Used as a booster in distribution networks.

COMPOUND GENERATORS

Over compounded cumulative generators are used in lighting and heavy power supply.
Flat compounded generators are used in offices, hotels, homes, schools, etc.
Deferentially compounded generators are mainly used for arc welding purpose.

CONSTUCTIONAL PART OF DC MACHINES

NUMBER	SPECIFICATION
1	Shaft
2	End-bearings
3	Commutator
4	Brushes
5	Armature
6	Main-pole
7	Main-pole field winding
8	Frame
9	End-shield
10	Ventilator
11	Basement
12	Bearings
13	Eye Bolt



DC MACHINE NAME PLATE DETAILS

S1 duty means we can run the motor for 365 days X 24 hours

Maker Name		
M/C No. Machine Model Number	REF: Manufacture Reference Purpose	KW/HP: Maximum Power
FRAME: ASHC 132L	RPM: Rated Speed	INS CL: Insulation Class
EXTN. Excitation System	ARM V: Armature Voltage	DUTN: Operating Hours (S1)
TYPE: Field Coil Position	ARM A: Armature Current	MTG: Mounting of the motor (B3)
BRG.CE: Commutator end	FIELD V: Field Voltage	AMB: Ambient temperature
BRG.NCE	FIELD A: Field Current	Wt.
PROTN: IP55	COOLING: IC 0041	G D^2
	DC MOTOR	CROMPTON GREAVES Ltd. Made in India

132L means the height of the motor from footer to shaft center is 132 mm and L means the core size is length

European Conformity

Protection from dirt, dust, oil, and other non-corrosive material

The fan cooled motor

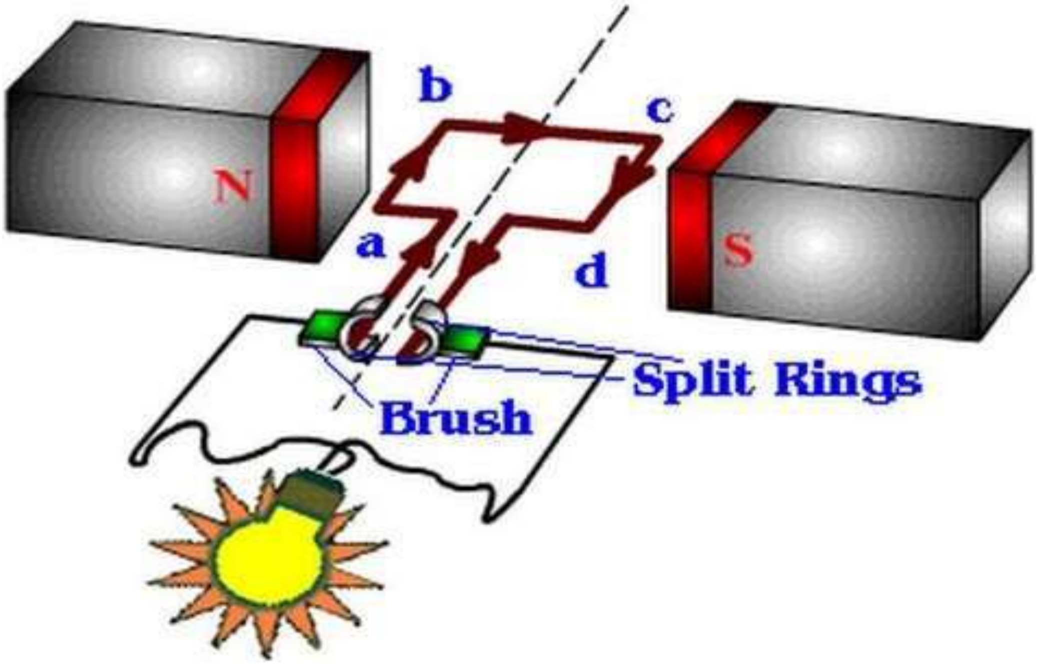
MACHINE CERTIFICATION & MARK

COMMON CERTIFICATION NAME	MARK
Canadian Standards Association (CSA)	
European Conformity	
CSA Gas Appliance Certification	
EPA Energy Star	
Factory Mutual (FM)	
Federal Communications Commission (FCC)	
Intertek Equipment Testing Laboratory (ETL)	
Standards Council of Canada Lab test Certification	
Underwriters Laboratory (UL)	
Underwriters Laboratory Recognized Component Mark	


Thank you

Module:2

DC GENERATOR



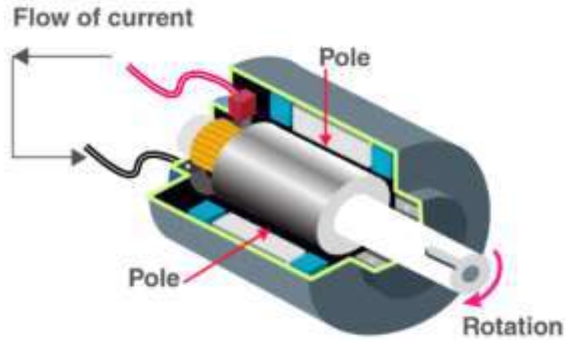
Topic:

- **Concept of DC Generator**
- **Function of Different component parts of DC Generator**
- **Working Principle of DC generator**

DC GENERATOR

Electrical generators are standalone machines that provide electricity when power from the local grid is unavailable. These generators supply backup power to businesses and homes during power outages. Generators do not create electrical energy but they convert mechanical or chemical energy into electrical energy. Based on the output, generators are classified into two types as AC generators and DC generators.

A DC generator is an electrical machine whose main function is to convert mechanical energy into dc electricity. When conductor slashes magnetic flux, an emf will be generated based on the electromagnetic induction principle of Faraday’s Laws. This electromotive force can cause a flow of current when the conductor circuit is closed.

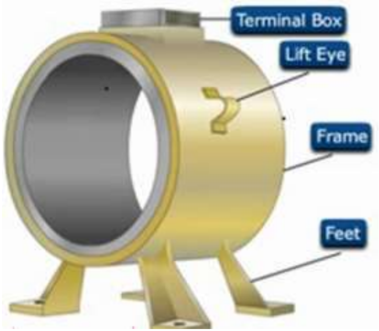


FUNCTION OF PARTS OF DC GENERATOR

DC generator consists of the following main parts:

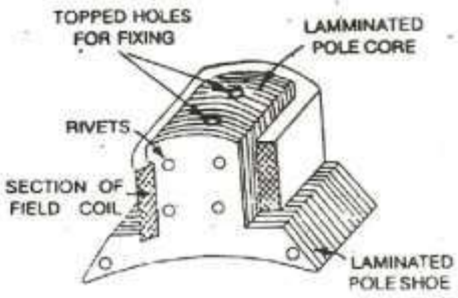
1. Yoke/Main Cover

Yoke is the main cover of the DC Generator made up of iron or any other material. It provides a mechanical support for the poles. It acts as a protecting cover for the whole machine. It also carries the magnetic flux produced by the poles. These yokes are made up of cast iron and for large machines cast steel or rolled steel is used.



2. Pole Cores

Pole Cores are used as field magnets. These are used to spread out the flux in the air gap and it is also used to support the exciting coils. Pole cores are the solid piece and are made up of cast iron or cast steel. In modern age pole cores are made up of thin laminations of enameled steel. The thickness of lamination is from 1 milli meter to 0.25 milli meter. The laminated poles are more secured than the solid piece pole cores.



FUNCTION OF PARTS OF DC GENERATOR

3. Field Coils

Field coils are the coils of a conductor wounded across the pole core. When current is passed through these coils the poles reacts as an electromagnet and magnetic flux is produced in it.

4. Armature Core

Armature core is cylindrical or drum shaped and is built up of circular steel sheets or laminations. It is set to the shaft. The slots are punched on its outer side. In small machines or motors the armature slots are set directly to the shaft. These laminations are used for the cooling purposes for the armature and to reduce the eddy current losses and voltage drops. The circular stampings or slots are cut out in one piece.

FUNCTION OF PARTS OF DC GENERATOR

5. Armature Winding

The armature windings are in a wound form. These windings are insulated from each other and normally copper winding are generally used in it. These conductors or winding is placed in the armature slots which are lined with insulation.

6. Commutator

The commutator provides a collection of currents from the armature winding or conductors. It converts the alternating current which is induced in the armature conductors into direct current (DC). It is a cylindrical shaped and have wedge shaped segments. These segments are insulated from each other. The number of segments are equal to the number of armature coils. Each segment is connected to the armature conductor through riser or strip. These segments have V-grooves to prevent from centrifugal forces.

FUNCTION OF PARTS OF DC GENERATOR

7. Brush Gear

Brush gears holds heavy carbon brushes and are used to transfer huge amount of excitation current from it to the terminal junction. Normally these are used in Highly Rated DC Generators. The brush gear is used to change its position according to the requirement either you want small output current or either you want maximum current and the most important use case of the brush gear is to adjust the carbon brushes in different direction to get maximum DC output from the DC Generator.

8. Terminals

Installed in the main cover or yoke of the DC Generator to connect directly to the load connection.

9. Suppressor Box

A **Suppressor box** is used to reduce the irrelevant and unwanted noise of a high KV rated DC Generators.

10. Terminal Cover

Terminal cover is a cap which protects the joints of the DC generator terminals and the load terminals and this cover is also used for safety measures to prevent from electric shock and fire.

FUNCTION OF PARTS OF DC GENERATOR

11. Carbon Brushes and Bearings

In DC generator, Carbon brushes are used to collect current from the commutator and then provide it to its main contacts. These brushes are commonly made up of carbon and graphite. These brushes are rectangular shaped. These brushes are mounted on the brush holders and the brush holder is mounted on a spindle. These brushes remain joined with the commutator by a spring. A flexible copper pigtail is mounted on the top of the carbon brushes which convey current from the brushes to the holder.

Bearings are used to rotate shaft very easily. Usually ball bearings are frequently used in heavy machines due to its flexibility. Ball bearings work very efficiently in heavy machines.

FUNCTION OF PARTS OF DC GENERATOR

12. Bearing Support Head

Bearing support head looks like the shape of bearing and it holds the bearing in its case to provide support and alignment and it is fixed to straight the bearing and it provides the complete support in a required direction to provide uninterruptible function.

13. Shaft

A **Shaft** of a DC Generator is a mechanical component. It consists of a mild steel and it provides torque and rotation. It is prototype and long and it is used for coupling in DC Generator to provide mechanical energy.

14. Shaft Spline

Shaft spline is a small component installed on a shaft sometime it is fixed on a shaft and sometimes it comes in variable form. A shaft spline consists of teeth and in a circular form and is used for coupling/joining the other shaft to it for mechanical input for DC Generator.

FUNCTION OF PARTS OF DC GENERATOR

15. Clamps

Clamps are used to hold the load wires tightly and make the load terminals safe and clean.

16. Window Strap

Window strap is basically a net made up of iron and it is connected to the yoke and it is used to provide air gap to the DC Generator for the purpose of cooling and it provides a better temperature for cooling.

17. Retaining Cap

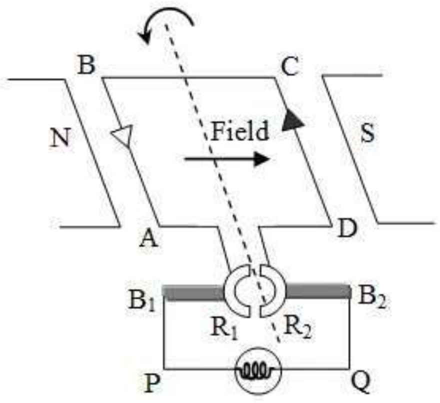
Retaining cap are made up of alloy of a non-magnetic steel and is tighten on the shaft to provide support to the shaft against centrifugal **forces** during rotation.

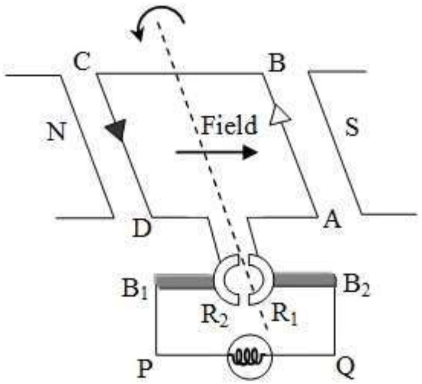
18. End Cover

End cover is a part of yoke and it covers from the end of DC Generator with the help of bolts and it is used to protect the generator from its end.

WORKING PRINCIPLE OF DC GENERATOR

DC Generator working principle based on Faraday's law of electromagnetic induction, we know that when a current-carrying conductor is placed in a varying magnetic field, an emf is induced in the conductor. According to Fleming's right-hand rule, the direction of the induced current changes whenever the direction of motion of the conductor changes. Let us consider an armature rotating clockwise and a conductor at the left moving upwards. When the armature completes a half rotation, the direction of motion of the conductor will be reversed downward. Hence, the direction of the current in every armature will be alternating. But with a split ring commutator, connections of the armature conductors get reversed when a current reversal occurs. Therefore, we get unidirectional current at the terminals.



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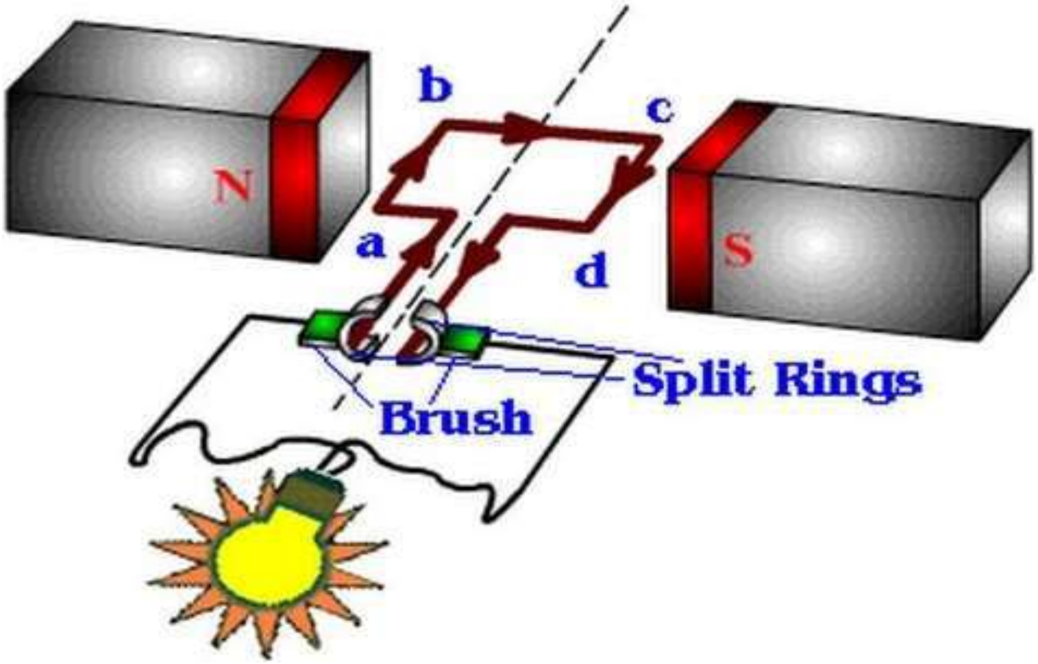
Module:2

DC GENERATOR



Topic:

- **FLEMING’S RIGHT HAND & LEFT HAND RULE**
- **E.M.F EQUATION OF D.C MACHINE**
- **PROBLEM SOLVING**

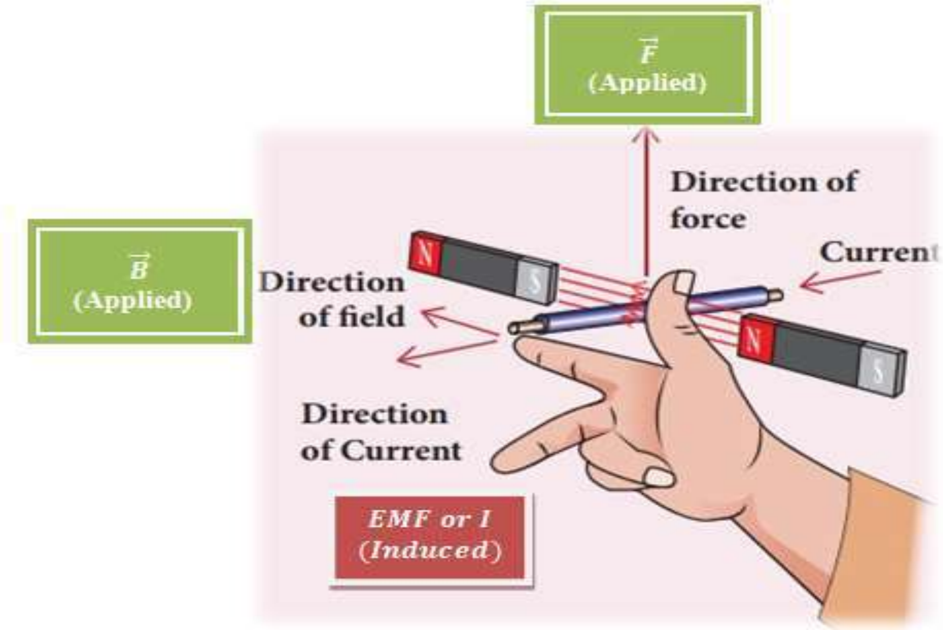
FLEMING’S RIGHT HAND RULE

The thumb, fore finger and middle finger of the right hand are stretched to be perpendicular to each other

1. The *thumb* represents the direction of the movement of conductor

2. The *fore-finger* represents direction of the magnetic field.

3. The *middle finger* represents direction of the induced current.



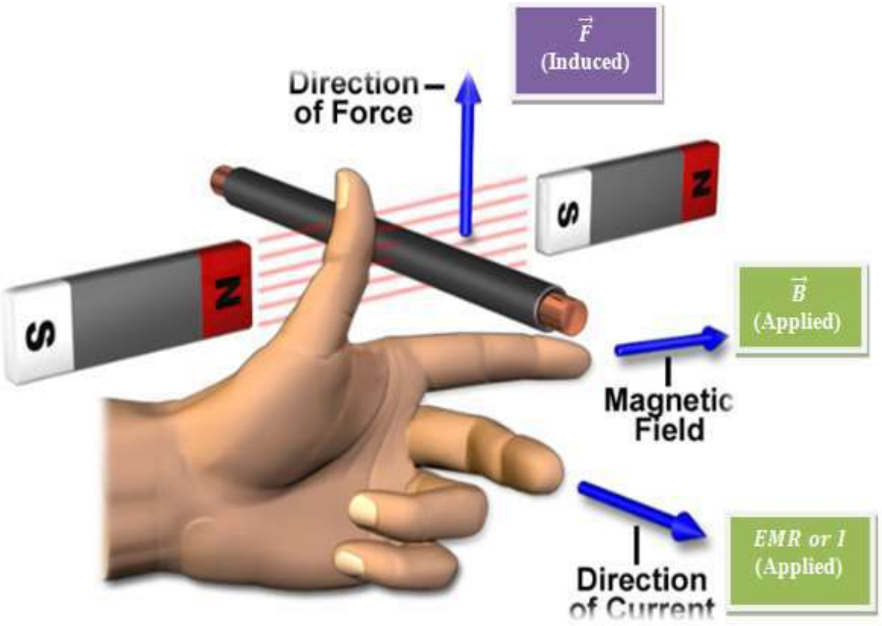
FLEMING'S LEFT HAND RULE

Relate the thumb with thrust, fore finger with field and center-finger with current as explained below.

1. The *Thumb* represents the direction of *Thrust* on the conductor (force on the conductor).

2. The *Fore finger* represents the direction of the *magnetic Field*.

3. The *Center finger* (middle finger) the direction of the *Current*.



DIFFERENCE BETWEEN FLEMING'S LEFT-HAND AND RIGHT-HAND RULE

SL.NO.	LEFT-HAND RULE	RIGHT-HAND RULE
1	It was invented by John Ambrose Fleming	It was invented by John Ambrose Fleming
2	It is used for electric motors	It is used for electric generators
3	The purpose of the rule is to find the direction of motion in an electric motor	The purpose of the rule is to find the direction of induced current when a conductor moves in a magnetic field.
4	The thumb represents the direction of the thrust on the conductor	The thumb represents the direction of motion of the conductor.
5	The index finger represents the direction of the Magnetic Field	The index finger represents the direction of the Magnetic Field
6	The middle finger represents the direction of the current	The middle finger represents the direction of the induced current

E.M.F EQUATION OF DC MACHINES

As the armature rotates, a voltage is generated in its coils. In the case of a generator, the emf of rotation is called the **Generated emf** or **Armature emf** and is denoted as Eg. In the case of a motor, the emf of rotation is known as **Back emf** or **Counter emf** and represented as Eb. The expression for emf is same for both the operations. I.e., for Generator as well as for Motor.

The derivation of **EMF equation for DC generator** has two parts:

1. Induced EMF of one conductor
2. Induced EMF of the generator

E.M.F EQUATION OF DC MACHINES

Let,
P – Number of poles of the machine
ϕ – Flux per pole in Weber.
Z – Total number of armature conductors.
N – Speed of armature in revolution per minute (r.p.m).
A – Number of parallel paths in the armature winding.
In one revolution of the armature, the flux cut by one conductor is given as

Total flux produced by all the poles $= \phi \times P$

Time taken to complete one revolution $= \dfrac{60}{N}$

Now, according to Faraday's law of induction, the induced emf of the armature conductor is denoted by "e" which is equal to rate of cutting the flux.

$$e = \frac{d\phi}{dt} \quad and \; e = \frac{total\ flux}{time\ take}$$

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

Z/A = number of conductors connected in series

E = emf of one conductor × number of conductor connected in series.

Induced emf of DC generator is $e = \phi P \dfrac{N}{60} X \dfrac{Z}{A}\ volts$

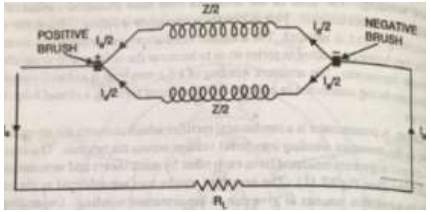
For a **wave wound machine A = 2**
E = ΦZNP/120 Volt

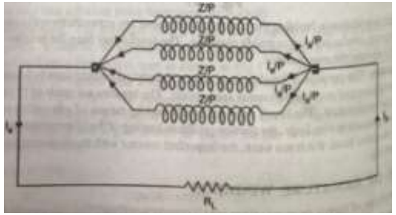
Lap wound machine A =P
E = ΦZN/60 Volt

E.M.F EQUATION OF DC MACHINES

Problem Solving

Problem-01: A 4 pole, lap wound, d.c. generator has a useful flux of 0.07 Wb per pole. Calculate the generated emf. when it is rotated at a speed of 900 r.p.m. with the help of prime mover. Armature consists of 440 number of conductors. Also calculate the generated emf. if lap wound armature is replaced by wave wound armature.





Induced emf of DC generator is

$$e = \phi P \frac{N}{60} X \frac{Z}{A} \, volts$$

Solution :

Given that,

P = 4

Z = 440

Φ = 0.07 Wb

and N = 900 r.p.m.

Lap wound machine A =P=4

$$E = \frac{\phi N Z}{60} = \frac{0.07 \times 900 \times 440}{60} = 462 \text{ V}$$

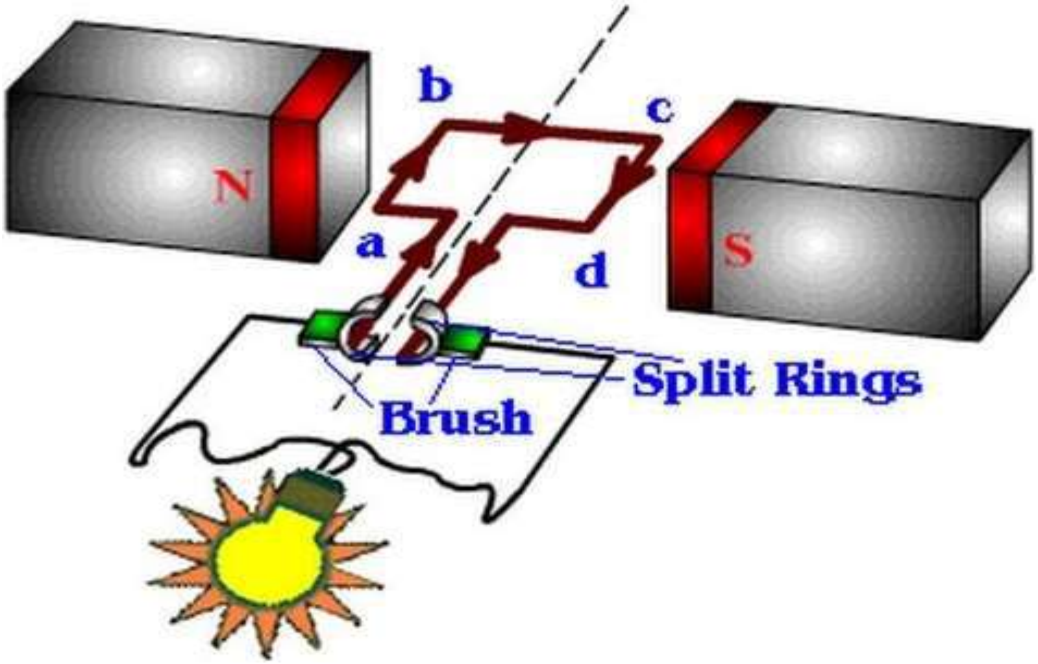
For a **wave wound machine A = 2**

$$E = \frac{\phi P N Z}{120} = \frac{0.07 \times 900 \times 4 \times 440}{120} = 924 \text{ V}$$


Thank you

Module:2

DC GENERATOR



Topic:

- **Concept of Residual Magnetism**
- **Voltage Buildup Process**
- **Conditions For Voltage Buildup**
- **How to Restore the Residual Magnetism**
- **Concept of Critical Field Resistance and Critical Speed**

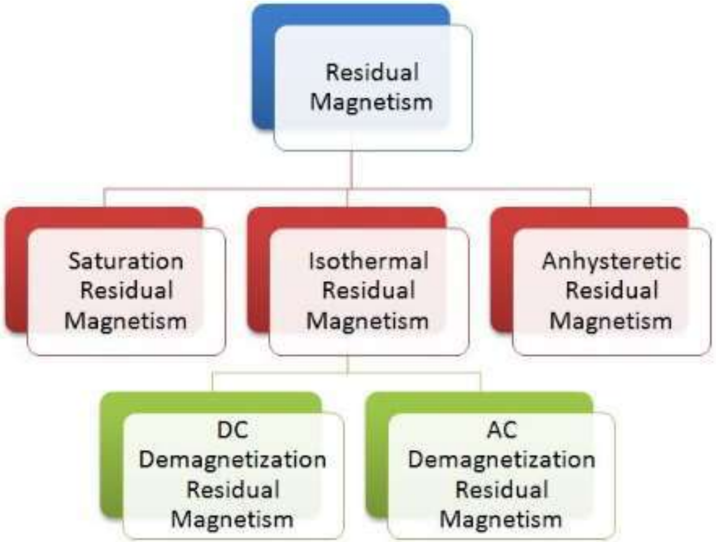
CONCEPT OF RESIDUAL MAGNETISM

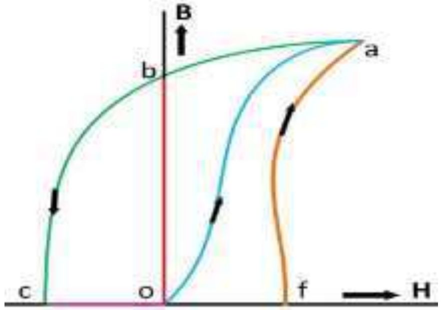
The amount of magnetization left behind after removing the external magnetic field from the circuit.

The value of the flux density retained by the magnetic material is called Residual Magnetism and the power of retaining this magnetism is called Retentivity of the material.

Magnetization occurs by applying the current in one direction, and the flux density is increased until the saturation point is reached.

This phenomenon of the residual magnetism is widely seen in the transformers, generators, and motors. It is also called as Remanence.





REDUCTION OF RESIDUAL MAGNETISM

Residual Magnetism can be reduced by the following methods

1. It can be reduced by 45-50 % by the use of hot-rolled steel material.

2. The saturation level of the magnetic material can be decreased by providing higher exciting current.

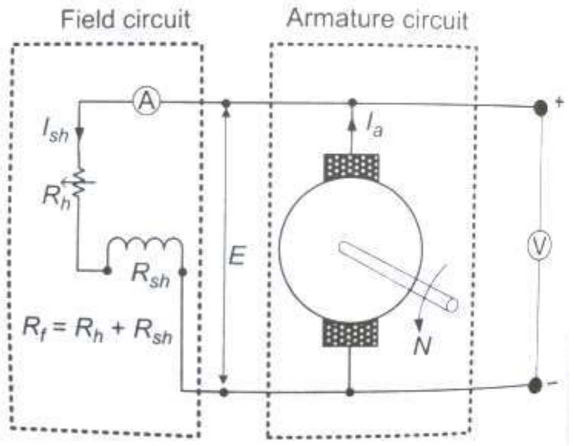
3. The magnetization process should be started with constant force and gradually increasing until the saturation is achieved and then reducing it slowly to demagnetize it further.

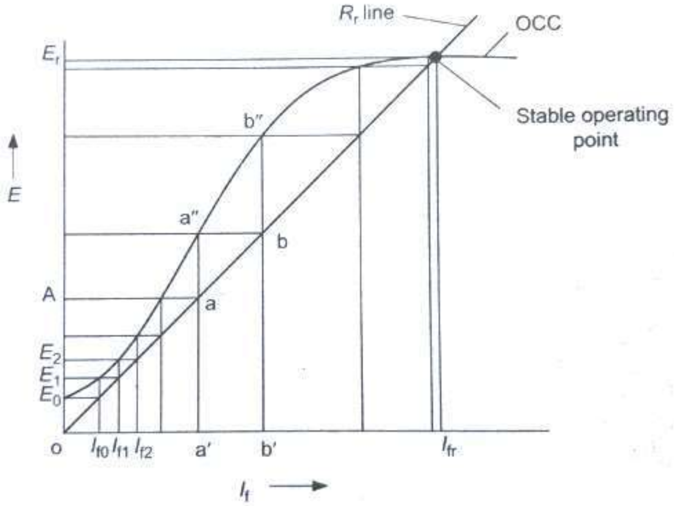
4. In the process of magnetization and demagnetization of magnetic material the electric force, or the applied current should almost be similar.

VOLTAGE BUILD UP PROCESS

Building up is the process by which the output voltage or induced EMF of a self excited
DC shunt generator gradually builds up from the initial starting point to its final steady value. For building up of voltage in a self excited shunt generator, there must be residual magnetism. If the field circuit is closed after the generator speed is brought up to its desired value, then a small voltage would appear across the generator armature terminals. This small induced EMF, which is proportional to the product of speed and residual flux present, is approximately 2 to 3 percent of the rated voltage. This small voltage appearing across the armature terminals will make a small current to start flowing through the shunt field circuit connected across the armature.

The field circuit should be so connected that the MMF due to this initial current strengthens the residual flux. The resultant flux in the field is thus increased, leading to an increase in the EMF induced in the armature. This in turn, will cause further increase in the shunt field current and this process goes on I cycles until the final steady value of EMF is induced in the armature.





ESSENTIAL CONDITIONS OF THE VOLTAGE BUILD UP

1. Poles should contain some residual flux.

2. Field and armature winding must be correctly connected so that initial mmf adds residual flux.

3. Open circuit its shunt field resistance should be less then the critical resistance.

4. If excited on load circuits its shunt field resistance should more then a certain minimum value of resistive which is given by internal

5. Speed of prime mover of generator must be above critical speed.

6. Generator must be on load.

7. Brushes must have proper contact with commutator.

FACTORS AFFECTING VOLTAGE BUILDING OF A DC GENERATOR

There are some factors which affect the voltage building of a self-excited d.c. generator. These factors are:

(*i*) reversed shunt field connection

(*ii*) reversed rotation and

(*iii*) reversed residual magnetism.

RESTORE PROCESS OF RESIDUAL MAGNETISM

Residual magnetism in the generator exciter field allows the generator to build up voltage during start-up. This magnetism is sometimes lost due to shelf time or improper operation, among other reasons. Restoring this residual magnetism is possible and is sometimes referred to as "flashing the exciter field".

To restore the small amount of residual magnetism necessary to begin voltage buildup, connect a 12 volt battery to the exciter field while the generator is at rest, as follows:

1. Remove exciter field leads F+ and F- from the voltage regulator. Failure to remove the field leads from the regulator during flashing procedures may destroy the regulator.

2. Measure the exciter field resistance from the F+ to the F- lead. You should be able to read some resistance as you are measuring a continuous winding. An infinite resistance reading would indicate an open in the exciter field. Also check to be sure there is no path to ground.

3. Connect F+ to the positive pole of the battery.

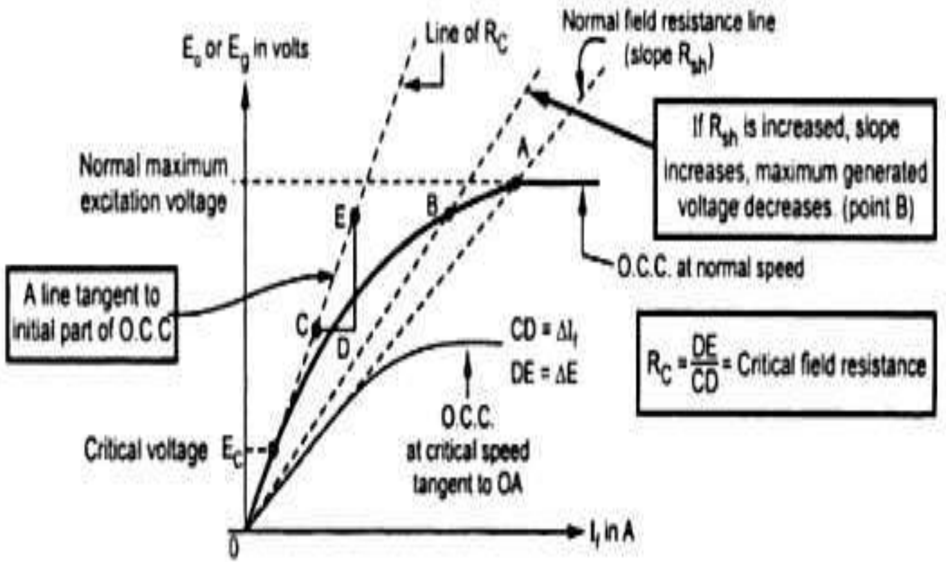
4. Hold the F- lead by the insulated portion of the lead wire, touch F- to the negative pole of the battery for about 5 to 10 seconds, then remove.

5. Reconnect F+ and F- to the regulator. Repeat the procedure if the generator fails to build voltage.

CRITICAL FIELD RESISTANCE

Critical resistance as that resistance of the field circuit at a given speed at which generator just excites and starts voltage building while beyond this value generator fails to excite.

A decrease in the resistance of the field circuit reduces the slope of the field resistance line result in higher voltage. If the speed remain constant , an increase in the resistance of field circuit increases the slop of field resistance line, resulting in a lower voltage. If the field circuit resistance is increased to Rc which is terminal as the critical resistance of the field, the field resistance line becomes a tangent to the initial part of the magnetization curve. when the field resistance is higher than this value, the generator fail to excite.



CRITICAL SPEED

As speed changes, the open circuit characteristics also changes, similarly for different shunt field resistances, the corresponding lines are also different.

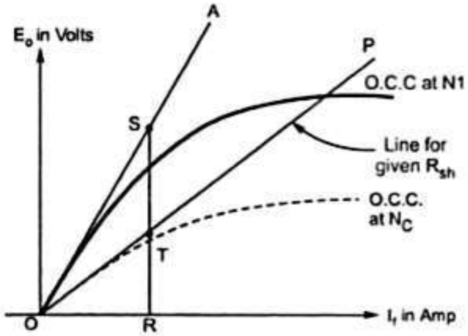
The speed for which the given field resistance acts as critical resistance is called the critical speed, denoted as N_C.

Graphically critical speed can be obtained for given R_{sh}. The steps are,

1. Drawn O.C.C. for given speed N_1.
2. Draw a line tangential to this O.C.C. say OA.
3. Draw a line representing the given R_{sh} say OP.
4. Select any field current say point R.
5. Draw vertical line from R to intersect OA at S and OP at T.
6. Then the critical speed N_C is,

$$\frac{RT}{RS} = \frac{N_C}{N_1}$$

$$N_C = N_1 \frac{RT}{RS}$$

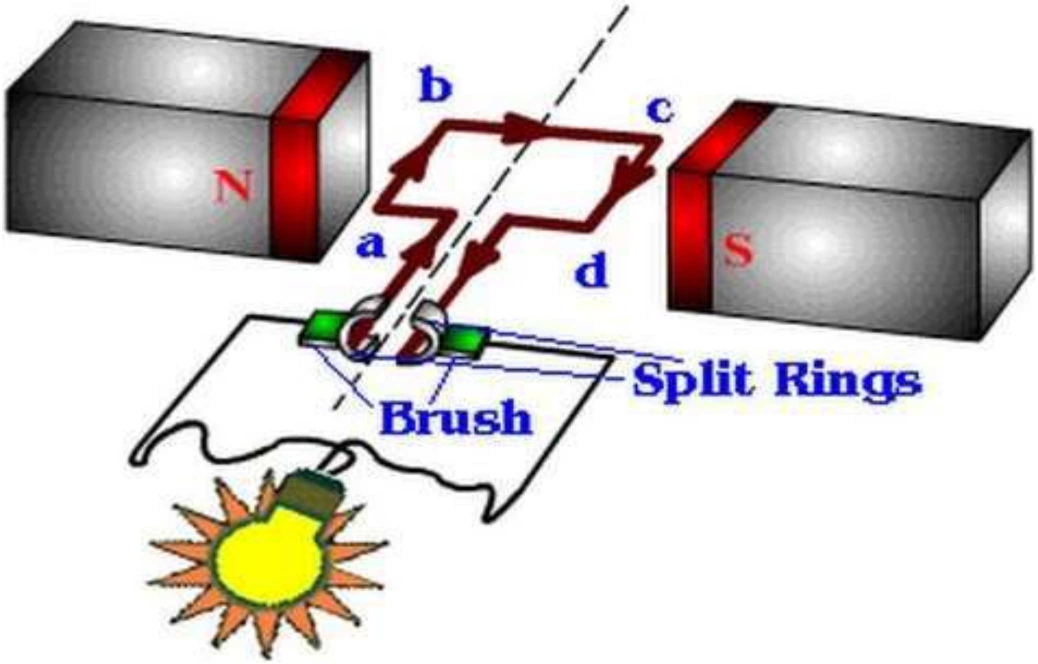


$$N_C = N_1 \times \frac{RT}{RS}$$


Thank you

Module:2

DC GENERATOR



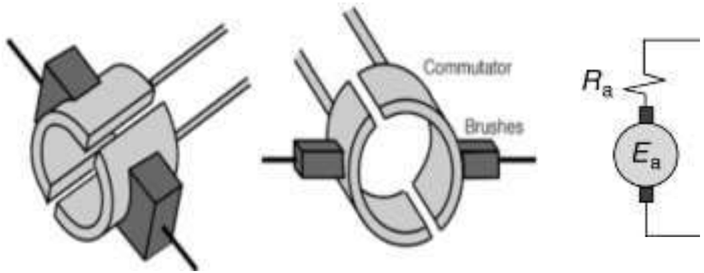
Topic:

- Types of D.C Generators
- Problem Solving

ARMATURE RESISTANCE

The resistance offered by the armature circuit is known as armature resistance. R_a

The armature resistance consists of
1. Resistance of armature winding
2. Resistance of brushes



1. Armature Winding Resistance

Armature Winding resistance is the ohmic resistance of the copper winding wires.

2. Resistance of Brushes

A brush is used to provide electrical contact between the stationary contacts and moving parts like commutator or slip rings. Brushes are mainly made of carbon material which is high resistance brushes compared to copper brushes.

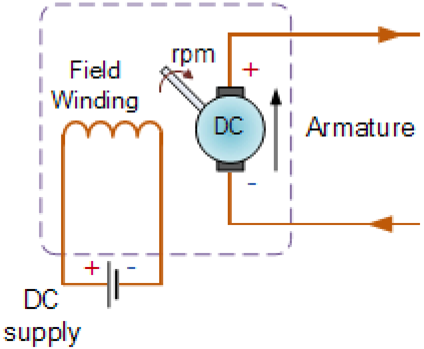
The armature resistance depends upon the construction of the machine. Except for small machines, its value is generally less than 1 ohm.

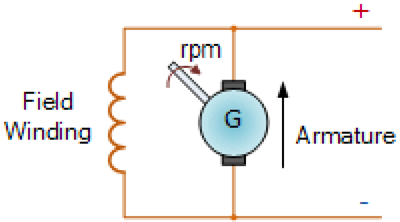
TYPES OF DC GENERATOR

The magnetic field in a d.c generator is normally produced by electromagnets rather than permanent magnets. Generators are generally classified according to their methods of field excitation. On this basis d.c generators are divided into the following two classes:

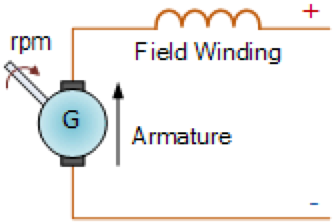
1. Separately excited d.c Generators
2. Self-excited d.c Generators

The behavior of a d.c generator on load depends upon the method of field excitation adopted.



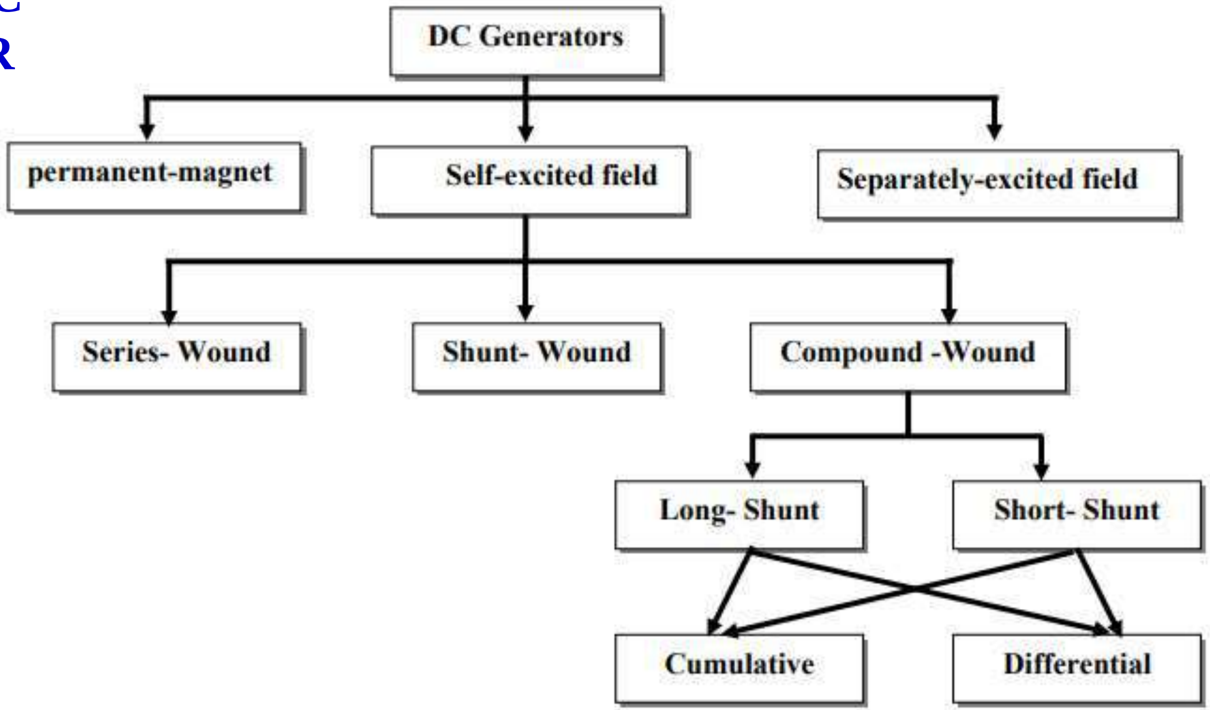


Shunt Wound Self-excited
DC Generator



Series Wound Self-excited
DC Generator

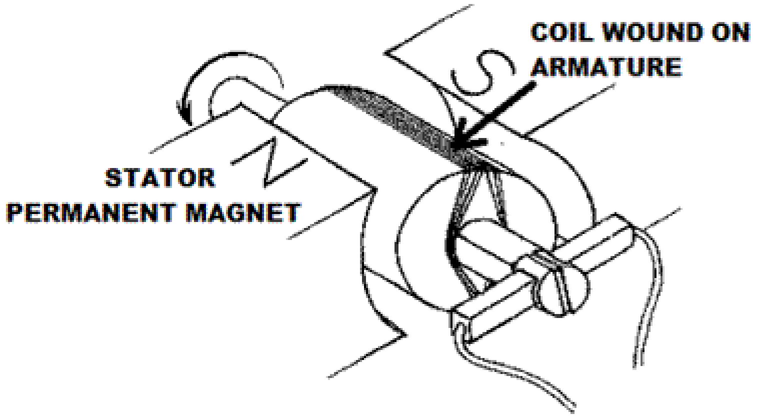
TYPES OF DC GENERATOR



TYPES OF DC GENERATOR

Permanent Magnet DC Generator

When the flux in the magnetic circuit is created through the use of permanent magnets, then it is known as a Permanent magnet DC generator.
It consists of an armature and one or several permanent magnets situated around the armature. This type of DC generator generates does not generate much power.



As such they are rarely found in industrial applications. They are normally used in small applications – like dynamos in motorcycles.

TYPES OF DC GENERATOR

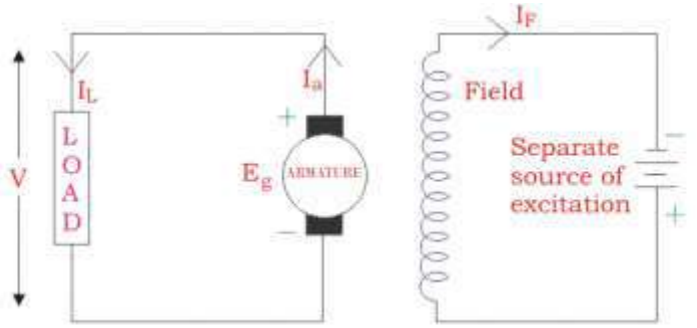
Separately Excited DC Generator

These are the generators whose field magnets are energized by some external DC source, such as a battery.

The voltage output depends upon the speed of rotation of armature and the field current. The greater the speed and field current, greater is the generated emf

$$e = \phi P \frac{N}{60} X \frac{Z}{A} \; volts$$

I_a = Armature current
I_L = Load current
V = Terminal voltage
E_g = Generated EMF



$$Armature\ Current\ I_a = I_L$$

$$Terminal\ Voltage\ V = E_g - I_a R_a$$

$$Electric\ Power\ Developed = E_g I_a$$

$$Power\ Delivered\ to\ Load = E_g I_a - I_a^2 R_a = I_a(E_g - I_a R_a) = V I_a$$

TYPES OF DC GENERATOR

Self-excited DC generators are generators whose field magnets are energized by the current supplied by themselves. In these type of machines, field coils are internally connected with the armature.

Due to residual magnetism, some flux is always present in the poles. When the armature is rotated, some EMF is induced. Hence some induced current is produced. This small current flows through the field coil as well as the load and thereby strengthening the pole flux.

As the pole flux strengthened, it will produce more armature EMF, which cause the further increase of current through the field. This increased field current further raises armature EMF, and this cumulative phenomenon continues until the excitation reaches the rated value.

According to the position of the field coils self-excited DC generators may be classified as:

1. Shunt Wound Generators
2. Series Wound Generators
3. Compound Wound Generators

TYPES OF DC GENERATOR

Shunt Wound Generators

In these type of DC generators, the field windings are connected in parallel with armature conductors.

R_{sh} = Shunt winding resistance

I_{sh} = Current flowing through the shunt field

R_a = Armature resistance

I_a = Armature current

I_L = Load current

V = Terminal voltage

E_g = Generated EMF

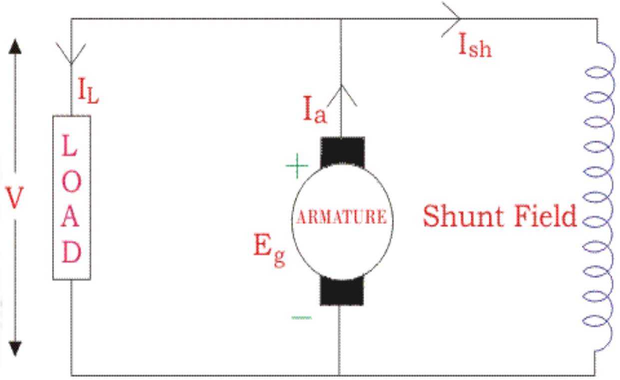
Shunt field current, $I_{sh} = V/R_{sh}$

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 $= V I_L$



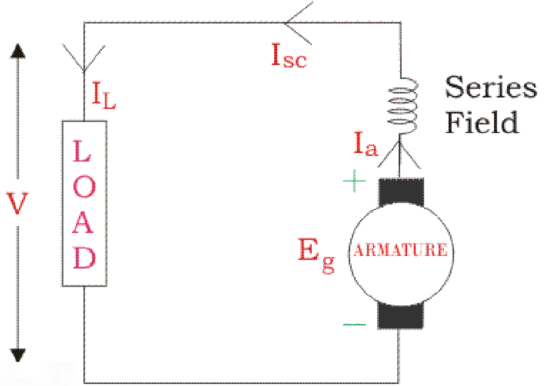
TYPES OF DC GENERATOR

Series Wound Generator

In these type of generators, the field windings are connected in series with armature conductors.

R_{sc} = Series winding resistance
I_{sc} = Current flowing through the series field
R_a = Armature resistance

I_a = Armature current
I_L = Load current
V = Terminal voltage
E_g = Generated EMF



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

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

$$\text{Power developed in armature} = E_g I_a$$

$$\text{Power delivered to load} = E_g I_a - I_a^2 (R_a + R_{se}) = I_a[E_g - I_a(R_a + R_{se})] = VI_a \text{ or } VI_L$$

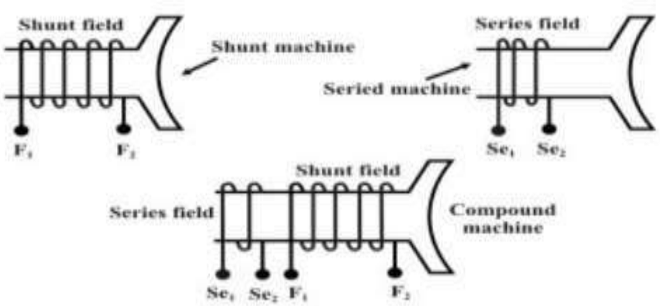
TYPES OF DC GENERATOR

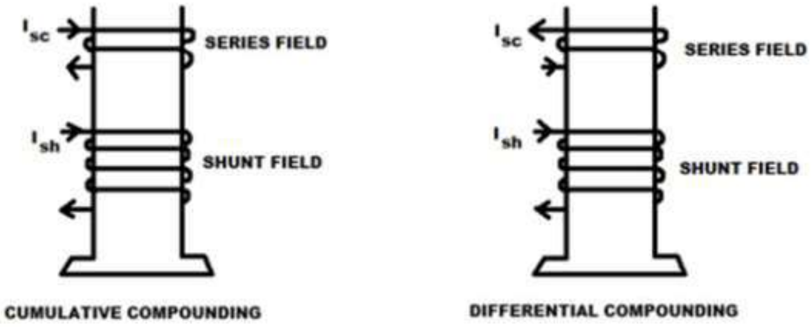
Compound Wound DC Generator

Compound wound generators have both series field winding and shunt field winding. One winding is placed in series with the armature, and the other is placed in parallel with the armature.

In a compound wound generator, the shunt field is stronger than the series field. When the series field assists the shunt field, generator is said to be **commutatively compound wound**.

On the other hand, if the series field opposes the shunt field, the generator is said to be **differentially compound wound**.





TYPES OF DC GENERATOR

Short Shunt Compound Wound DC Generator

Short Shunt Compound Wound DC Generators are generators where only the shunt field winding is in parallel with the armature winding

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

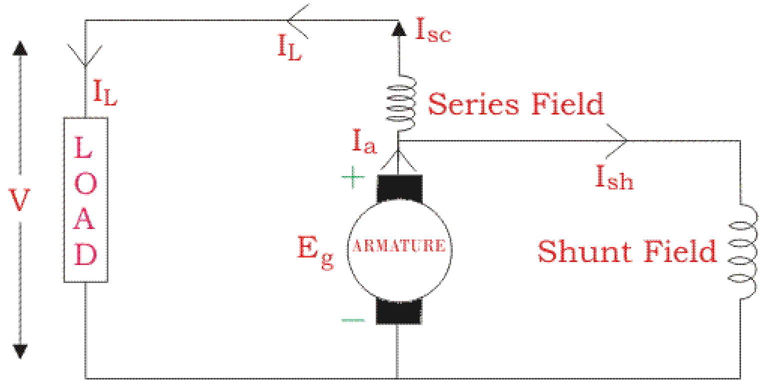
Series field current, $I_{se} = I_L$

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

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

Power developed in armature $= E_g I_a$

Power delivered to load $= V I_L$



TYPES OF DC GENERATOR

Long Shunt Compound Wound DC Generator

Long Shunt Compound Wound DC Generator are generators where the shunt field winding is in parallel with both series field and armature winding

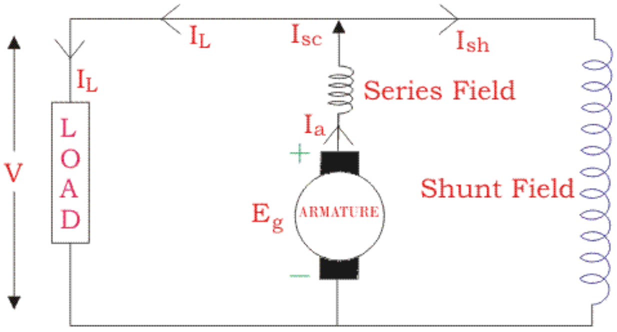
Series field current, $I_{se} = I_a = I_L + I_{sh}$

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

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

Power developed in armature $= E_g I_a$

Power delivered to load $= V I_L$



Problem 02: A four-pole generator, having lap-wound armature winding has 51 slot, each slot containing 20 conductors. What will be the voltage generated in the machine when driven at 1500 r.p.m assuming the flux per pole to be 7 mWb.?

Solution:

$$E_g = \frac{Zn\phi}{60}\left(\frac{P}{a}\right)$$

$$\phi = 7\times10^{-3}\,Wb\,,\; Z = 51\times20 = 1020$$

$$a = P = 4 \qquad \text{(lap-wound)}$$

$$E_g = \frac{7\times10^{-3}\times1020\times1500}{60}\left(\frac{4}{4}\right) = 178.5\ \text{V}$$

Problem 03: A shunt generator delivers 450A at 230 V and the resistance of the shunt field and armature are 50 Ω and 0.03 Ω respectively. Calculate the generated emf.

Solution:

Current through shunt field winding

$$I_f = \frac{230}{50} = 4.6\,\text{A}$$

∴ Armature current

$$I_a = I_L + I_f$$

$$= 450 + 4.6 = 454.6A$$

Armature voltage drop

$$I_a R_a = 454.6 \times 0.03 = 13.6\,\text{V}$$

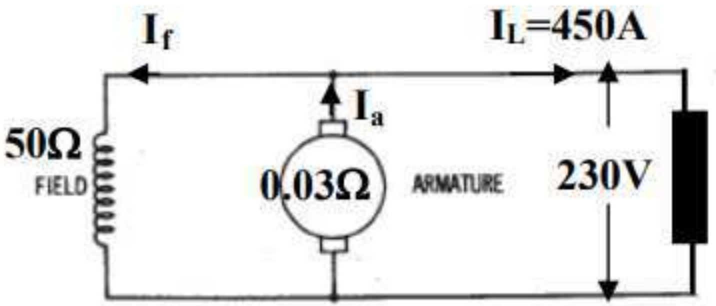
Now,

E_g = terminal voltage + armature drop

$$E_g = V + I_a.R_a$$

∴ e.m.f generated in the armature

$$E_g = 230 + 13.6 = 243.6\,\text{V}$$



Problem 04: An 8-pole D.C shunt generator with 778 wave-connected armature conductors and running at 500 r.p.m . supplies a load of 12.5Ω resistance at terminal voltage of 250 V. The armature resistance is 0.24Ω and the field resistance is 250Ω. Find the armature current, the induced emf and the flux per pole.

Solution:

Load current

$$I_L = \frac{V}{R} = \frac{250}{12.5} = 20 \text{ A}$$

Shunt current

$$I_f = \frac{250}{250} = 1 \text{ A}$$

Armature current

$$I_a = 20 + 1 = 21 \text{ A}$$

Induce e.m.f $= 250 + (21 \times 0.24) = 255.04$ V

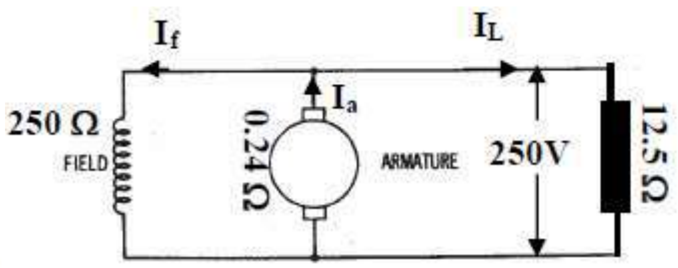
Now

$$E_g = \frac{Zn\phi}{60}\left(\frac{P}{a}\right)$$

$a = 2$ (wave-wound)

$$255.04 = \frac{778 \times 500 \times \varphi}{60}\left(\frac{8}{2}\right)$$

$$\phi = 9.83 \text{ mWb.}$$



Problem 05: A 4-pole, long-shunt lap-wound compound generator delivers a load current of (50 A) at (500 V). The armature resistance is (0.03 Ω), series field resistance is (0.04 Ω) and shunt field resistance is (200 Ω). The brush drop may be taken as (1V). Determine the emf. generated. Calculate also the no. of conductors if the speed is (1200 r.p.m) and flux per poles (0.02 Wb). Neglect armature reaction.

Solution:

$$I_{sh} = \frac{500}{200} = 2.5 \text{ A}$$

$$I_a = I_{sh} + I = 50 + 2.5 = 52.5 \text{ A}$$

$$\text{Series field drop} = 52.5 \times 0.04 = 2.1 \text{ V}$$

$$\text{Armature drop} = 52.5 \times 0.03 = 1.575 \text{ V}$$

$$\text{Brush drop} = 2 \times 1 = 2 \text{ V}$$

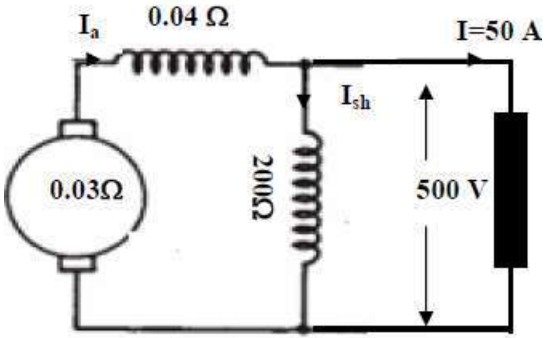
$$\text{e.m.f } E_g = 500 + 2.1 + 1.575 + 2 = 505.67 \text{ V}$$

now,

$$E_g = \frac{Z \cdot \phi \cdot n}{60}\left(\frac{p}{a}\right)$$

$$505.67 = \frac{Z \times 0.02 \times 1200}{60}\left(\frac{4}{4}\right)$$

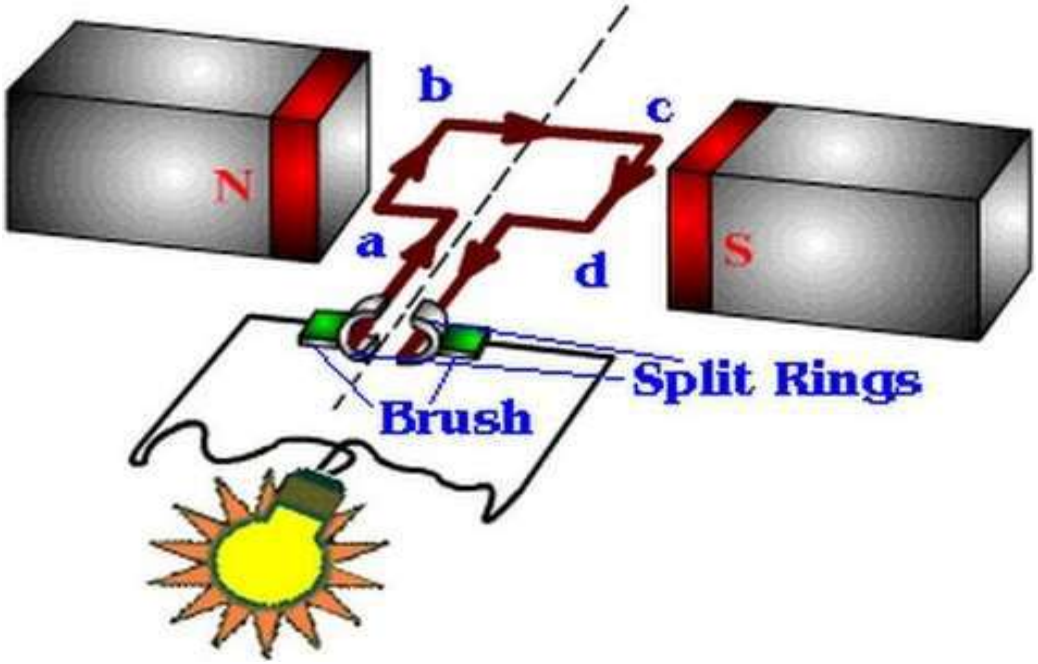
$$Z = 1264$$




Thank you

Module:2

DC GENERATOR



Topic:

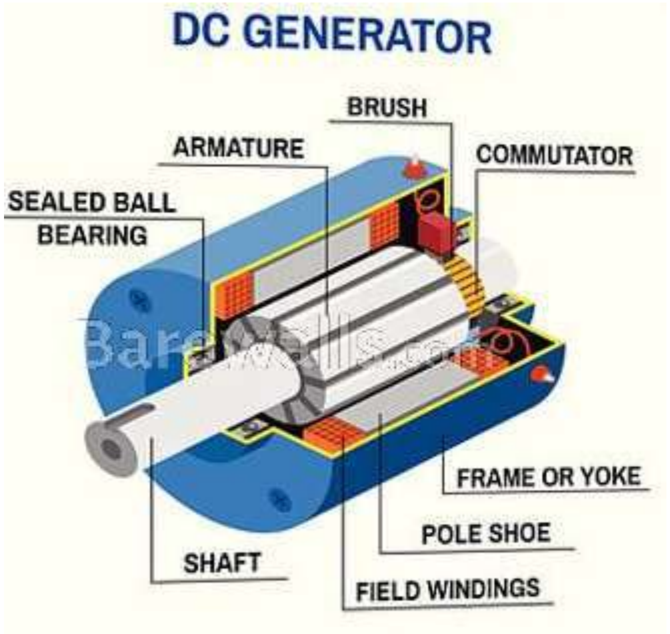
- Losses of D.C Machines
- Efficiency of D.C Machines
- Condition for Maximum Efficiency
- Power Stages
- Problem Solving

LOSSES IN A DC MACHINES

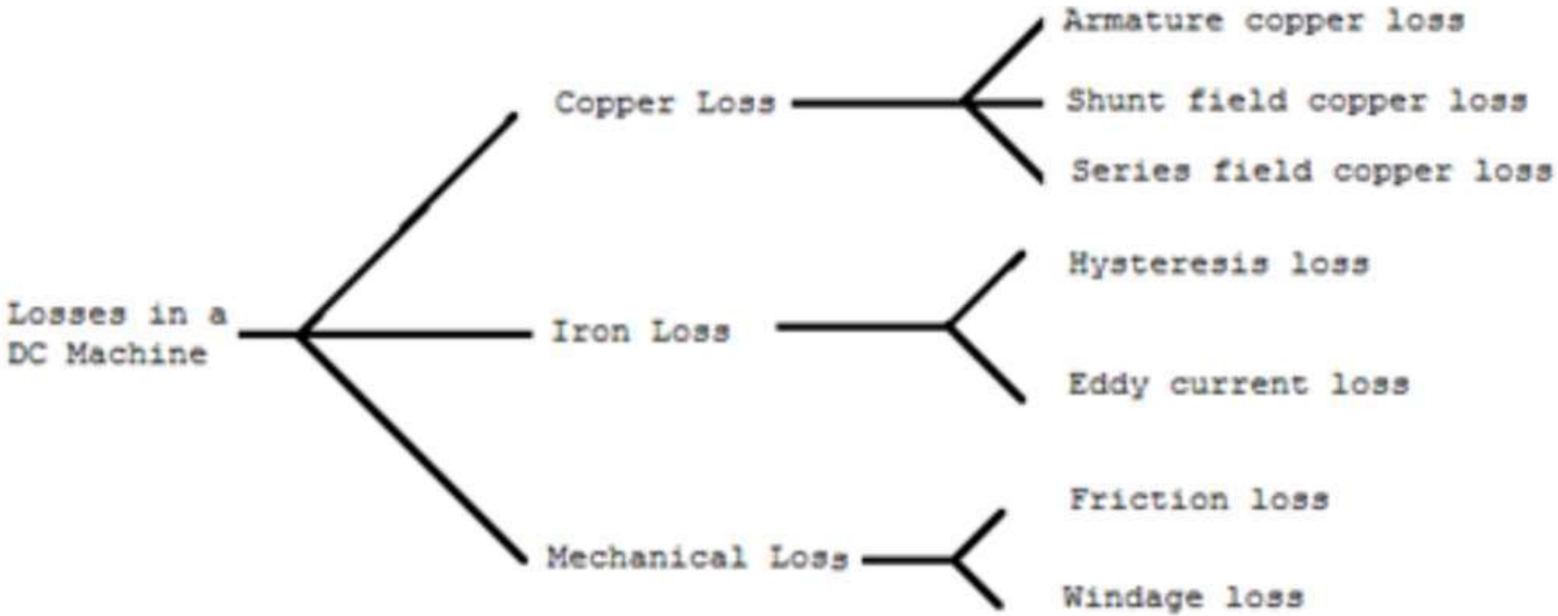
The losses can be divided into three types in a dc machine (Generator or Motor). They are

1. Copper losses
2. Iron or core losses
3. Mechanical losses.

All these losses seem as heat and therefore increase the temperature of the machine. Further the efficiency of the machine will reduce.



LOSSES IN A DC MACHINES



LOSSES IN A DC MACHINES

1. Copper Losses:

This loss generally occurs due to current in the various windings on of the machine. The different winding losses are;

Armature copper loss = $I^2_a\ R_a$

Shunt field copper loss = $I^2_{sh}R_{sh}$

Series field copper loss = $I^2_{se}\ R_{se}$

Note: There's additionally brush contact loss attributable to brush contact resistance (i.e., resistance in the middle of the surface of brush and commutator). This loss is mostly enclosed in armature copper loss.

LOSSES IN A DC MACHINES

2. Iron Losses

This loss occurs within the armature of a d.c. machine and are attributable to the rotation of armature within the magnetic field of the poles.
They're of 2 types viz.,
(i) Hysteresis loss (ii) Eddy current loss.

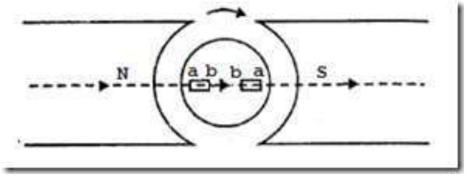
Hysteresis loss:

Hysteresis loss happens in the armature winding of the d.c. machine since any given part of the armature is exposed to magnetic field of reverses as it passes underneath sequence poles. The above fig shows the 2 pole DC machine of rotating armature. Consider a tiny low piece ab of the armature winding. Once the piece ab is underneath N-pole, the magnetic lines pass from a to b. Half a revolution well along, identical piece of iron is underneath S-pole and magnetic lines pass from b to a in order that magnetism within the iron is overturned. So as to reverse constantly the molecular magnets within the armature core, particular quantity of power must be spent that is named hysteresis loss. It's given by Steinmetz formula.

The formula is
Hysteresis loss $P_h = \eta B^{16}_{max}$ f V watts

Where,
η = Steinmetz hysteresis co-efficient
B_{max} = Maximum flux Density in armature winding
F = Frequency of magnetic reversals
= NP/120 (N is in RPM)
V = Volume of armature in m^3

If you want to cut back this loss in a d.c. machine, armature core is created of such materials that have an lesser value of Steinmetz hysteresis co-efficient e.g., silicon steel.



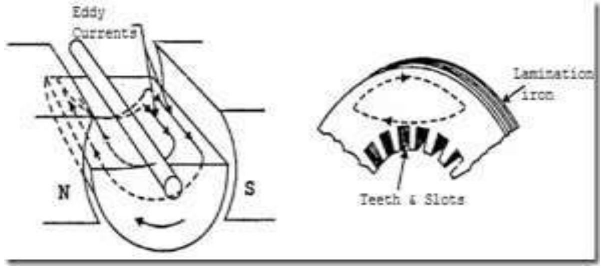
LOSSES IN A DC MACHINES

Eddy current loss:

In addition to the voltages evoked within the armature conductors, some of other voltages evoked within the armature core. These voltages turn out current currents within the coil core as shown in Fig. These are referred to as eddy currents and power loss attributable to their flow is named eddy current loss. This loss seems as heat that increases the temperature of the machine and efficiency will decrease.

If never-ending cast-iron core is employed, the resistance to eddy current path is tiny attributable to massive cross-sectional space of the core. Consequently, the magnitude of eddy current and therefore eddy current loss are massive. The magnitudes of eddy current are often decreased by creating core resistance as high as sensible. The core resistances are often greatly exaggerated by making the core of skinny, spherical iron sheets referred to as lamination's shown in the fig. The lamination's are insulated from one another with a layer of varnish. The insulating layer features a high resistance, thus only small amount of current flows from one lamination to the opposite. Also, as a result of every lamination is extremely skinny, the resistance to current passing over the breadth of a lamination is additionally quite massive. Therefore laminating a core will increase the core resistance that drops the eddy current and therefore the eddy current loss.

Eddy Current loss $P_e=K_eB^2_{max}f^2t^2V$ Watts



LOSSES IN A DC MACHINES

3. Mechanical Loss

These losses are attributable to friction and windage.
Friction loss occurs due to the friction in bearing, brushes etc.
windage loss occurs due to the air friction of rotating coil.

These losses rely on the speed of the machine. Except for a given speed, they're much constant.

4. Stray Losses

These losses are the miscellaneous type of losses. The following factors are considered in stray load losses.
The distortion of flux because of armature reaction.
Short circuit currents in the coil, undergoing commutation.
These losses are very difficult to determine. Therefore, it is necessary to assign the reasonable value of the stray loss. For most machines, stray losses are taken by convention to be one percent of the full load output power.

LOSSES IN A DC MACHINES

Constant and Variable Losses

The losses in a d.c. machine is also further classified into (i) constant losses (ii) variable losses.

Constant losses

Those losses in a d.c. generator that stay constant at all loads are referred to as constant losses. The constant losses in a very d.c. generator are:

(a)iron losses

(b)mechanical losses

(c)shunt field losses

Generally this copper loss is constant for shunt and compound generators.

Variable losses

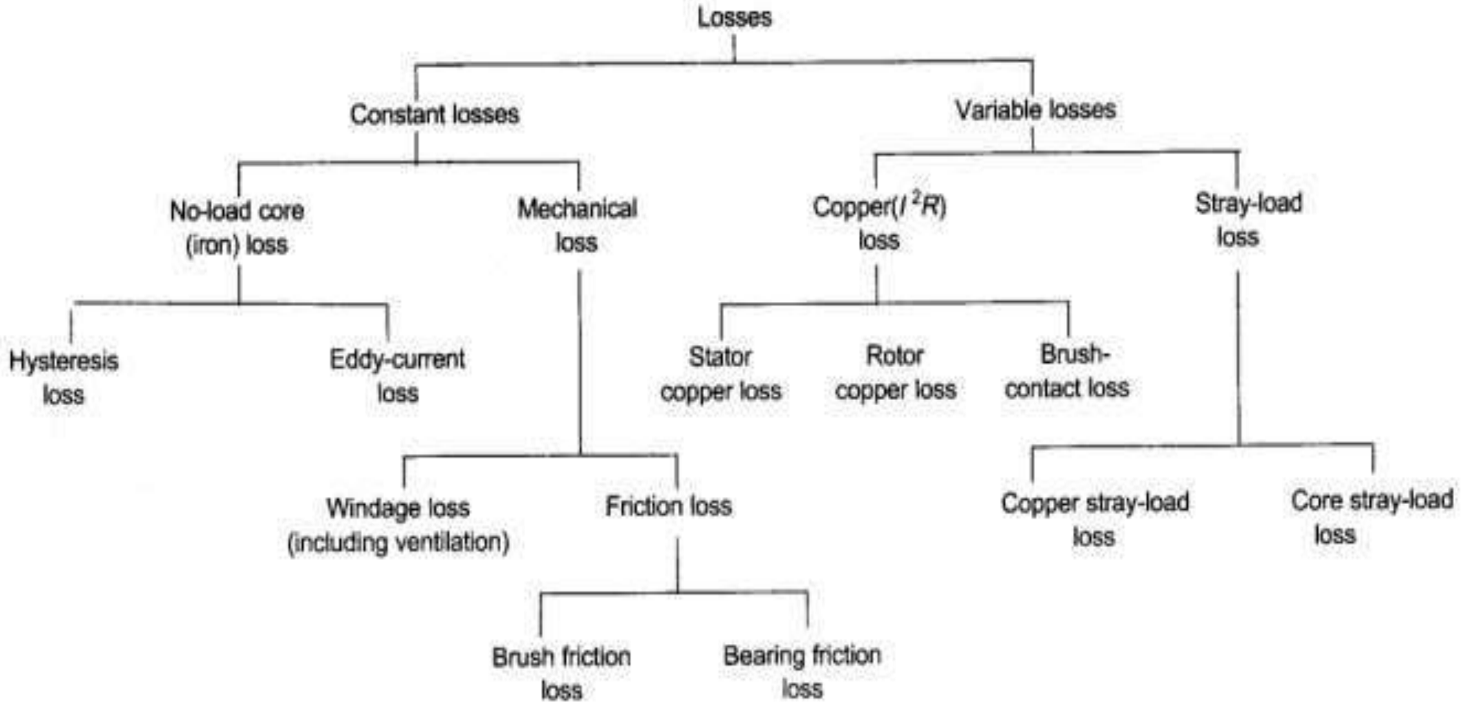
Those losses in a d.c. generator that differ with load are referred to as variable losses. The variable losses in a very d.c. generator are:

Copper loss in armature winding (I^2R_a)

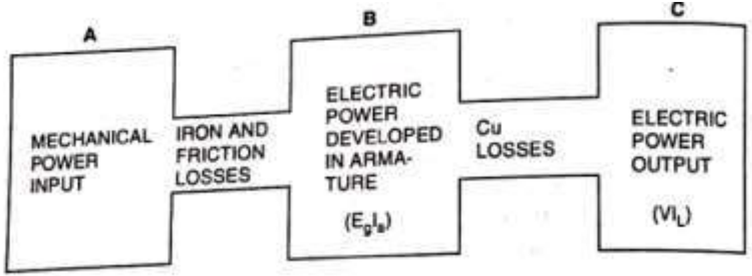
Copper loss in series field winding ($I^2_{se}R_{se}$)

Total losses = Constant losses + Variable losses.

LOSSES IN A
DC MACHINES



EFFICIENCY IN A DC MACHINES



$$1.\ Mecanical\ Efficiency\ \eta_m = \frac{B}{A} = \frac{E_g I_a}{Mechanical\ Power\ Input}$$

$$2.\ Electrical\ Efficiency\ \eta_e = \frac{B}{A} = \frac{VI_L}{E_g I_a}$$

$$3.\ Overall\ or\ Commercial\ Efficiency\ \eta_c = \frac{C}{A} = \frac{VI_L}{Mechanical\ Power\ Input}$$

$$Clearly\ \eta_c = \eta_m \times \eta_e$$

$$Now\ Commercial\ Efficiency\ \eta_c = \frac{C}{A} = \frac{Output}{Input} = \frac{Input - Total\ Loss}{Input} = \frac{Output}{Output + Total\ Loss}$$

CONDITION FOR MAXIMUM EFFICIENCY

The efficiency of a DC generator is not constant but varies with load. Consider a shunt generator delivering a load Current I_L at a terminal voltage V.

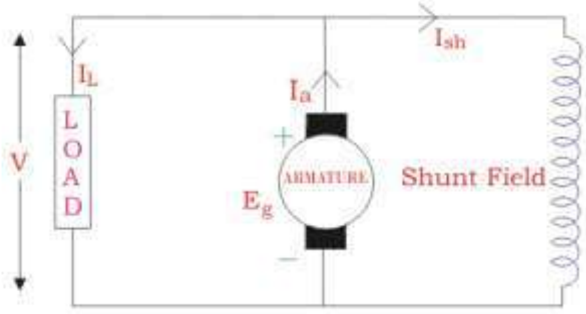
Generator Output = VI_L

Generator Input = Output+ Total Losses

$= VI_L$ + Variable Losses + Constant Losses

$= VI_L + I_a^2 R_a + W_C$

$= VI_L + (I_L + I_{Sh})^2 R_a + W_C$ Since $I_a = I_L + I_{sh}$



The shunt field current I_{sh} is generally small as compared to I_L and therefore can be neglected

Generator Input= $VI_L + (I_L)^2 R_a + W_C$

$$Efficiency\ \eta = \frac{Output}{Input} = \frac{VI_L}{VI_L + (I_L)^2 R_a + W_C} = \frac{1}{1 + \left(\frac{I_L R_a}{V} + \frac{W_C}{VI_L}\right)}$$

The efficiency will be maximum when the denominator of above equation is minimum

CONDITION FOR MAXIMUM EFFICIENCY

$$\frac{d}{dI_L}\left(\frac{I_L R_a}{V} + \frac{W_C}{VI_L}\right) = 0$$

or $$\frac{R_a}{V} - \frac{W_C}{VI_L^2} = 0$$

or $$\frac{R_a}{V} = \frac{W_C}{VI_L^2}$$

or $$I_L^2 R_a = W_C$$

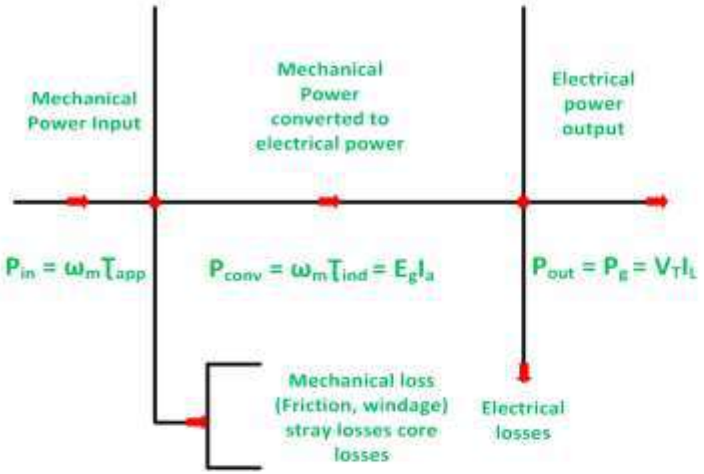
i.e. **Variable loss = Constant loss**

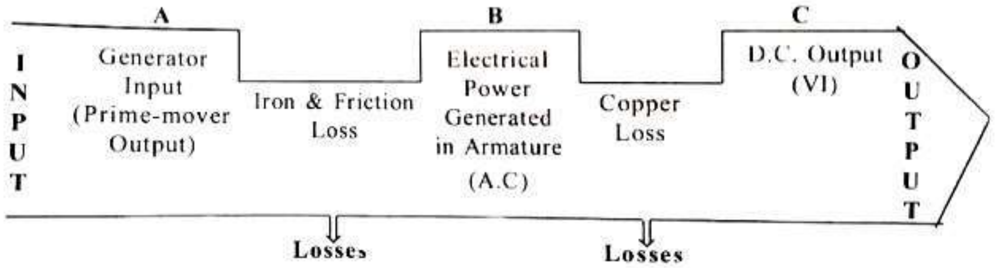
The load current corresponding to maximum efficiency is given by ;

$$I_L = \sqrt{\frac{W_C}{R_a}}$$

POWER STAGES INA DC MACHINES

The Power Flow Diagram is used to determine the efficiency of a generator or motor. In the below figure of power flow diagram of DC Generator, it is shown that initially the mechanical power is given as an input which is converted into electrical power, and the output which is obtained is in the form of electrical power. There are various losses such as friction, windage, stray losses and core losses.





PROBLEM SOLVING

A 20hp, 250V shunt motor with R_a=0.22 Ω, R_f=170 Ω. At no-load and rated voltage, the speed is 1200 rpm and the armature current is 3 A. At full-load and rated voltage, the line current is 55A. What is the full-load speed?

Solution

At No-load

$$I_{f\,n.l} = \frac{V_t}{R_f} = \frac{250}{170} = 1.47\ A\ ,$$

$$N_{n.l} = 1200\ \ r.p.m$$

$$E_{n.l} = V_t - I_a R_a = 250 - (3)(0.22) = 249.34\ V$$

At Full-load

$$I_{f\,f.l} = \frac{V_t}{R_f} = \frac{250}{170} = 1.47\ A\ \ , N_{f.l} = \ ??$$

$$E_{f.l} = V_t - I_a R_a = 250 - (55)(0.22) = 238.22\ V$$

$$\frac{E_{n.l}}{E_{f.l}} = \frac{I_{f\,n.l} N_{n.l}}{I_{f\,f.l} N_{f.l}}$$

$$\frac{249.34}{238.22} = \frac{1200}{N_{f.l}}$$

$$N_{f.l} = 1146.5\ \ r.p.m$$

PROBLEM SOLVING

A 230V shunt motor delivers 30hp at the shaft at 1120rpm. If the motor has an efficiency of 87% at this load, determine:

a) The total input power.
b) The line current.

Solution

(a) $\eta = \frac{P_{o/p}}{P_{i/p}}$

$$P_{i/p} = \frac{P_{o/p}}{\eta}$$

$$= \frac{30 * 746}{0.87}$$

$$= 25.72\ Kw$$

$$P_{i/p} = 25.72\ Kw$$

(b) $P_{i/p} = V_t I_l$

$$I_l = \frac{P_{i/p}}{V_t}$$

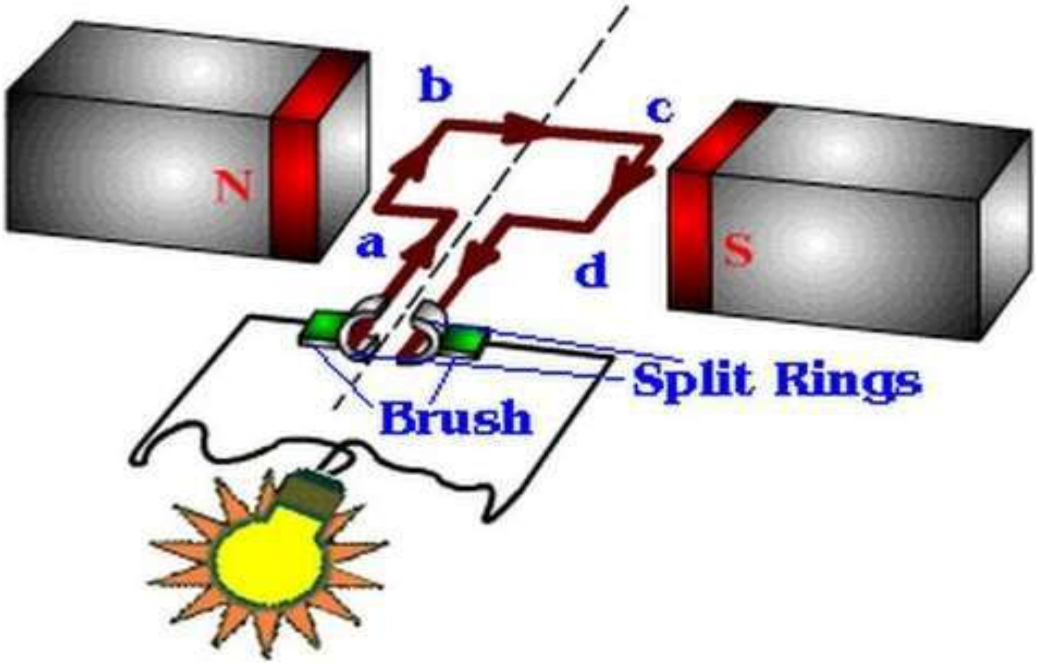
$$= \frac{25.72 * 10^3}{230}$$

$$= 111.84\ A$$


Thank you

Module:2

DC GENERATOR



Topic:

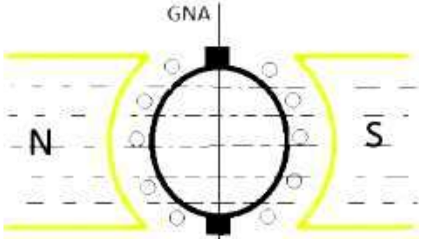
- Armature Reaction
- Effect of Armature Reaction
- Minimize Armature Reaction

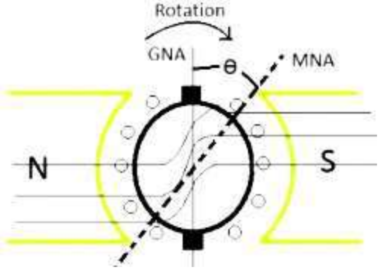
ARMATURE REACTION IN A DC MACHINES

GNA and MNA

GNA (Geometrical Neutral Axis) may be defined as the axis which is perpendicular to the stator field axis.

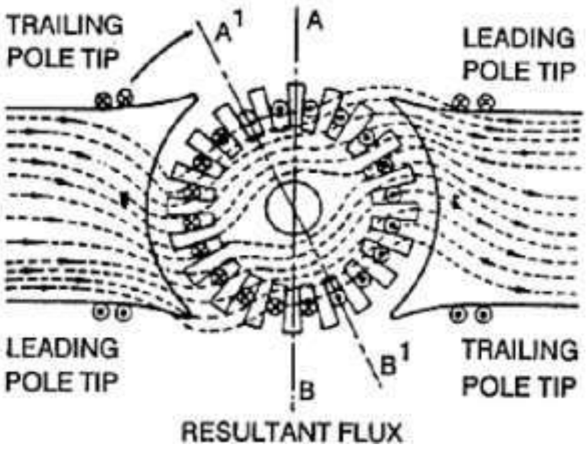
EMF is induced in the armature conductors when they cut the magnetic field lines. But, there is an axis along which armature conductors move parallel to the flux lines. MNA (Magnetic Neutral Axis) may be defined as the axis along which no emf is generated in the armature conductors as they move parallel to the flux lines. Brushes are always placed in MNA because reversal of current in the armature conductor takes place along this MNA axis.





Leading and Trailing Pole tip

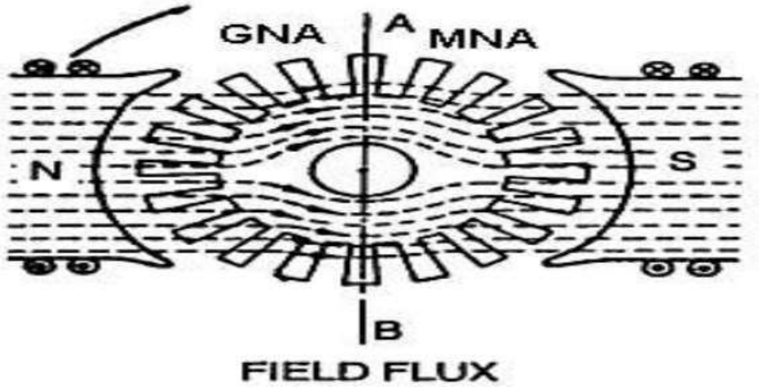
The tip of the pole from where the armature conductors come into influence is called leading tip and the other tip opposite in direction to it will be the trailing tip.



ARMATURE REACTION IN A DC MACHINES

Armature Reaction in a d.c. machine is basically the effect of armature produced flux on the main flux or field flux .

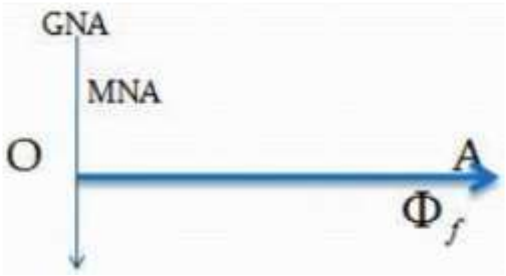
The armature reaction simply shows the effect of armature field on the main field. In other words, the armature reaction represents the impact of the armature flux on the main field flux. The armature field is produced by the armature conductors when current flows through them. And the main field is produced by the magnetic poles.



To understand this process let us first assume a 2- pole d.c. machine at no load . At that instant there is no armature current . So the flux due to mmf produced by field current in the machine at north pole of the magnet will flow towards the south pole of the magnet.

ARMATURE REACTION IN A DC MACHINES

The net / resultant flux of the system can be taken as a straight horizontal line OA and can be shown in phasor as

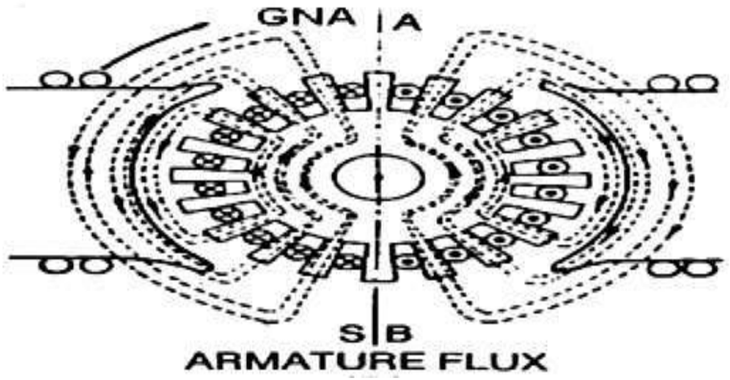


Also at that instant the Magnetic Neutral Axis (M.N.A) of the machine will coincide with the Geometrical Neutral Axis (G.N.A) of the machine as the M.N.A is always perpendicular to the net flux.

ARMATURE REACTION IN A DC MACHINES

Now when the dc machine is loaded , current flows in armature windings . This armature current set up armature flux . With field windings unexcited , the flux can be shown as vertical lines across armature conductors .

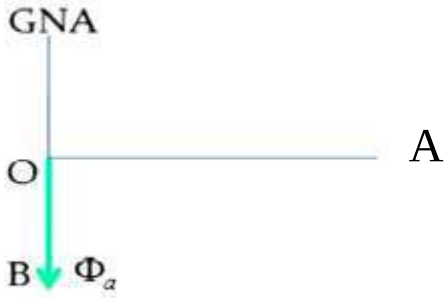
The conductors on the left side of the M.N.A will have current flowing in inside direction whereas on right side of MNA , the current will flow in outside direction. The direction of the flux thus produced can be determined by using Maxwell‘s Right hand Screw rule.



ARMATURE REACTION IN A DC MACHINES

The resultant flux of the system is a straight vertical line OB and can be shown in phasor as

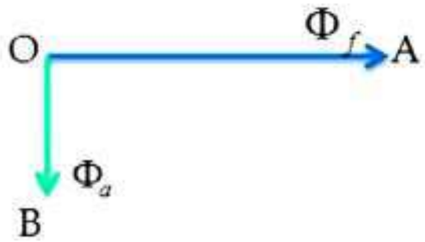
Note that the magnitude of OB will always be less than OA since the cause of armature flux is field flux and it is known to us that effect is always less than cause. Here armature flux is the effect and field flux is its cause.



ARMATURE REACTION IN A DC MACHINES

An examination to the above two phasor reveals that the path of armature flux is perpendicular to the main field flux.

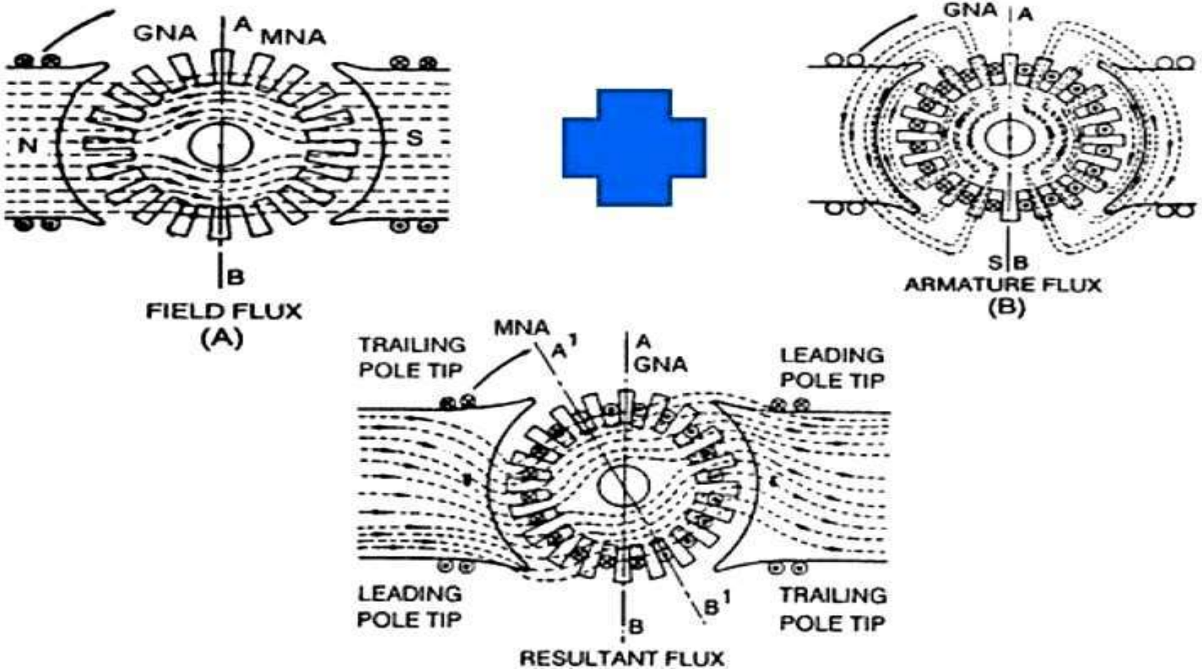
In other words, the path of the armature flux crosses the path of the main field flux. This can be shown in phasor as



Thus the effect of armature flux on the main field flux is entirely ‘cross-magnetizing’ and it is for this reason that the flux produced by armature mmf is also called as cross-flux.

ARMATURE REACTION IN A DC MACHINES

When the current flows in both the armature and field windings, the resultant flux distribution is obtained by superimposing theses two fluxes.

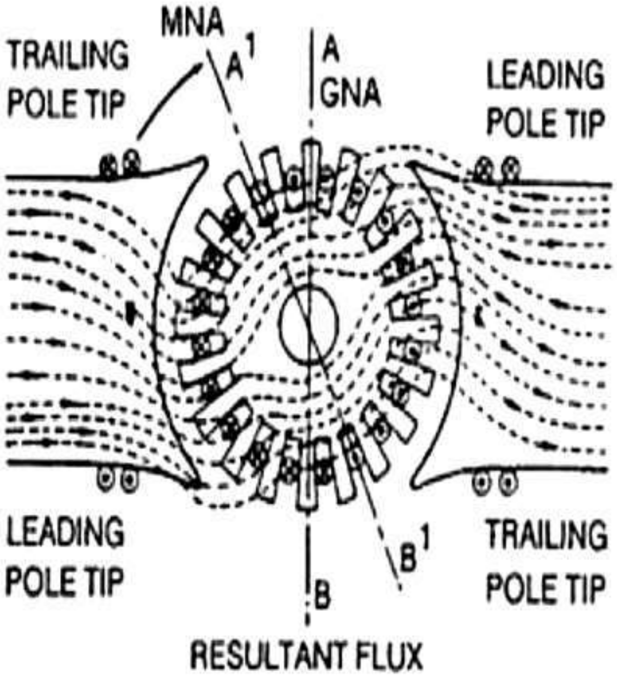


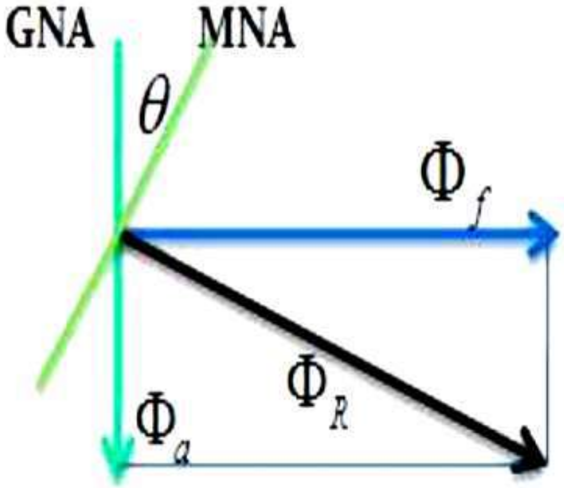
ARMATURE REACTION IN A DC MACHINES

It is observed that the armature flux aids the main field flux at the lower end of the N-pole and at the upper end of the S-pole, therefore at these two poles, the armature flux strengthens the main field flux.

Likewise, the armature flux weakens the main field flux at Upper end of the N-pole and at lower end of the S-pole.

ARMATURE REACTION IN A DC MACHINES

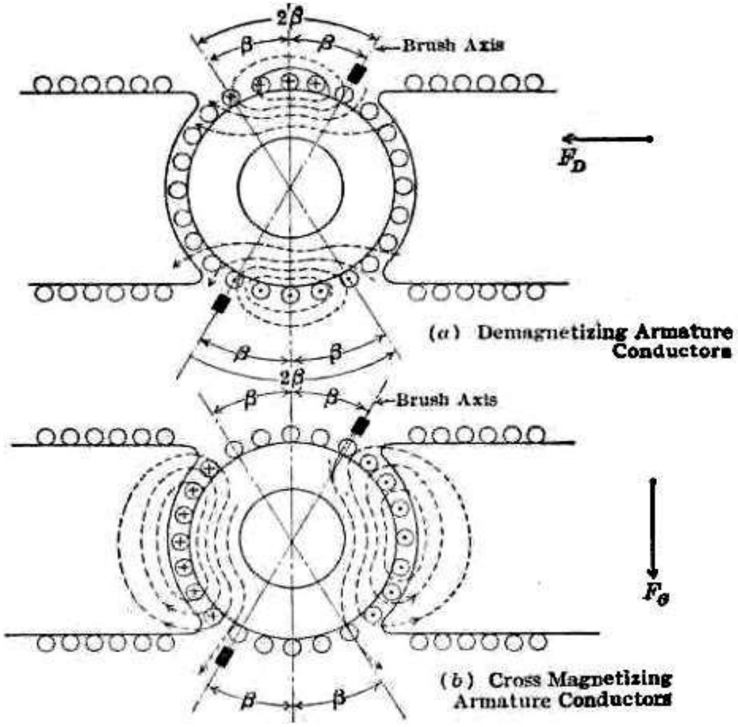




ARMATURE REACTION IN A DC MACHINES

Now, if there is no magnetic saturation, then the amount of strengthening and weakening of the main field flux are equal and the resultant flux per pole remains unaltered from its no load value.

Actually, the magnetic saturation does occurs and as a consequence, the strengthening effect is less as compared to the weakening effect and the resultant flux is decreased from its no-load value. This is called 'Demagnetizing effect of armature reaction'



ARMATURE REACTION IN A DC MACHINES

So when the machine is run loaded , M.N.A will shift from G.N.A of the machine .

The resultant shift is completely dependent on the magnitude of armature current.

Thus, greater the value of armature current , greater is the shift of MNA from GNA .

It may therefore be stated from the above that net effect of armature flux on the main field flux is:

1. To distort the main field flux thereby causing non-uniform distribution of flux under the main poles.
2. To shift the MNA in the direction of the rotation for a generator and against the direction of rotation for a motor.
3. To reduce the main field flux from its no-load value due to magnetic saturation.

EFFECT OF ARMATURE REACTION IN A DC MACHINES

The armature reaction produces the following two undesirable effects:

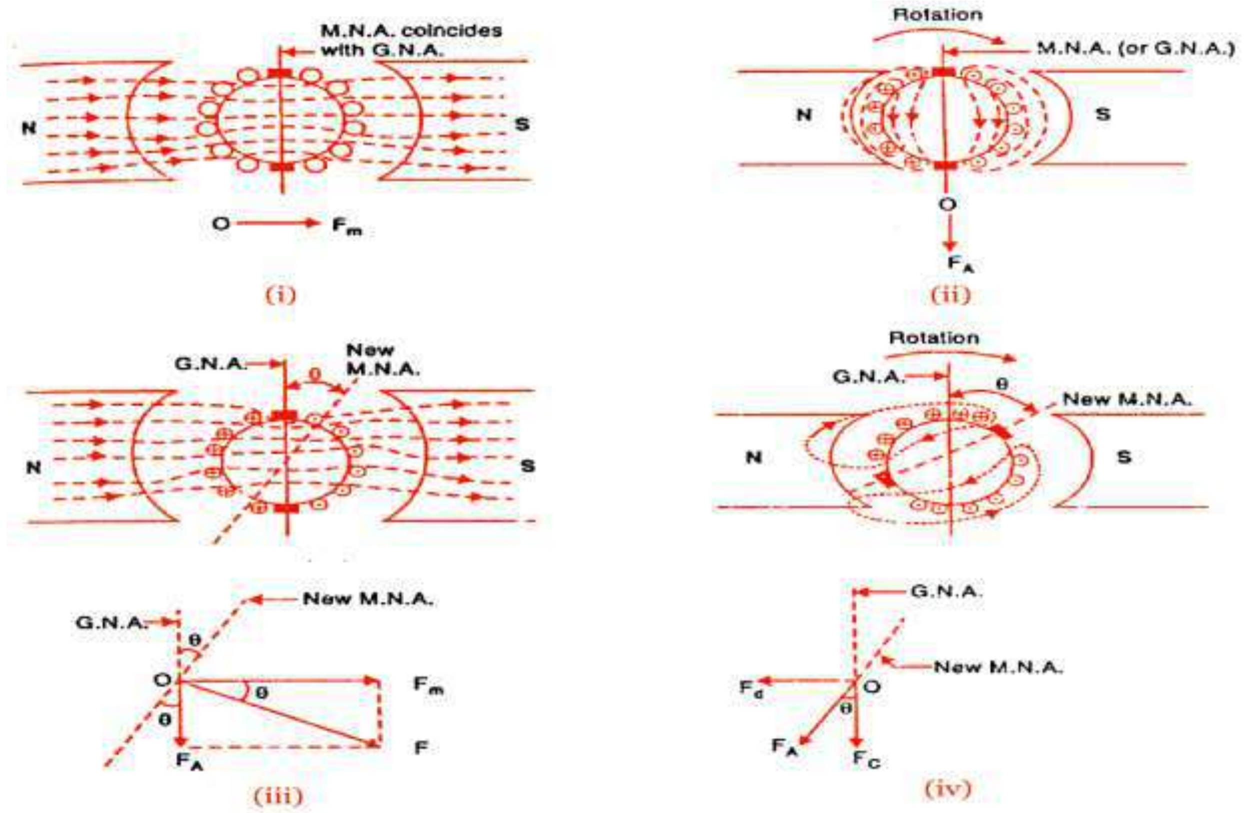
1. It demagnetizes or weakens the main flux.

2. It cross-magnetizes or distorts the main flux.

Because of the armature reaction the flux density of over one-half of the pole increases and over the other half decreases. The total flux produces by each pole is slightly less due to which the magnitude of the terminal voltage reduces. The effect due to which the armature reaction reduces the total flux is known as the demagnetizing effect.

The armature reaction induces flux in the neutral zone, and this flux generates the voltage that causes the commutation problem.

EFFECT OF ARMATURE REACTION IN A DC MACHINES

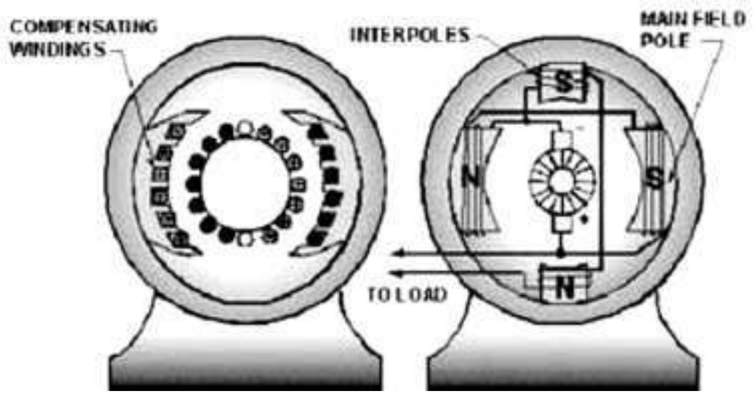


METHODS OF REDUCE ARMATURE REACTION IN A DC MACHINES

There are various methods of reducing the armature reaction, some of them are:-

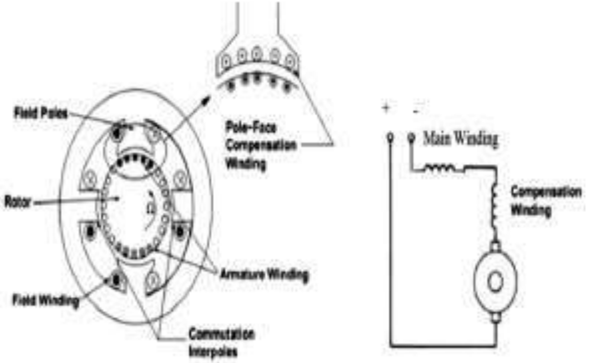
1. Compensate Windings
2. Interlopes or copoles
3. By using eccentric poles
4. Using laminated poles
5. Punching rectangular holes in field pole
6. Stronger main field flux as compared to armature flux

COMPENSATING WINDIGS



The compensating windings consist of a series of coils embedded in slots in the pole faces.

These coils are connected in series with the armature in such a way that the current in them flows in opposite direction to that flowing in armature conductors directly below the pole shoes.



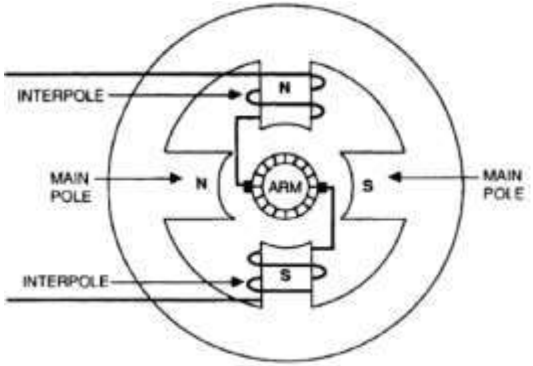
The series-connected compensating windings produce a magnetic field, which varies directly with armature current.

As the compensating windings are wound to produce a field that opposes the magnetic field of the armature, they tend to cancel the effects of the armature magnetic field.

INTERPOLES

Another way to reduce the effects of armature reaction is to place small auxiliary poles called "interlopes" between the main field poles.

Interlopes have a few turns of large wire and are connected in series with the armature.



Interlopes are wound and placed so that each interlope has the same magnetic polarity as the main pole ahead of it, in the direction of rotation.

The field generated by the interlopes produces the same effect as the compensating winding. This field, in effect, cancels the armature reaction for all values of load current.

BY USING ECCENTRIC POLES

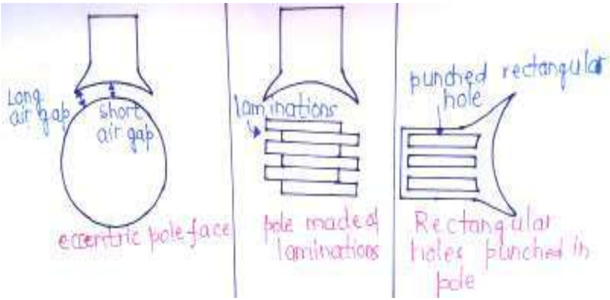
A dc machine fitted with eccentric pole face has short air-gap length at the pole centre and longer air gap lengths under the pole tips. This increases the reluctance of the pole tips which reduces the magnitude of armature cross flux and hence armature reaction is minimized.

USING LAMINATED POLES

If magnetic pole used is assembled as shown, the laminations will sandwich air between them and therefore reluctance of armature cross flux is increased due to low permeability of air.

PUNCHING RECTANGULAR HOLES IN FIELD POLE

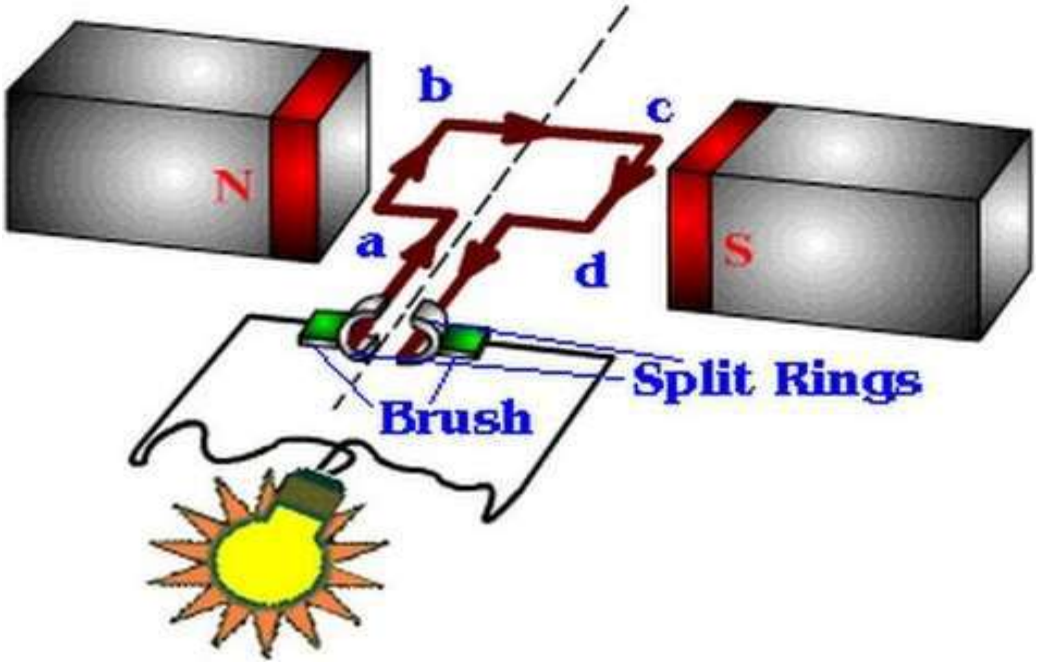
This also increases reluctance of armature cross flux with main flux remaining almost unaffected. The constructional techniques mentioned above reduce the main flux also to some extent and therefore main field mmf must be raised accordingly. But the effect is more pronounced on armature flux and therefore the methods are used.




Thank you

Module:2

DC GENERATOR



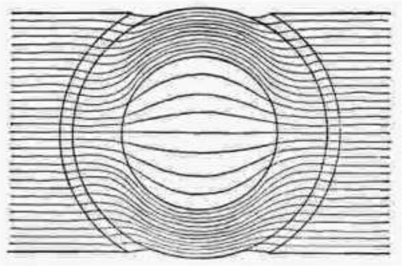
Topic:

- **CONCEPT OF ARMATURE WINDING**
- **TYPES OF ARMATURE WINDING**
- **LAP WINDING**
- **WAVE WINDING**

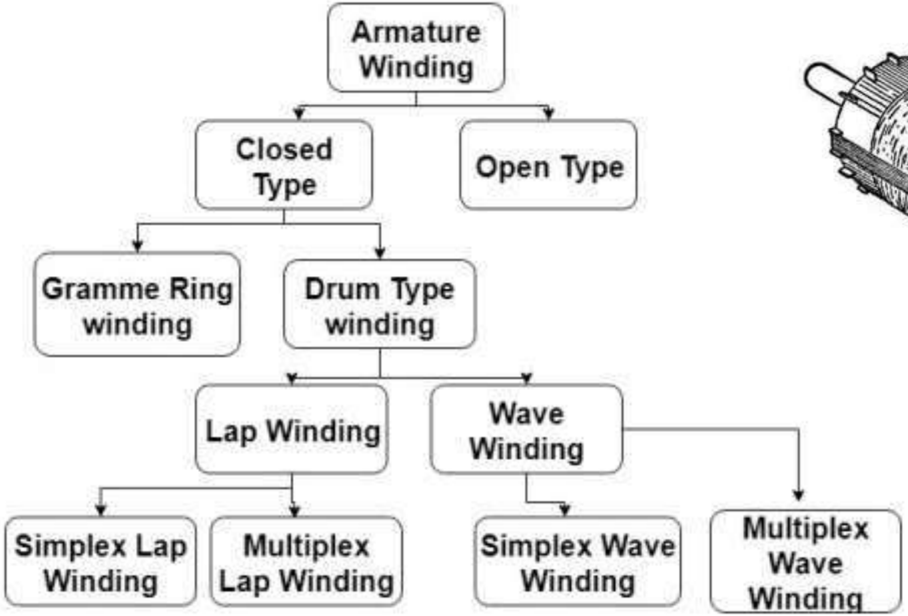
ARMATURE WINDINGS OF DC MACHINES

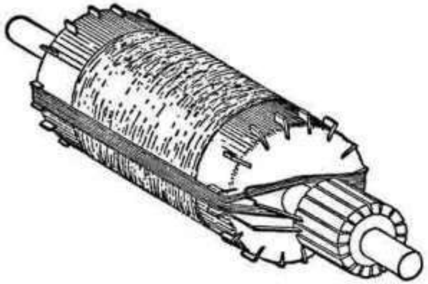
- The armature winding is the main current-carrying winding in which the electromotive force or counter-emf of rotation is induced.
- The current in the armature winding is known as the armature current.
- The location of the winding depends upon the type of machine.
- The armature windings of dc motors are located on the rotor, since they must operate in union with the commutator.
- In DC rotating machines other than brushless DC machines, it is usually rotating.

TYPES OF ARMATURE WINDINGS OF DC MACHINES



Gramme Winding





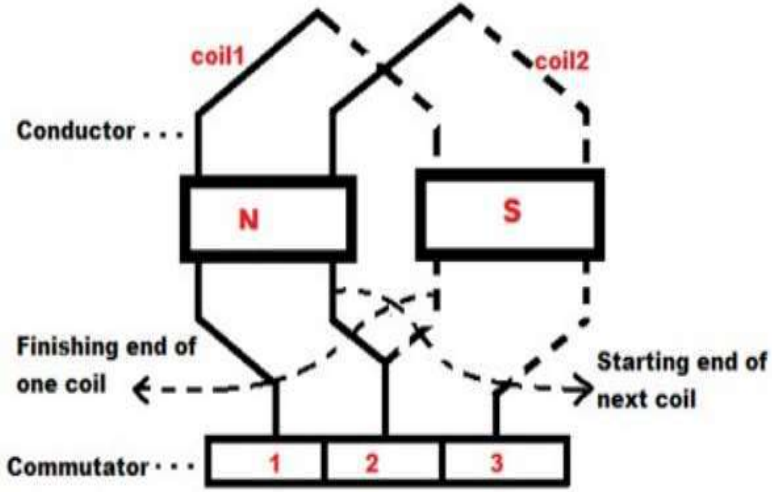
Drum Wound

LAP WINDING

1. Lap winding is the winding in which successive coils overlap each other. It is named "Lap" winding because it doubles or laps back with its succeeding coils.

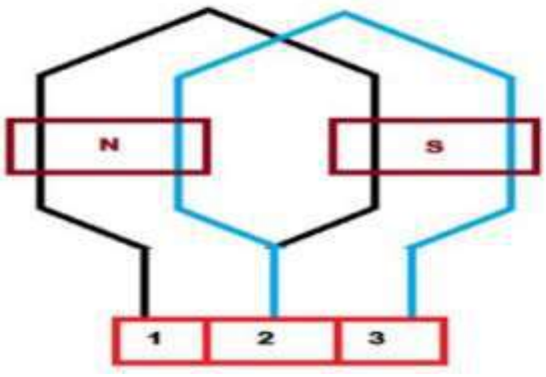
2. In this winding the finishing end of one coil is connected to one commutator segment and the starting end of the next coil situated under the same pole and connected with same commutator segment.

3. It is used for high current and low voltage applications.



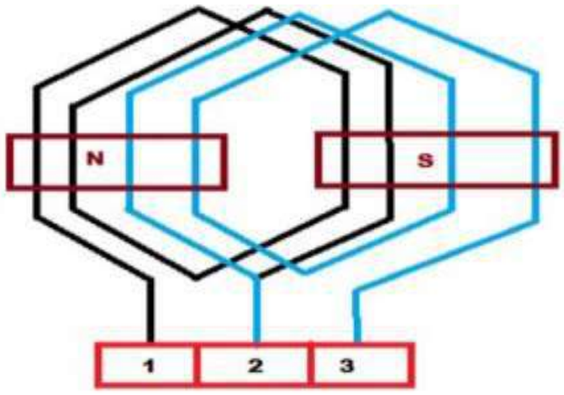
Simplex Lap Winding

A winding in which the number of parallel path between the brushes is equal to the number of poles is called simplex lap winding.



Duplex Lap Winding

A winding in which the number of parallel path between the brushes is twice the number of poles is called Duplex lap winding.

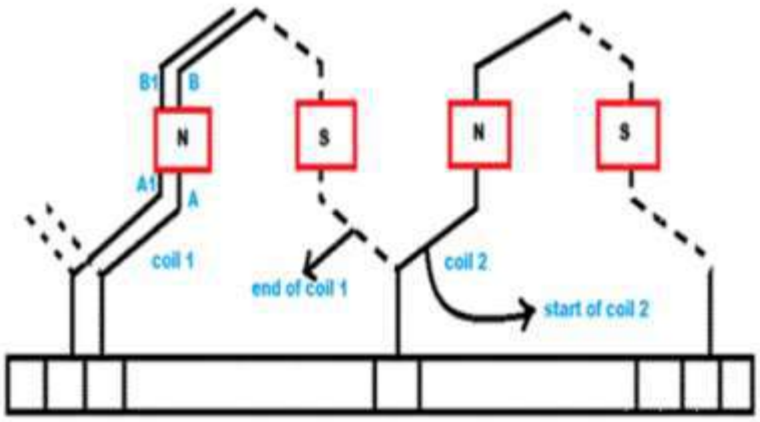


WAVE WINDING

1. Wave winding is one type of armature winding. In this winding the end of
   one coil is connected to the starting of another coil of the same polarity as that of the first coil.

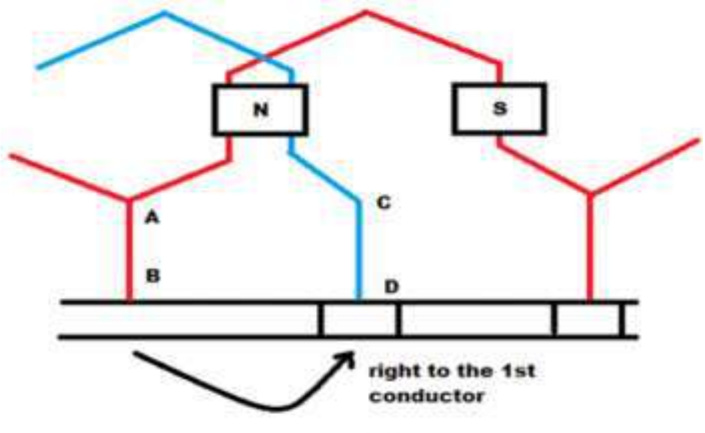
2. This winding forms a wave with its coil, that's why it is named as wave winding. It is also called series winding because its coils are connected in series.

3. It is used for high voltage and low current applications.



Progressive Wave Winding

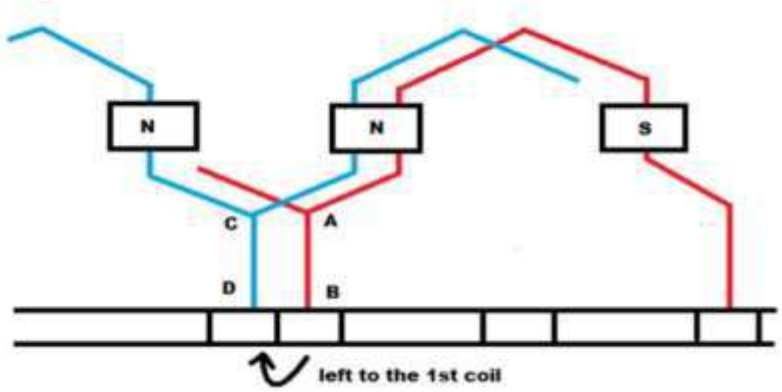
If after one round of the armature the coil falls in a slot right to its starting slot the winging is called Progressive wave winding.



progressive wave winding

Retrogressive Wave Winding

If after one round of the armature the coil falls in a slot left to its starting slot the winging is called Retrogressive wave winding.



COMPARISON BETWEEN LAP & WAVE WINDING

SL.NO.	Basis For Comparison	Lap Winding	Wave Winding
1	Definition	The coil is lap back to the succeeding coil.	The coil of the winding form the wave shape.
2	Connection	The end of the armature coil is connected to an adjacent segment on the commutator.	The end of the armature coil is connected to commutator segments some distance apart.
3	Parallel Path	The numbers of parallel path are equal to the total of number poles.	The number of parallel paths is equal to two.
4	Other Name	Parallel Winding or Multiple Winding	Two-circuit or Series Winding.
5	EMF	Less	More
6	Number of Brushes	Equal to the number of parallel paths.	Two
7	Types	Simplex and Duplex lap winding.	Progressive and Retrogressive wave winding
8	Efficiency	Less	High
9	Additional Coil	Equalizer Ring	Dummy coil
10	Winding Cost	High (because more conductor is required)	Low
11	Uses	In low voltage, high current machines.	In high voltage, low current machines.

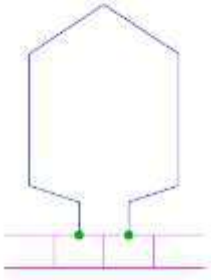
IMPORTANT TERMS OF ARMATURE WINDINGS

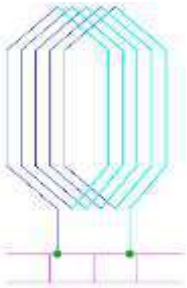
1. Pole pitch

Pole pitch is the distance between the two head to head poles in dc generator and it is the division between the number of conductors of armature winding and poles of DC generator. For example: if there are 60 conductors and 4 poles then 60/4 equals to 15 and this 15 is the pole pitch.

2. Winding Element and Conductor in Armature

There should be two types of windings enrolled on armature of dc generator. These two windings either single turn coil or a multi turn coil. A single turn coil has two conductors and multi turn coil has so many conductors. The conductors are placed in the slots of the armature. The side of the coil is known as winding element.





IMPORTANT TERMS OF ARMATURE WINDINGS

3. Coil pitch

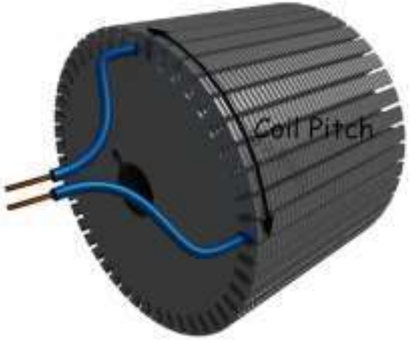
Coil pitch is the distance between the two sides of a coil. If the coil pitch and the pole pitch are equal to each other then the coil span will be 180 degrees and the coil sides will be arranged under opposite poles and maximum EMF will produced in the coil sides and then we will use the term that the winding is full pitched.

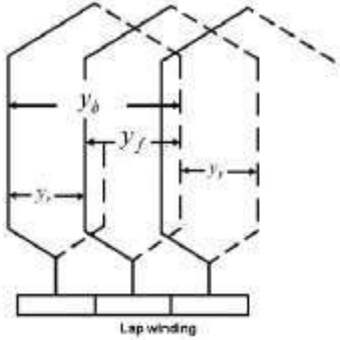
4. Pitch of winding

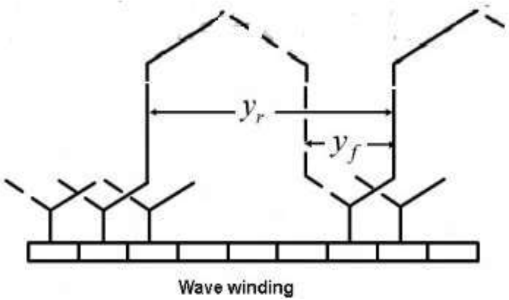
It is the distance between the two turns of a conductor. The pitch of the winding is denoted by Y. The formula to find the pitch of winding is given below:

$Y = Y_b - Y_f$ **For Lap Winding**

$Y = Y_b + Y_f$ **For Wave Winding**







IMPORTANT TERMS OF ARMATURE WINDINGS

5. Front Pitch

It is the number of armature conductors covered by a coil on the front of an armature is called the front pitch. It is the distance between the first conductor of a coil and the second conductor of a next coil which are connected together at the end of the commutator. For example: element 8 is connected to the element number 3 so the front pitch Y_F will be 8 – 3 = 5.

6. Back Pitch

It is the distance between the two conductors of a coil in armature which are connected to each other on the back side of armature. It is denoted by Y_B. For example: element 8 is connected to the element 1 on the back side of the armature so the back pitch will be 8 – 1 = 7.

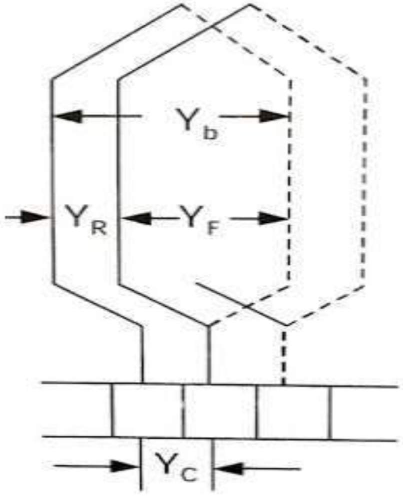
7. Resultant Pitch

It is the distance between the two coils wounded on the armature. This distance starts from the starting point of the first coil and ends at the starting point of the other coil wounded in the armature. It is denoted by Y_R.

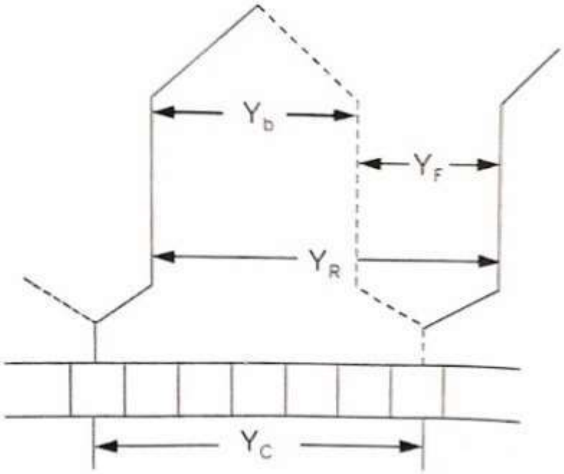
IMPORTANT TERMS OF ARMATURE WINDINGS

8. Commutator Pitch

It is the distance between the two conductors from where these two conductors are connected to the commutator bar/segment. It is denoted by Y_G.



Lap Winding

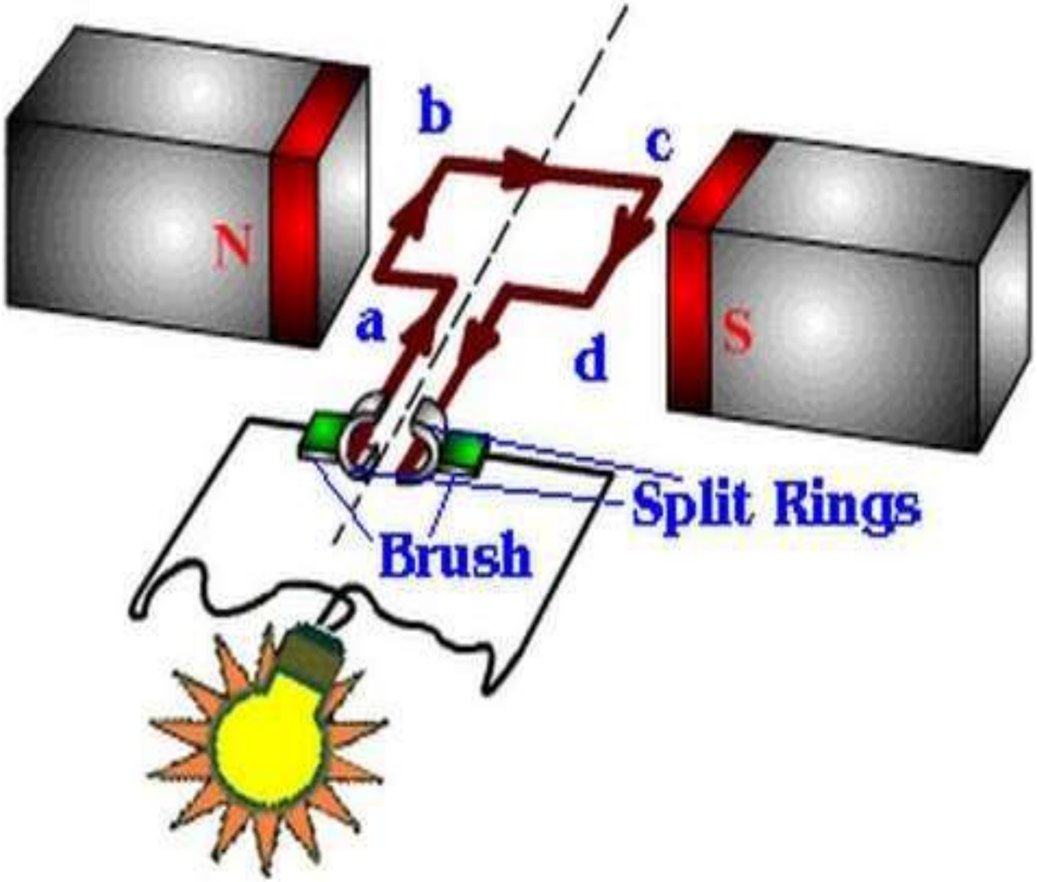


Wave Winding


Thank you

Module:2

DCGENERATOR



Topic:

- **CHARACTERISTICS OF DC GENERATORS**
  - **SEPARATELY EXCITED DC GENERATOR**
  - **SELF EXCITED DC GENERATOR**
    - ✓ **SHUNT GENERATOR**
    - ✓ **SERIES GENERATOR**
    - ✓ **COMPOUND GENERATOR**

CHARACTERISTICS OF DC GENERATORS

According to the Excitation D.C generators may be classified as

(i) Separately excited generator

(ii) Self excited generator

Self excited generator may be classified as

- (i) Shunt generator
- (ii) Series generator
- (iii) Compound generator.

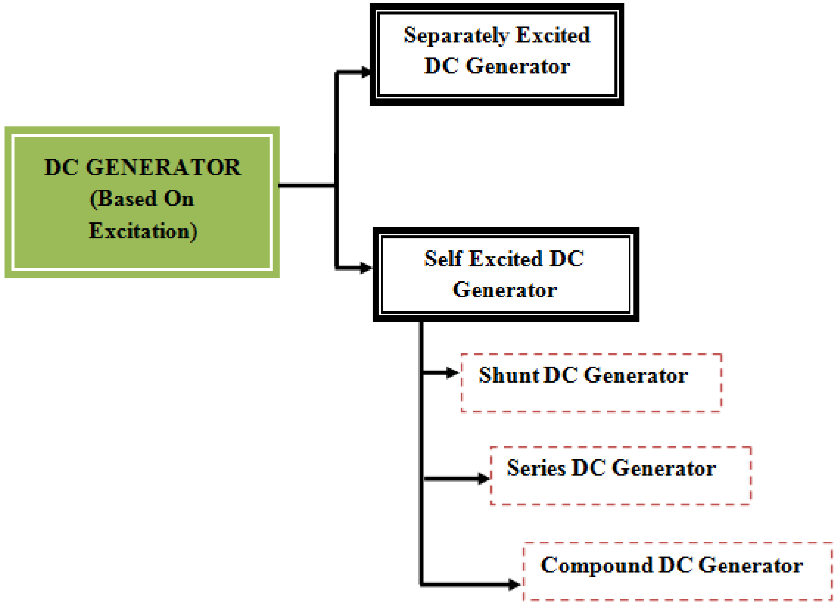
In a separately excited generator field winding is energized from a separate voltage source in order to produce flux in the machine. So long the machine operates in unsaturated condition the flux produced will be proportional to the field current.

In order to implement shunt connection, the field winding is connected in parallel with the armature. It will be shown that subject to fulfillment of certain conditions, the machine may have sufficient field current developed on its own by virtue of its shunt connection.

CHARACTERISTICS OF DC GENERATORS

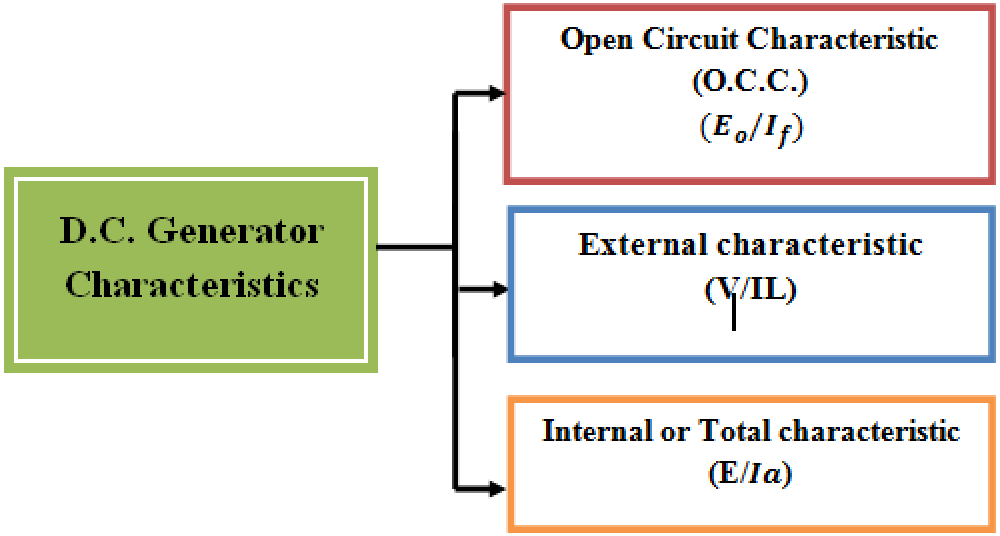
In series d.c machine, there is one field winding wound over the main poles with fewer turns and large cross sectional area. Series winding is meant to be connected in series with the armature and naturally to be designed for rated armature current. Obviously there will be practically no voltage or very small voltage due to residual field under no load condition (Ia = 0)

A compound generator has two separate field coils wound over the field poles. The coil having large number of turns and thinner cross sectional area is called the shunt field coil and the other coil having few number of turns and large cross sectional area is called the series field coil. Series coil is generally connected in series with the armature while the shunt field coil is connected in parallel with the armature. If series coil is left alone without any connection, then it becomes a shunt machine with the other coil connected in parallel.



CHARACTERISTICS OF DC GENERATORS

The speed of a d.c. machine operated as a generator is fixed by the prime mover. For general-purpose operation, the prime mover is equipped with a speed governor so that the speed of the generator is practically constant. Under such condition, the generator performance deals primarily with the relation between excitation, terminal voltage and load. These relations can be best exhibited graphically by means of curves known as generator characteristics. These characteristics show at a glance the behavior of the generator under different load conditions.



CHARACTERISTICS OF DC GENERATORS

D.C. Generator Characteristics:

The following are the three most important characteristics of a d.c. generator:

1. Open Circuit Characteristic (O.C.C.):

This curve shows the relation between the generated emf. at no-load (E_0) and the field current (I_f) at constant speed. It is also known as magnetic characteristic or no-load saturation curve. Its shape is practically the same for all generators whether separately or self-excited. The data for O.C.C. curve are obtained experimentally by operating the generator at no load and constant speed and recording the change in terminal voltage as the field current is varied.

CHARACTERISTICS OF DC GENERATORS

2. Internal or Total characteristic (E/Ia)

This curve shows the relation between the generated emf. on load (E) and the armature current (Ia). The emf. E is less than E0 due to the demagnetizing effect of armature reaction. Therefore, this curve will lie below the open circuit characteristic (O.C.C.). The internal characteristic is of interest chiefly to the designer. It cannot be obtained directly by experiment. It is because a voltmeter cannot read the emf. generated on load due to the voltage drop in armature resistance. The internal characteristic can be obtained from external characteristic if winding resistances are known because armature reaction effect is included in both characteristics.

3. External characteristic (V/IL)

This curve shows the relation between the terminal voltage (V) and load current (IL). The terminal voltage V will be less than E due to voltage drop in the armature circuit. Therefore, this curve will lie below the internal characteristic. This characteristic is very important in determining the suitability of a generator for a given purpose. It can be obtained by making simultaneous measurements of terminal voltage and load current (with voltmeter and ammeter) of a loaded generator.

CHARACTERISTICS OF DC GENERATORS

When the generator is loaded then the voltage drops due to two main reasons-

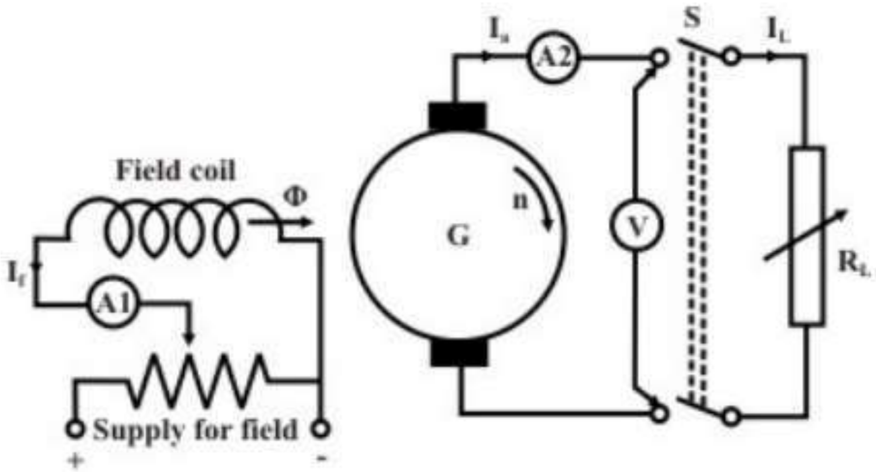
1. Due to armature reaction,
2. Due to ohmic drop (I_aR_a).

Characteristic of Separately Excited DC Generator

In a separately excited DC Generator, a separate source of DC power is connected to the field winding. This source can be a battery, a diode rectifier, another DC Generator or a controlled rectifier.

1. <u>No-load Characteristic</u>

The variation of armature generated emf E_g with field current I_f for constant speed N. The circuit connection diagram is shown below.



CHARACTERISTICS OF DC GENERATORS

As armature generated voltage $(E_g) = P\Phi ZN / 60A$

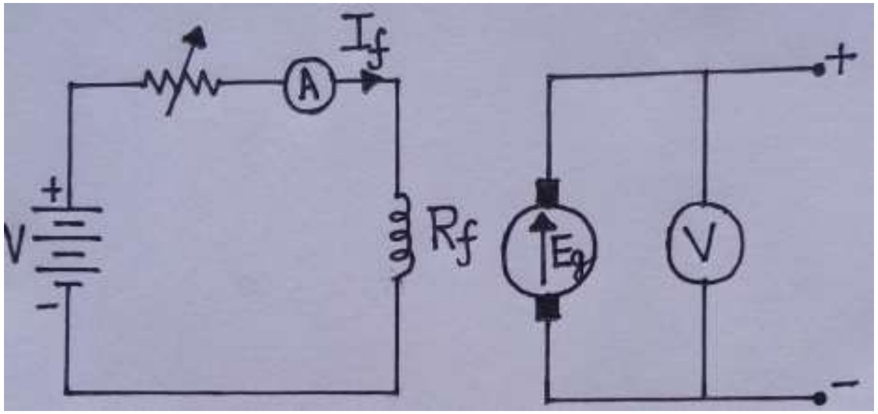
Therefore, for constant speed N

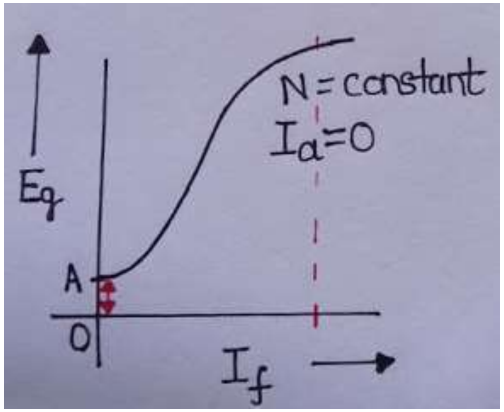
$E_g \propto \Phi \propto I_F$ $\Phi = N_F I_F$ / reluctance

It is seen that even when field winding is not energized, the voltmeter indicates a small voltage, due to presence of residual flux in the field poles as shown by OA in the characteristics.

When I_F is increased from zero, the curve is found to be a straight line, because the entire field mmf is almost spent in forcing the flux through the air gap and mmf required by the iron is almost negligible as its reluctance remains almost constant.

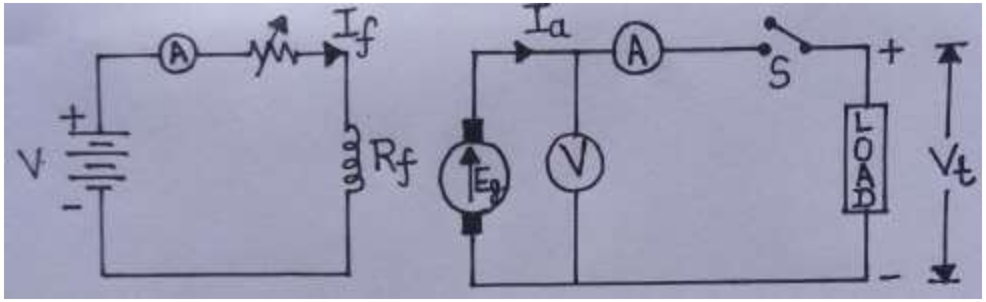
With larger I_F , saturation sets in and mmf required by the iron increases rapidly as its reluctance increases rapidly.



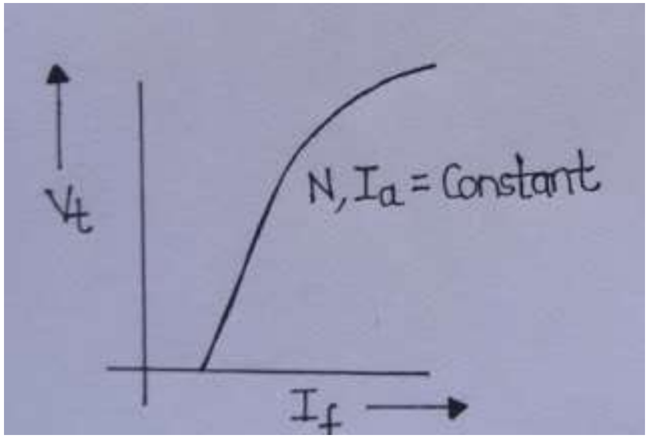


2. **Load Characteristic**

Variation of terminal voltage V_t with field current for constant armature current and armature speed.



To obtain load characteristic of separately excited dc generator, run the armature at rated speed and close the switch S.



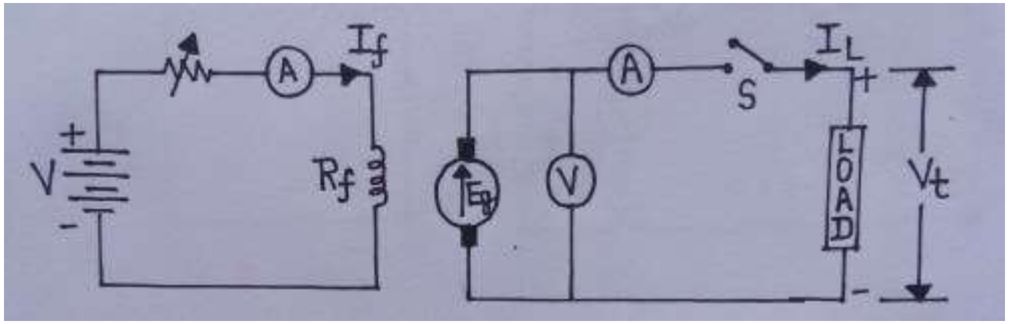
Now, adjust I_F till I_a is equal to rated armature current and take instrument readings.

Vary the load and field current such that I_a and N remain constant, but terminal voltage V_t changes and keep taking more readings.

CHARACTERISTICS OF DC GENERATORS

3. **External Characteristic**

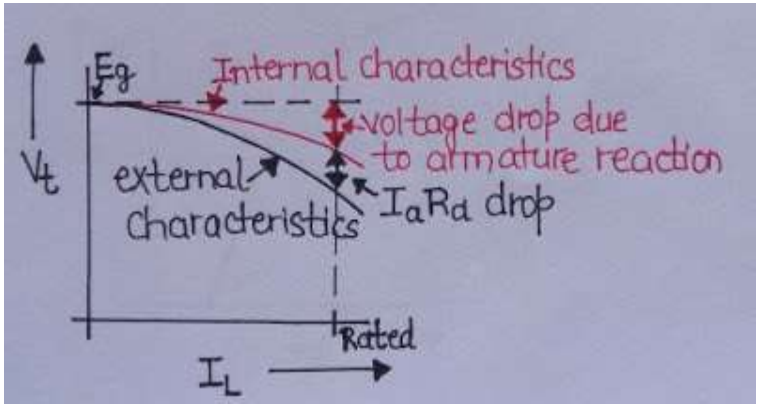
variation of terminal voltage V_t with load current I_L for constant speed N and constant field current I_F .



Firstly, generator is run at rated speed and its field winding is excited to give rated terminal voltage at no-load.

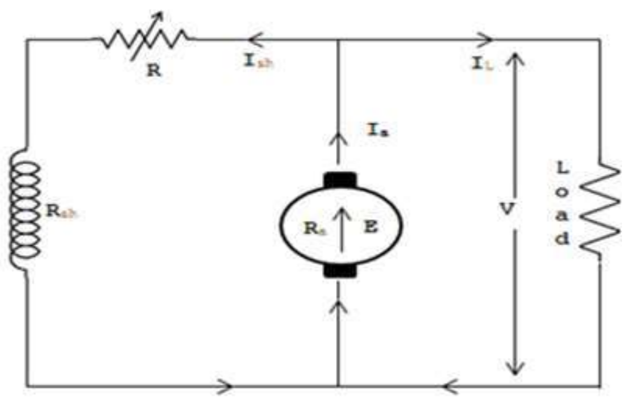
Now, close the switch S , vary load resistance and note V_t and I_L . Keep repeating it for various readings.

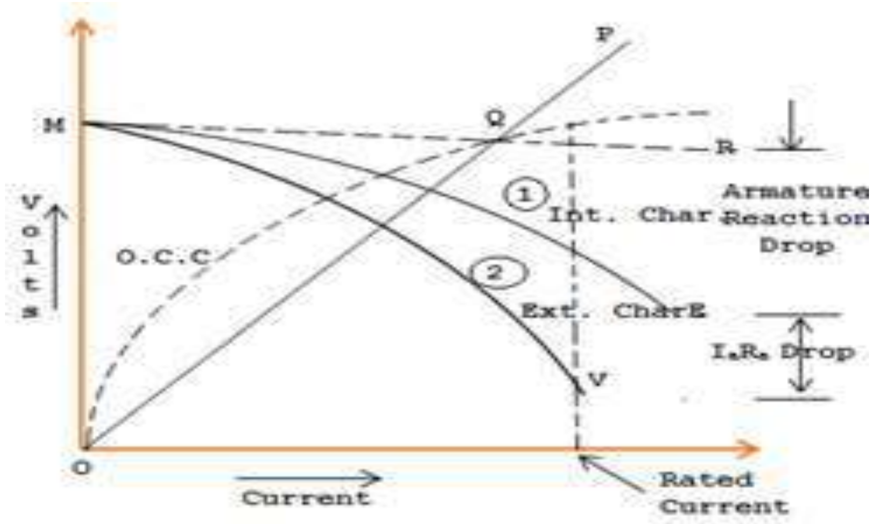
The decrease in terminal voltage with increase in load is due to the voltage drops caused by armature reaction and armature resistance (includes brush contact resistance).



CHARACTERISTICS OF DC GENERATORS

Characteristic of Shunt Excited DC Generator





(i) O.C.C

The O.C.C. of a shunt generator is similar in shape to that of a series generator as shown in Fig. The line OP represents the shunt field circuit resistance. When the generator is run at normal speed, it will build up a voltage OM. At no-load, the terminal voltage of the generator will be constant (= OM) represented by the horizontal dotted line MR.

(ii) Internal characteristic

The internal characteristic of a shunt Generator is shown in the curve 1. As soon as the generator gets loaded, flux per pole is decreased because of armature reaction. For that reason, emf. E generated on load is a smaller amount than the emf. generated at no load. Thus the internal characteristics curve of shunt generator (E/Ia) drops down slightly.

(iii) External characteristic

Curve 2 shows the external characteristic of a shunt generator. It gives the relation between terminal voltage V and load current IL.

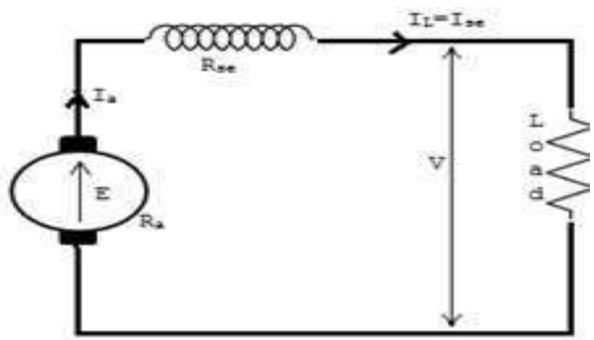
$$V = E - I_a R_a = E - (I_L + I_{sh}) R_a$$

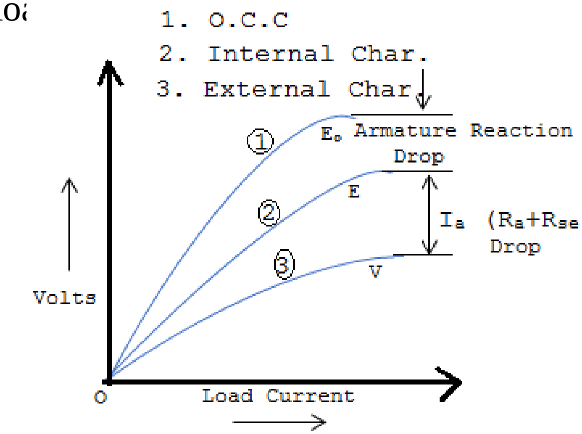
Therefore, external characteristic curve will lie below the internal characteristic curve by an amount equal to drop in the armature circuit [i.e., $(I_L + I_{sh})R_a$].

CHARACTERISTICS OF DC GENERATORS

Characteristic of Series Excited DC Generator

Since there's only one current that that flows through the full machine, the loa current is that the same because the exciting current.





(i) O.C.C

In the below fig the first curve shows that open circuit characteristic curve of a series generator. It will be obtained by experimentation by cut off the field winding from the machine and exciting it from a separate DC supply as mentioned in the O.C.C of DC Generator.

(ii) Internal characteristic

The second curve shows the internal characteristic of a series generator. It provides the relation amongst the generated emf. E on load and armature current. As a result of armature reaction, the flux in the machine will be less than that the flux at no load. Hence, emf. E generated underneath load conditions will be less than the emf. E_0 generated underneath no load conditions. Therefore, internal characteristic lies below the O.C.C. curve; the distinction between them representing the impact of armature reaction.

(iii) External characteristic

The external characteristic of a series generator is shown in curve of above fig. This curve shows the relation between terminal voltage and load current I_L: $V=E-I_a(R_a+R_{se})$

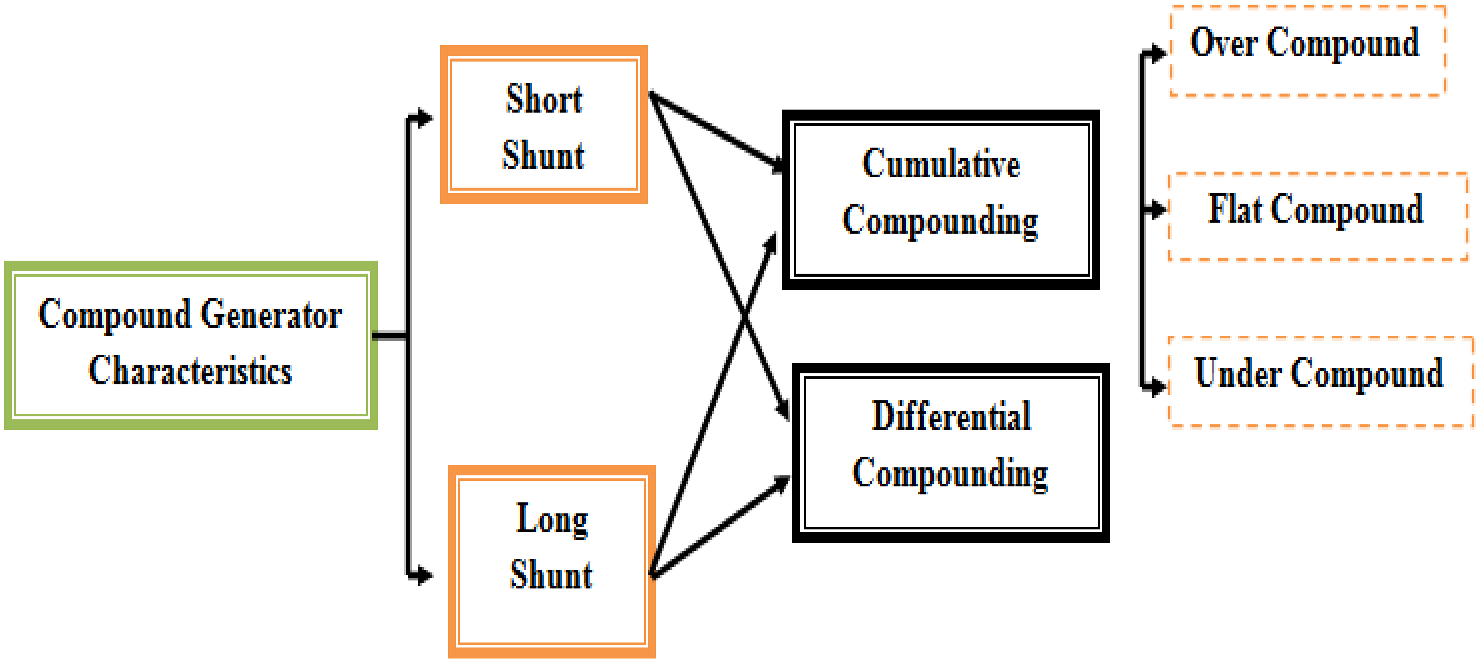
Therefore, external characteristic can lie below internal characteristic by an amount equal to resistance unit drop

[i.e., $I_a(R_a + R_{se})$] within the machine.

CHARACTERISTICS OF DC GENERATORS

Characteristic of Compound Excited DC Generator

There are mainly two types of dc compound generator. These are long shunt and short shunt. For more information for these two types of dc generator please check the post types of dc generator. Both of these generators can also be categorized as cumulatively compound and differentially compound dc generator. The differentially compound and cumulatively compound generators have their own typical characteristics. But the compound generators mostly affect the external characteristics of compound dc generator.



CHARACTERISTICS OF DC GENERATORS

Characteristic of Compound Excited DC Generator

(i) O.C.C

Like a separately excited dc generator, we use a separate source for the field for drawing OCC of a compound DC generator. In this case, we first disconnect the field winding from the machine. Then we excite the field from an external variable dc source. Now we slowly increase the field current from zero to its rated value. During this experiment, we run the generator with its rated speed without any connected load. Also, we gradually increase the field current and measure the output voltage at each step. Now we can draw the curve for open circuit characteristic with the measured voltages along with their corresponding field currents. The no-load or open circuit characteristic of a dc compound generator is similar to that of a separately excited dc generator.

(ii) Internal characteristic

The internal characteristics of a dc compound generator can be made flat for the range of field currents.

When the generator is differentially compounded, with the increase in load current, the voltage across the armature decreases more rapidly than a dc series generator.

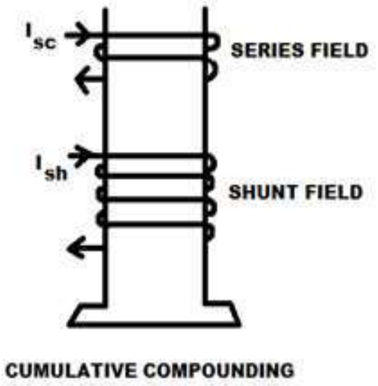
Besides a cumulatively compound generator shows more upward internal characteristic than a standard series generator.

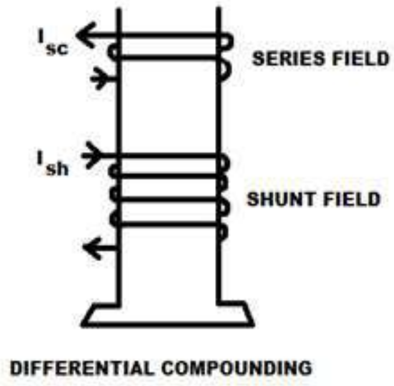
(iii) External characteristic

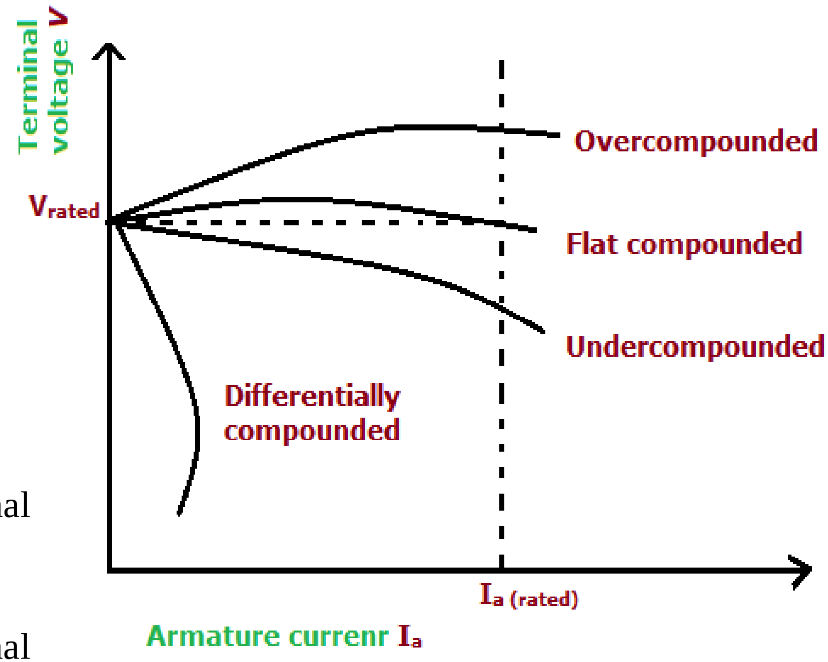
Here, we measure the load terminal voltages for different load currents. Then we plot the load terminal voltages and load currents. And we get the external characteristics of the dc compound generator. If the terminal voltage increases with the increasing load current, we call the machine as over compounded dc generator. Again, if the terminal voltage of the machine decreases with the increasing load current, we call this as under compounded dc generator. But by adjusting the field orientation we can make such a machine, which has almost constant terminal voltage for all the loading conditions. We call this generator as the flat compounded dc generator.

CHARACTERISTICS OF DC GENERATORS

Characteristic of Compound Excited DC Generator







Over compounded: the generator full load terminal voltage is higher than the no-load terminal voltage.

Flat compounded(Level compounded): The terminal voltage of generator at full load is equal to the no-load terminal voltage.

Under compounded: the generator terminal voltage at full load is less than the no-load terminal voltage.

In differential compounded generators, the terminal voltage drops very quickly with increasing armature current.

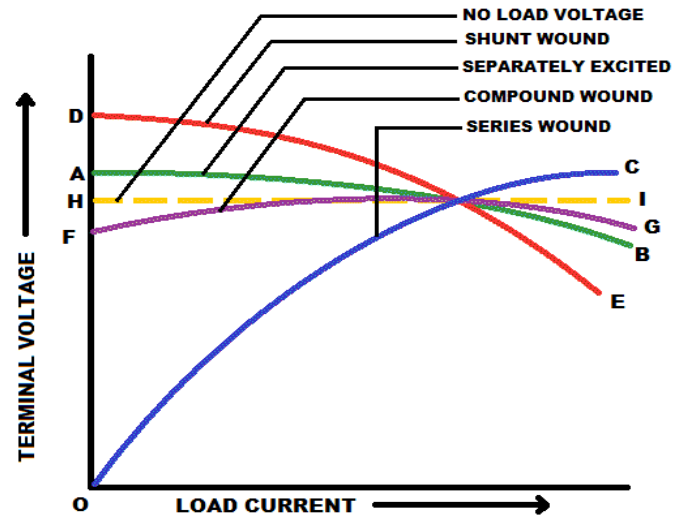
DC GENERATORS PERFORMANCE CURVES

Performance curves of a DC generator is that curves which shows the ability of delivering output voltage of a DC generator with the change in load current from no load to full load. These are also called characteristic curves. From the performance curve we can get a clear idea about the voltage regulation of various kind of DC generators. The lower the voltage regulation will be, the performance of the generator will be better.

In separately excited DC generators, the terminal voltage as the load increases and the load current started to flow.

In shunt wound DC generators, there is always some no load voltage due to the existence of shunt field winding. As the load increases, the terminal voltage of this type of DC generators decreases very quickly. It has very large demagnetizing armature reaction and armature resistance drop.

In series DC generators, the terminal voltage at no load will be zero because there is no current flowing through the field winding. When load increases then output voltage also increases.



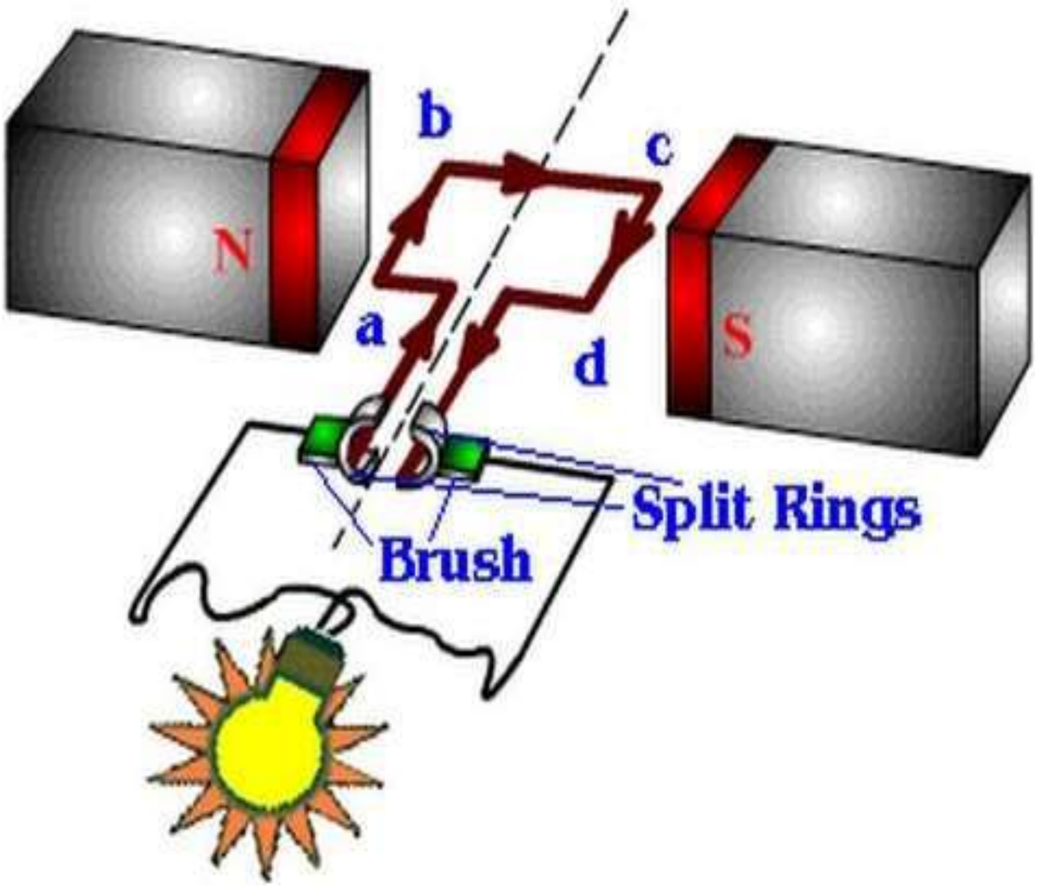
PERFORMANCE CURVES OF DC GENERATORS

At no load, the performance curve of this type of DC generator is same as that of shunt field generators because at no load, there is no current in the series field winding. When the load increases, then the terminal voltage drops due to the shunt DC generator, but the voltage rise in the series DC generator compensates the voltage drop. For these reason the terminal voltage remains constant.


Thank you

Module:2

DC GENERATOR



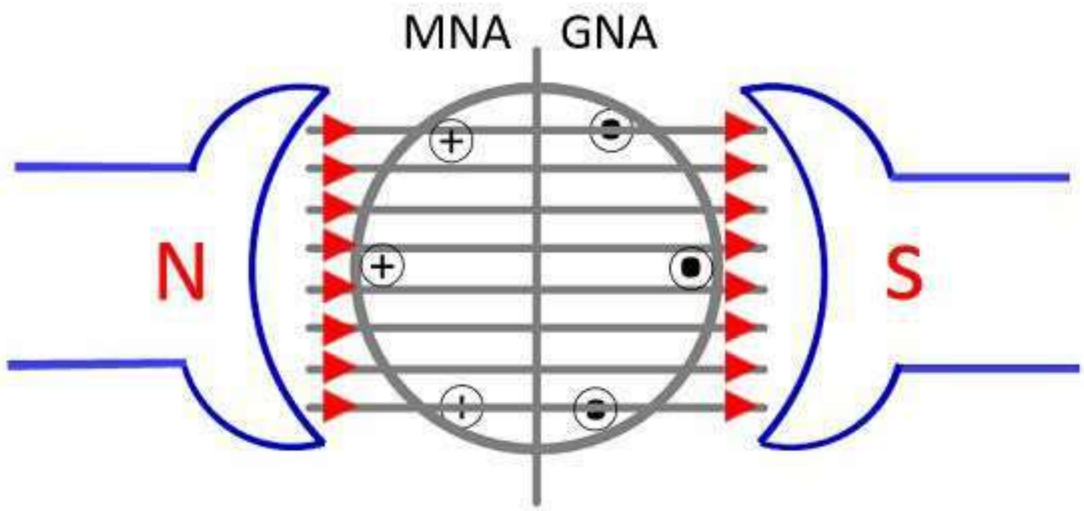
Topic:

- **FLUX DISTRIBUTION IN DC GENERATOR**
- **VOLTAGE REGULATION**
- **APPLICATION OF DC GENERATOR**

FLUX DISTRIBUTION IN DC GENERATOR

Armature mmf has definite effects on both the space distribution of the air-gap flux and the magnitude of the net flux per pole. The effect on flux distribution is important because the limits of successful commutation are directly influenced; the effect on flux magnitude is important because both the generated voltage and the torque per unit of armature current are influenced thereby.

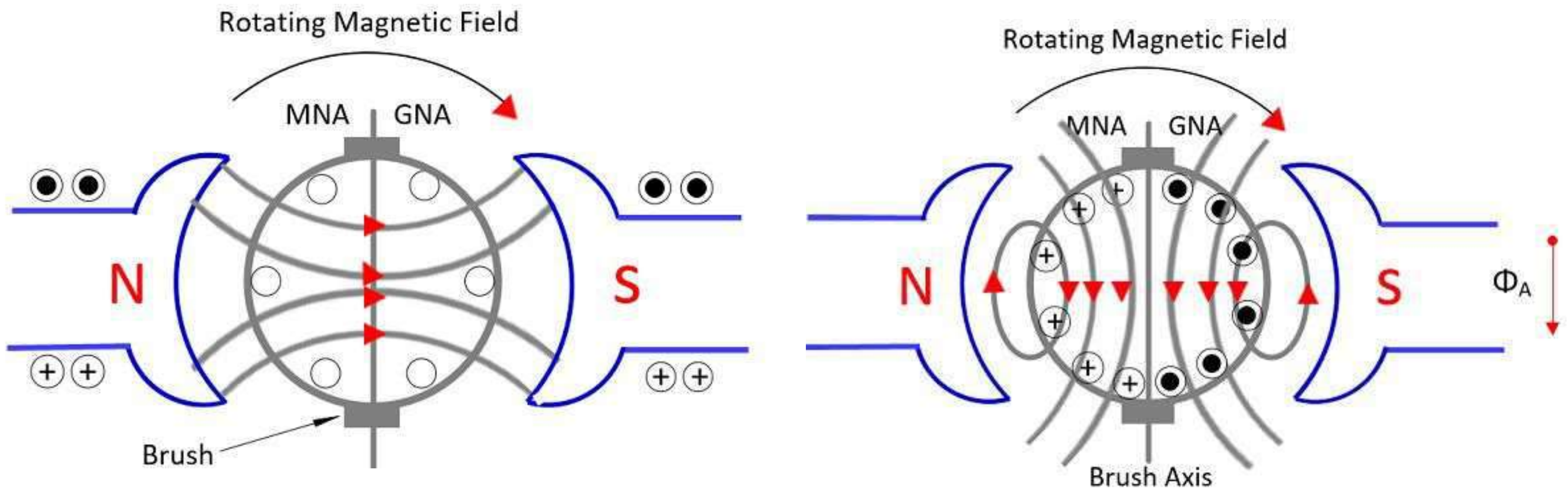
Distribution of armature flux simply shows the effect of armature field on the main field. In other words, the armature reaction represents the impact of the armature flux on the main field flux. The armature field is produced by the armature conductors when current flows through them. And the main field is produced by the magnetic poles.



FLUX DISTRIBUTION IN DC GENERATOR

The armature flux causes two effects on the main field flux.

- The armature flux distorted the main field flux
- It reduces the magnitude of the main field flux.

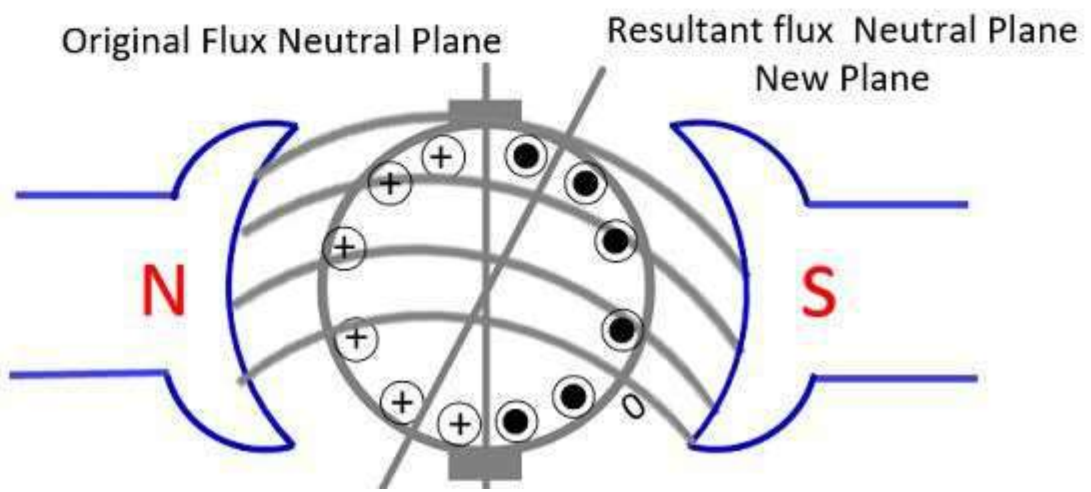


The brushes of the DC machines are always placed in this axis, and hence this axis is called the axis of commutation.

FLUX DISTRIBUTION IN DC GENERATOR

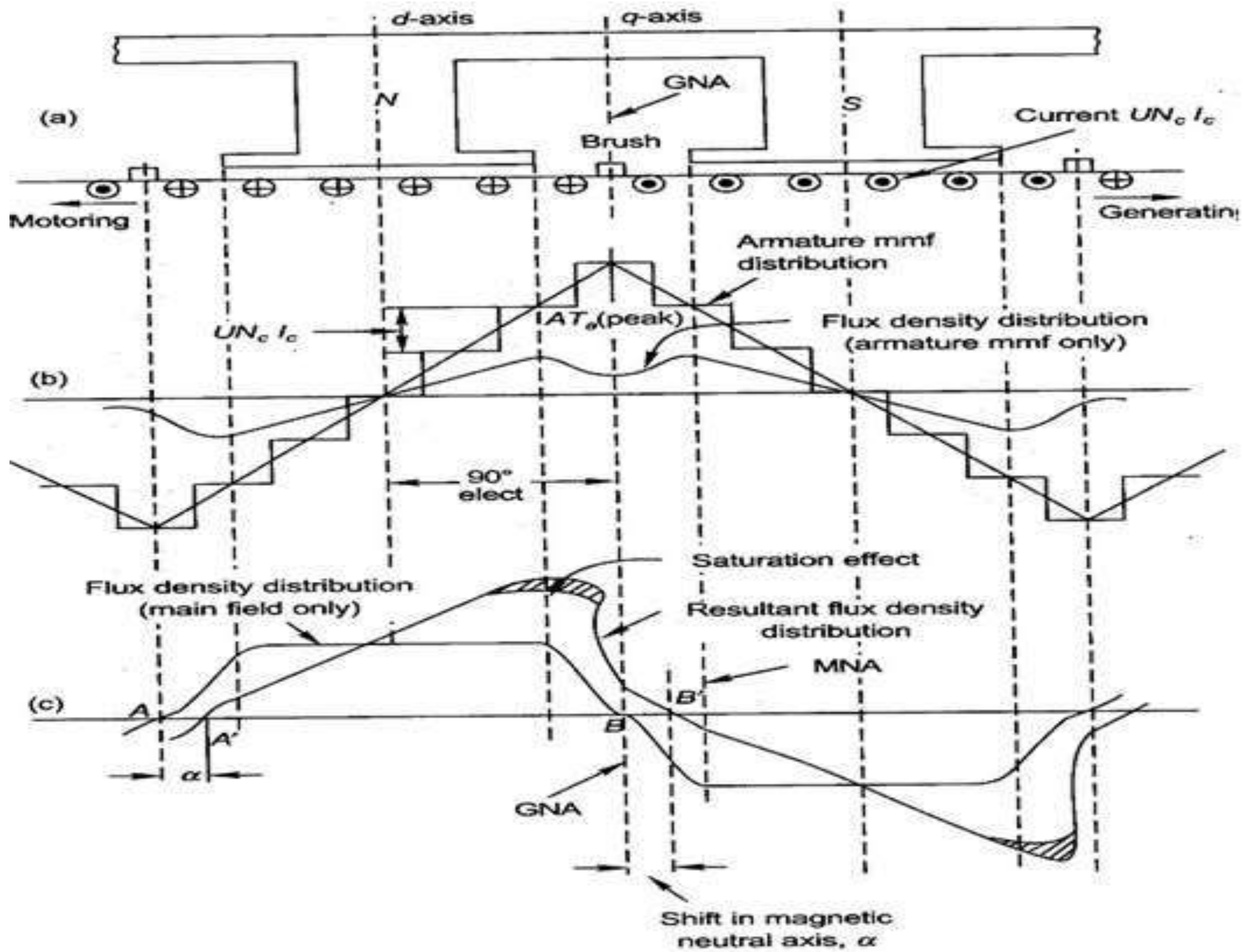
When the field flux enters into the armature, they may get distorted. The distortion increases the density of the flux in the upper pole tip of N-pole and the lower pole tip of the south pole. Similarly, the density of flux decreases in the lower pole tip of the north pole and the upper pole tip of the south pole.

The resultant flux induces in the generator are shifted towards the direction of the rotation of generator. The magnetic neutral axis of poles is always perpendicular to the axis of the resultant flux. The MNA is continuously shifted with the resultant flux.



GRAPHICAL PICTURE OF FLUX DENSITY DISTRIBUTION

The armature flux distribution in a dc machine is cross-magnetizing causing distortion in the flux density wave shape and a slight shift in MNA. It also causes demagnetization because a machine is normally designed with iron slightly saturated.



(a) Layout of armature and field of 2-poles of a dc machine
(b) Armature mmf and flux density distribution (brushes in geometrical neutral axis (GNA))
(c) Main field and resultant flux density distribution-shift (α) in magnetic neutral axis (MNA)

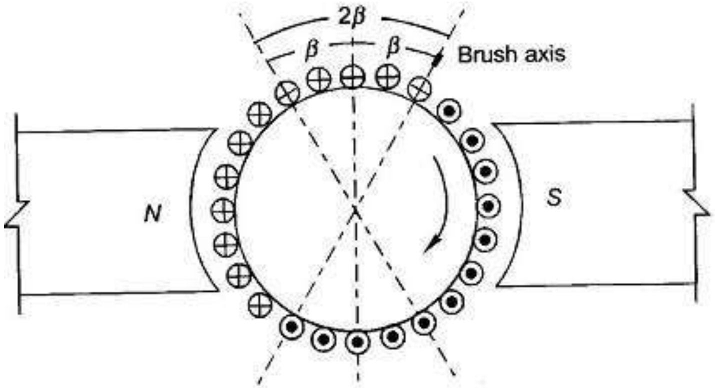
FLUX DISTRIBUTION IN DC GENERATOR

Distortion of flux density distribution resulting in increase of flux density on one side of the pole and decrease on the other, causes iron-loss in teeth to increase because these depend upon the square of the flux density (approximately). Distortion of flux distribution also has an adverse effect on commutation but this is overcome by Interpoles. This distortion, in fact, is an important factor limiting the short-time overloading capacity of a dc machine.

The cross-magnetizing effect of the armature reaction can be reduced by making the main field ampere-turns larger compared to the armature ampere-turns such that the main field mmf exerts predominant control over the air-gap flux. This is achieved by: Introducing saturation in the teeth and pole-shoe.

By chamfering the pole-shoes which increases the air-gap at the pole tips. This method increases the reluctance to the path of main flux but its influence on the cross-flux is much greater.

The best yet the most expensive method is to compensate the armature reaction mmf by a compensating winding located in the pole-shoes and carrying a suitable current.



Effect of brush shift

VOLTAGE REGULATION

It is clear from the impact of load changes on terminal voltage that a measure of the variation in terminal voltage with load is required.

The regulation of a generator refers to the VOLTAGE CHANGE that takes place when the load changes. It is usually expressed as the change in voltage from a no-load condition to a full-load condition, and is expressed as a percentage of full-load. It is expressed in the following formula:

$$VR = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100\%$$

where V_{nl} is the no-load voltage at the terminals of the generator and V_{fl} is the full-load voltage. The voltages in the above equation may be either phase of line-line quantities, as long as they are consistent (i.e. phase no-load and phase full-load)

In the ideal case, VR will equal 0%. In order to achieve this, the excitation voltage must be adjusted with load conditions, i.e. the field voltage must be controlled.

APPLICATION OF DC GENERATOR

Applications of Separately Excited DC Generators

These types of DC generators are generally more expensive than self-excited DC generators because of their requirement of separate excitation source. Because of that their applications are restricted. They are generally used where the use of self-excited generators are unsatisfactory.

1. Because of their ability of giving wide range of voltage output, they are generally used for testing purpose in the laboratories.

2. Separately excited generators operate in a stable condition with any variation in field excitation. Because of this property they are used as supply source of DC motors, whose speeds are to be controlled for various applications. Example- Ward Leonard Systems of speed control.

APPLICATION OF DC GENERATOR

Applications of Shunt Wound DC Generators

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

1. They are used for general lighting.

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

3. They are used for giving the excitation to the alternators.

4. They are also used for small power supply.

APPLICATION OF DC GENERATOR

Applications of Series Wound DC Generators

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

1. They are used for supplying field excitation current in DC locomotives for regenerative breaking.

2. This types of generators are used as boosters to compensate the voltage drop in the feeder in various types of distribution systems such as railway service.

3. In series arc lightening this type of generators are mainly used.

APPLICATION OF DC GENERATOR

Applications of Compound Wound DC Generators

Among various types of DC generators, the compound wound DC generators are most widely used because of its compensating property. We can get desired terminal voltage by compensating the drop due to armature reaction and ohmic drop in the in the line. Such generators have various applications.

1. Cumulative compound wound generators are generally used lighting, power supply purpose and for heavy power services because of their constant voltage property. They are mainly made over compounded.

2. Cumulative compound wound generators are also used for driving a motor.

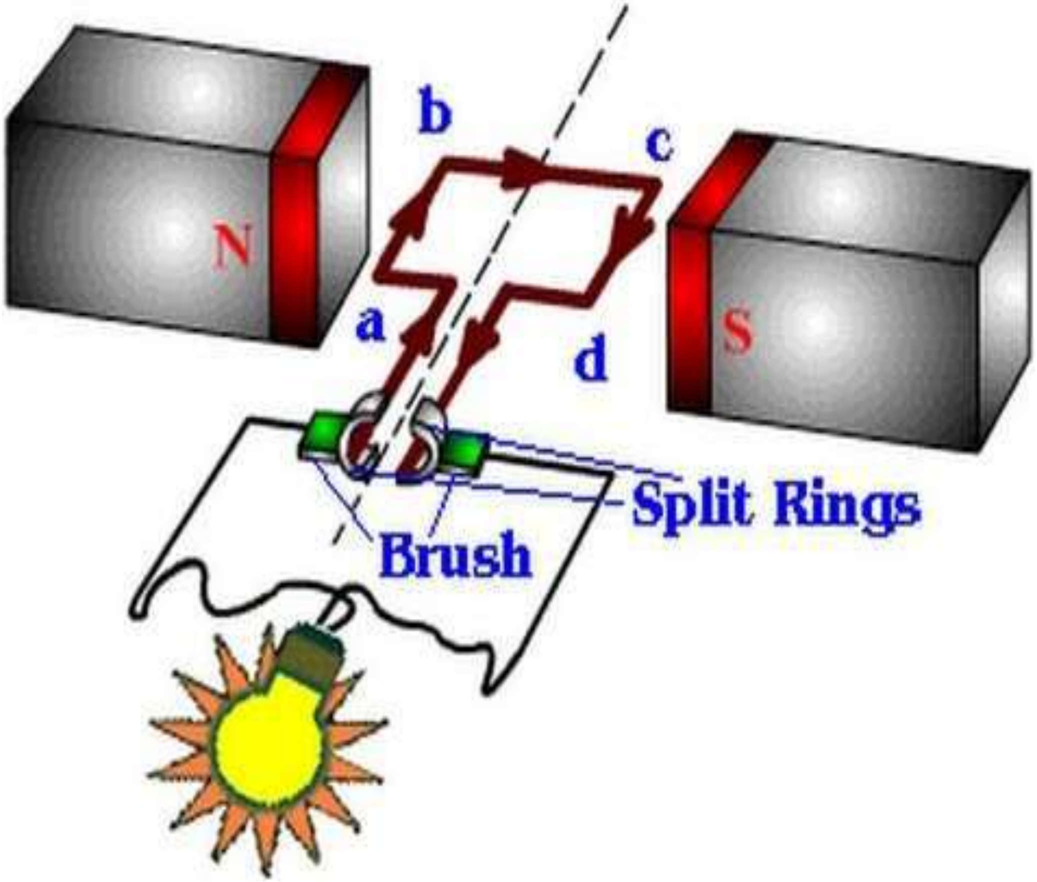
3. For small distance operation, such as power supply for hotels, offices, homes and lodges, the flat compounded generators are generally used.

4. The differential compound wound generators, because of their large demagnetization armature reaction, are used for arc welding where huge voltage drop and constant current is required.


Thank you

Module:2

DC GENERATOR



Topic:

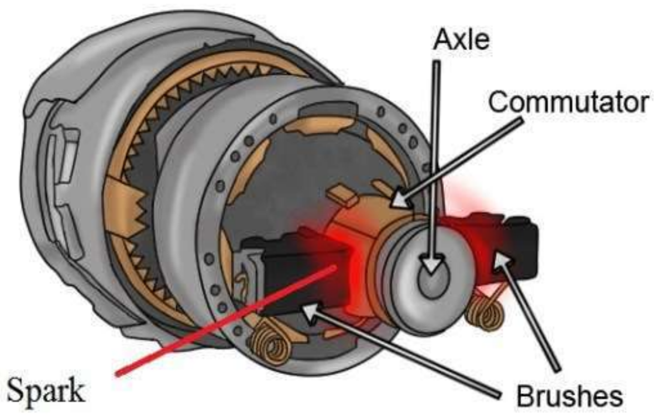
- **COMMUTATION PROCESS IN DC GENERATOR**
- **PARALLEL OPERATION OF DC GENERATORS**
- **CONCEPTS OF LOAD SHARING**

COMMUTATION PROCESS IN DC GENERATOR

An electrical generator is one kind of electrical machine, used to convert input mechanical form energy to electrical energy either AC (or) DC. Depending upon the output it is classified as an AC generator or a DC generator. The DC generator consists of a Yoke, armature core, pole core, bearings, brushes, and a commutator. Each component of the DC generator has its individual role to play in the operation. Among them, the working of a commutator is very important. As any machine delivers its output as an alternating power. Here, the commutator converts this alternating power to the required DC power in the case of a generator. So, the operation of the commutator plays a crucial role in the operation of these machines.

What is Commutation

It is the process of conversion of alternating current (AC) to Direct current (DC) and DC to AC. It can also be defined as the process of conversion of armature current with the help of commutator segments and brushes. The figure below represents the commutator.

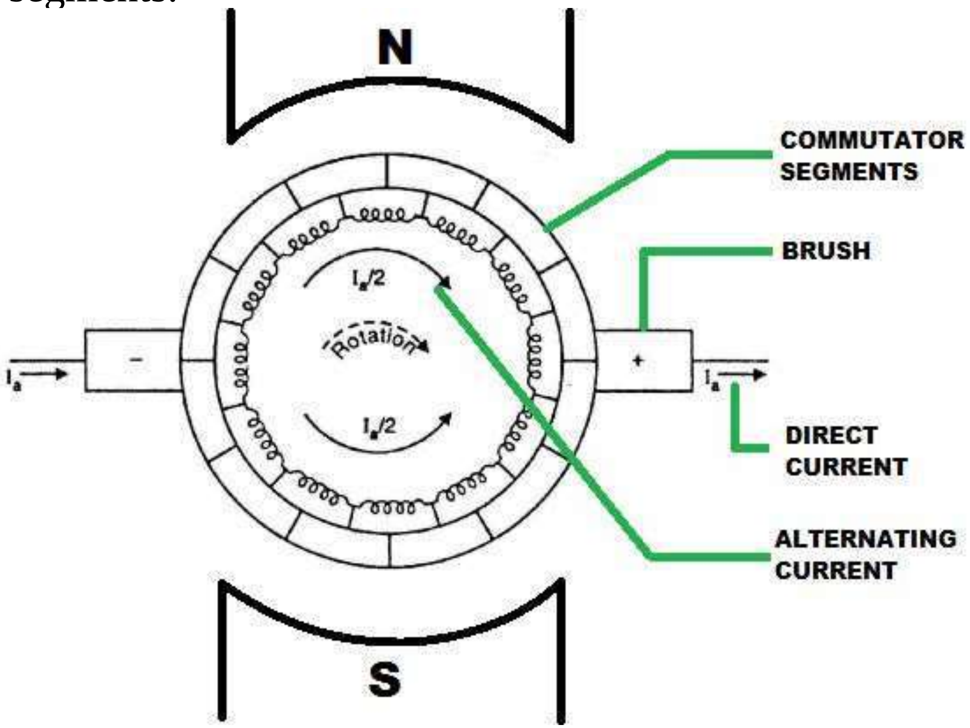


A good commutator process takes place when there is no sparking at the brush contacts. Poor commutator process occurs due to the sparking between the brushes and commutator segments. Due to this, there is a possibility of damage when operated continuously.

COMMUTATION IN DC GENERATOR

Each Armature coil contains two commutator attached at its end. For the transformation of current, the Commutator segments and brushes should maintain a continuously moving contact. To get larger output values more than one coil is used in DC machines. So, instead of one pair, we have a number of pairs of Commutator segments.

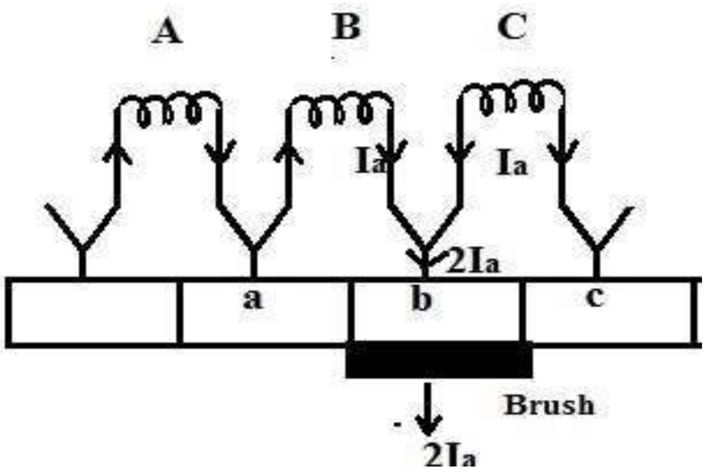
The coil is short-circuited for a very short period of time with the help of brushes. This period is known as commutation period. Let us consider a DC motor in which the width of the Commutator bars is equal to the width of the brushes. Let the current flowing through the conductor be Ia. Let a, b, c be the Commutator segments of the motor. The current reversal in the coil .i.e. commutation process can be understood by the below steps.



COMMUTATION IN DC GENERATOR

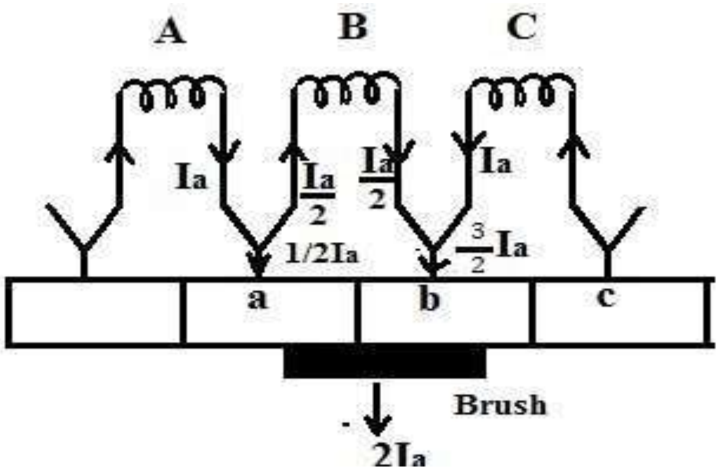
Position-1

Let the Armature starts rotating, then the brush moves over the commutator segments. Let the first position of the brush commutator contact be at segment b as shown above. As the width of the commutator is equal to the width of the brush, in the above position the total areas of commutator and brush are in contact with each other. The total current conducted by the commutator segment into the brush at this position will be 2Ia.



Position-2

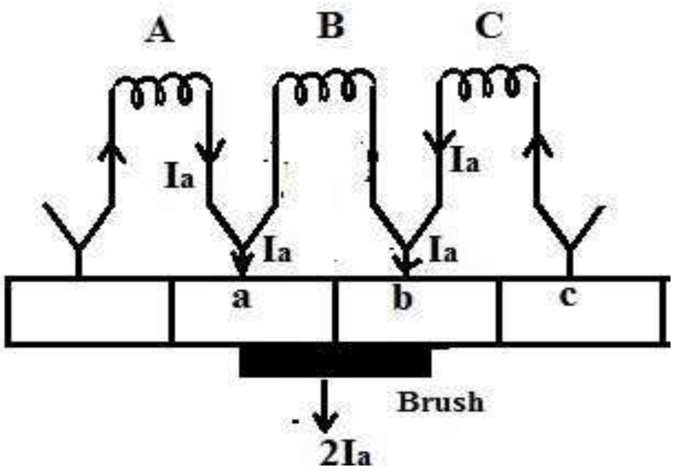
Now the armature rotates towards the right and the brush comes in contact with the bar a. At this position, the total conducted current will be 2Ia, but the current in the coil changes. Here the current flows through two paths A and B. 3/4th of the 2Ia comes from the coil B and remaining 1/4th comes from coil A. When KCL is applied at the segment a and b, the current through the coil B is reduced to Ia/2 and the current drawn through segment a is Ia/2.



COMMUTATION IN DC GENERATOR

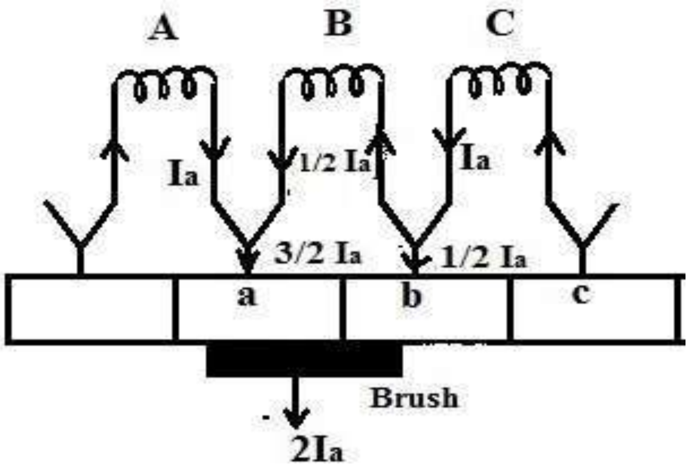
Position-3

At this position half of the brush, a surface is in contact with segment a and the other half is with segment b. As the total current drawn trough brush is 2Ia, current Ia is drawn through coil A and Ia is drawn through coil B. Using KCL we can observe that the current in coil B will be zero.



Position-4

In this position, one-fourth of the brush surface will be in contact with segment b and three fourth with segment a. Here the current drawn through coil B is –Ia/2. Here we can observe that the current in coil B is reversed.



CAUSES OF POOR COMMUTATION

Mechanical Reasons

1. Unequal commutator surface

There will be arc production continuously due to the uneven surface. Due to the continuous arc production, the portion of the commutator segments loses its life expectancy.

2. Improper brush pressure

As the brushes are attached to the commutator continuously pressure will be imparted on to the commutator segments. Due to this overheating takes place inside the commutator which decreases the life of the commutator.

3. Brushes placed in the holders

Due to improper holding of brushes, vibrations occur which produces noise. This might also decrease the efficiency and life expectancy.

Electrical Reasons

1. The voltage between adjacent commutator segments Increases

Due to the increase in voltage between adjacent commutator segments, the dielectric strength of Mica insulation gets damaged. This could also lead to the short-circuit of coils.

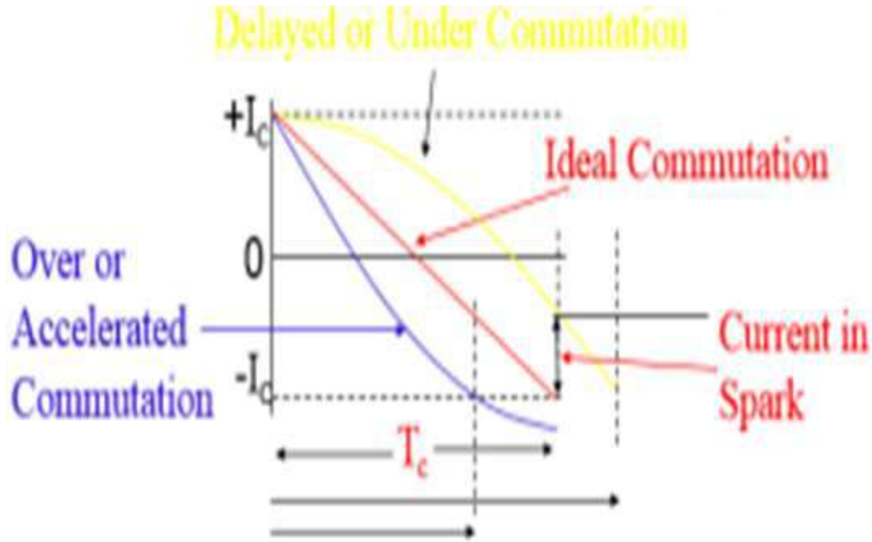
2. Current density at the trailing end of the brush increases

Due to the increase in current density, the surrounding air gets conducted which leads to sparking. Due to the sparking, the efficiency and life expectancy both will be decreased.

METHODS OF IMPROVING COMMUTATION

These problems arise mainly due to the circulating currents. If we can able to decrease these circulating currents. Then, the commutator operation can be improved. There are different methods to improve commutator operation. They are Using the open type of slots

1. By using Brush shifting
2. By using the resistance method
3. Using EMF method



By the usage of open type slots, the reluctance path is more such that the strength of leakage flux gets reduced. As reactance voltage is directly proportional to the leakage flux. As the leakage flux is reduced, the reactance voltage also gets reduced.

Due to the armature reaction, there will be a demagnetization effect of the magnetic field. The magnetic field is distorted due to the armature reaction. This affects the commutator segments and brushes, as they are aligned at no voltage position. Due to the demagnetization, some voltage flows in the commutator at no-load condition. This affects the life of commutator segments and brushes. To avoid these problems, the brush axis is shifted.

By replacing the low resistance carbon brushes with the high resistance carbon brushes we can decrease the circulating currents. Thus, by decreasing the circulating currents we can improve the commutator operation of a DC generator.

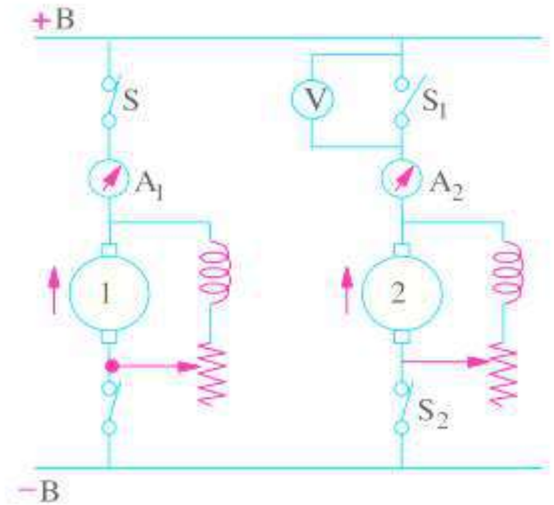
Emf commutator operation is attained by the addition of Interpol's or commutating poles. The strength of Interpol's is about 120% to 130% of cross magnetizing the magnetic field.

PARALLEL OPERATION OF D.C. GENERATORS

In a d.c. power plant, power is usually supplied from several generators of small ratings connected in parallel instead of from one large generator.

Parallel operation of DC generators is required to meet the extra load demand. It is always difficult to meet the extra load demand by a single generator, or it is not possible to give supply when one generator is out of order.

Normally the generators are coupled in parallel at most of the power station through bus-bars. Bus-bars have positive and negative terminals and they must be dense thick copper bars. The positive and negative terminals of the bus-bars are connected to the positive and negative terminal of the generator respectively.



REASON FOR WHY TO CHOOSE PARALLEL OPERATION OF DC GENERATOR

1. Continuity of service:

If a single large generator is used in the power plant, then in case of its breakdown, the whole plant will be shut down. However, if power is supplied from a number of small units operating in parallel, then in case of failure of one unit, the continuity of supply can be maintained by other healthy units.

2. Efficiency:

Generators run most efficiently when loaded to their rated capacity. Electric power costs less per kWh when the generator producing it is efficiently loaded. Therefore, when load demand on power plant decreases, one or more generators can be shut down and the remaining units can be efficiently loaded.

REASON FOR WHY TO CHOOSE PARALLEL OPERATION OF DC GENERATOR

3. Maintenance and repair:

Generators generally require routine-maintenance and repair. Therefore, if generators are operated in parallel, the routine or emergency operations can be performed by isolating the affected generator while the load is being supplied by other units. This leads to both safety and economy.

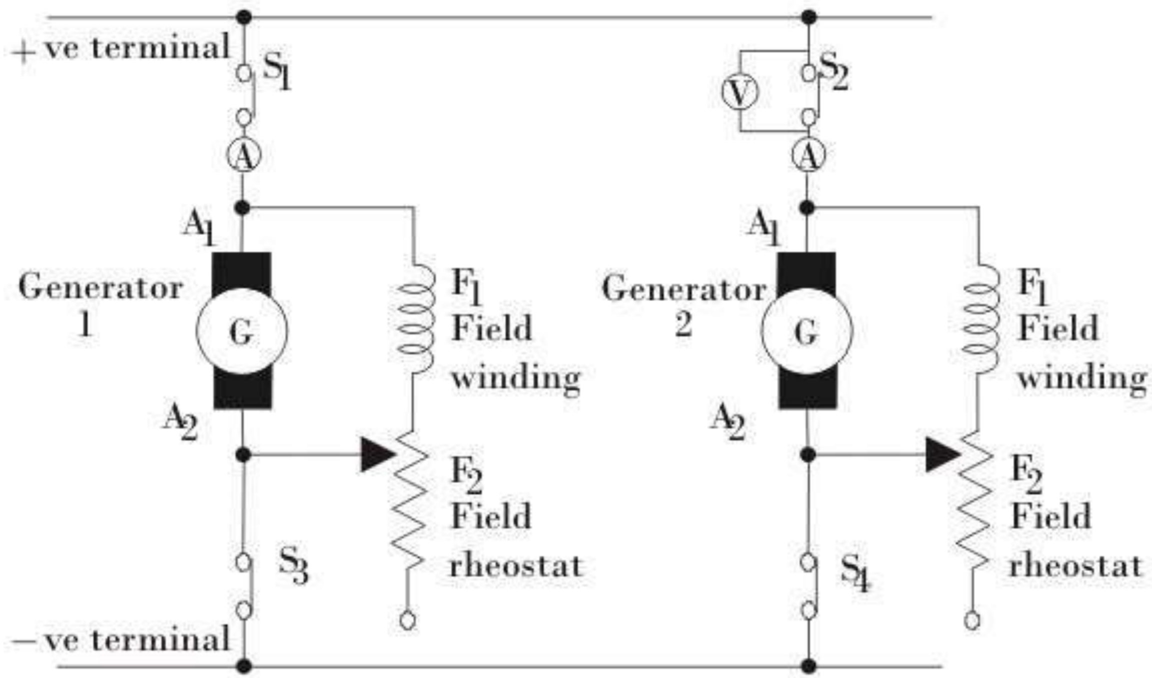
4. Increasing plant capacity:

In the modern world of increasing population, the use of electricity is continuously increasing. When added capacity is required, the new unit can be simply paralleled with the old units. In many situations, a single unit of desired large capacity may not be available. In that case, a number of smaller units can be operated in parallel to meet the load requirement. Generally, a single large unit is more expensive.

5. Non-availability of single large unit:

In many situations, a single unit of desired large capacity may not be available. In that case, a number of smaller units can be operated in parallel to meet the load requirement. Generally, a single large unit is more expensive.

CONNECTION OF PARALLEL DC GENERATORS



1. The generators in a power plant, connected by heavy thick copper bars, called bus-bars which act as positive and negative terminals. To connect the generators in parallel, Positive terminal of the generators are connected to the positive terminal of the bus-bars and negative terminals of generators are connected to negative terminal of the bus-bars

CONNECTION OF PARALLEL DC GENERATORS

2. To connect the 2 generators with the 1 existing working generators, first we have to bring the speed of the prime mover of the 2nd generator to the rated speed. At this point switch S_4 is closed.

3. The circuit breaker V_2 (voltmeter) connected across the open switch S_2 is closed to complete the circuit. The excitation of the generator 2 is increased with the help of field rheostat till it generates voltage equal to the voltage of bus-bars.

4. The main switch S_2 is then closed and the generator 2 is ready to be paralleled with existing generator. But at this point of time generator 2 is not taking any load as its induced emf. is equal to bus-bar voltage. The present condition is called floating, that means ready for supply but not supplying current to the load.

5. In order to deliver current from generator 2, it is necessary that its induced emf. E should be greater than the bus-bars voltage V. By strengthening the field current, the induced emf. of generator 2 could be improved and the current supply will get started. To maintain bus-bar voltage, the field of generator 1 is weakened so that value remains constant.0

CONDITIONS FOR PARALLEL OPERATION OF DC GENERATOR

1. The terminal voltage must be the same.

2. The polarities of the generator must be identical.

3. The prime movers driving the armature of the generators must have similar and stable rotational characteristics.

4. The change of voltage with the change of load must be the same character.

REQUIREMENT FOR PARALLEL OPERATION OF DC GENERATOR

Paralleling FC generator is required mainly for the following two types of situations.

1. Paralleling of shunt generators for the same or varying sizes.

2. Paralleling of compound generators of the same and varying sizes.

PRECAUTIONS DURING PARALLEL CONNECTION

1. The specification of each generator is different from one another. When they are synchronized together, their speed are locked into the overall speed of the system.

2. The entire load of the system should be distributed in all the generators.

3. There should be a controller for keeping check on parameters of the engine. This can be done with modern digital controllers which are available in market.

4. Voltage regulation in the whole system plays an important role. In case of voltage drop in one unit compare with other units, end up bearing the whole voltage load of the system of parallel generators.

5. While connecting terminals to the bus-bars, extra precaution should be made. If generator is connected with wrong polarity of the bar, it may result to a short circuit.

LOAD SHARING OF TWO GENERATORS

The load sharing between shunt generators in parallel can be easily regulated because of their drooping characteristics. The load may be shifted from one generator to another merely by adjusting the field excitation. Let us discuss the load sharing of two generators which have unequal no-load voltages.

Let E_1, E_2 = no-load voltages of the two generators

R_1, R_2 = their armature resistances

V = common terminal voltage (Bus-bars voltage)

then $I_1 = (E_1 - V)/R_1$ and $I_2 = (E_2 - V)/R_2$

Thus the current output of the generators depends upon the values of E1 and E3.These values may be changed by field rheostats. The common terminal voltage (or bus-bars voltage) will depend upon

1. The e.m.f.s of individual generators and

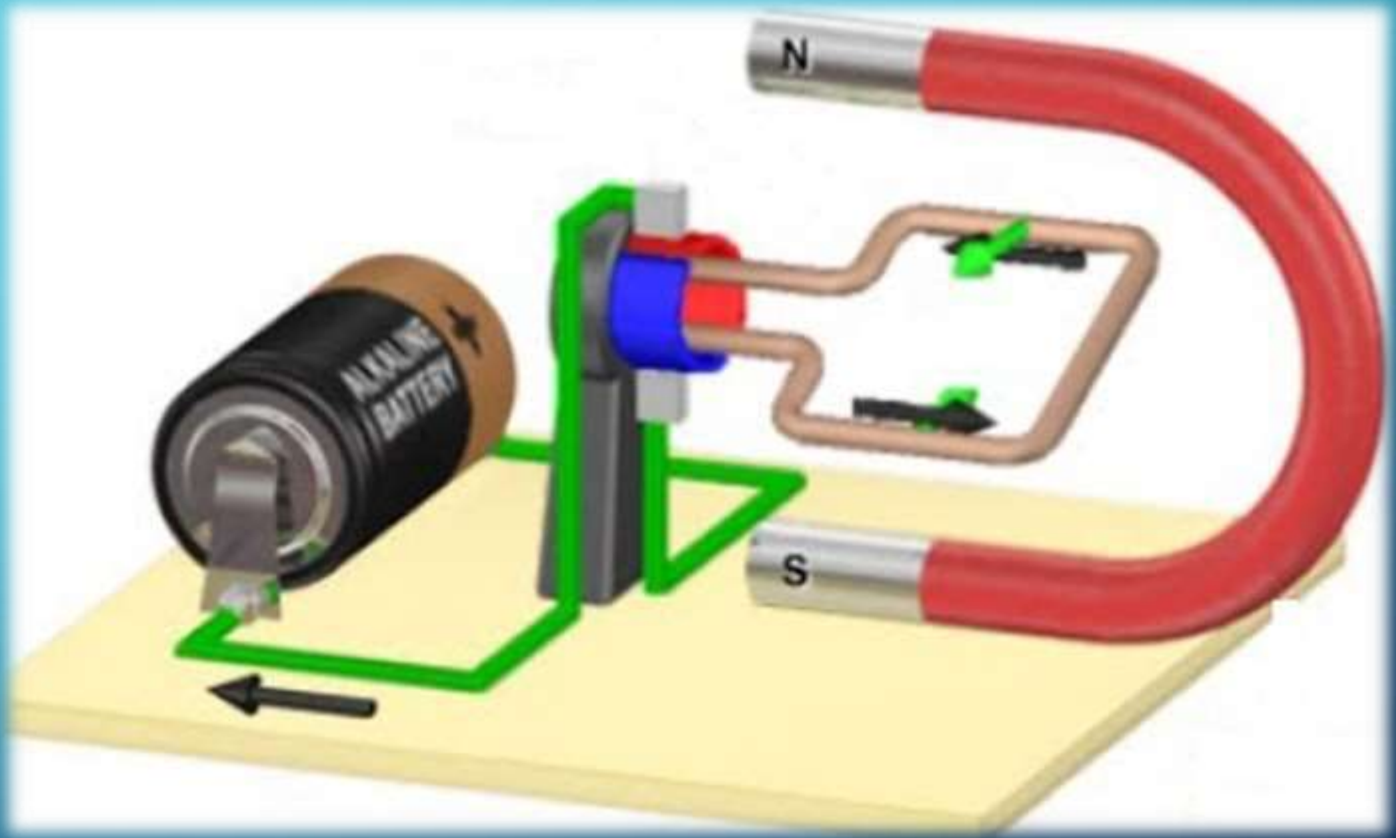
2. The total load current supplied.

It is generally desired to keep the bus bars voltage constant. This can be achieved by adjusting the field excitations of the generators operating in parallel.


Thank you

MODULE:3

DC MOTOR



Name of the course : Electrical Machine – I
Course Code : EE/S3/EMI
Semester : Third

3.1 Working principles, Back emf, Speed and Torque equation. (Numerical)

3.2 Characteristics of Series, Shunt & Compound motors.

3.3 Methods of speed control of DC motors. (Numerical)

3.4 Starting methods of DC motor – 3-point & 4-point starter.

3.5 Losses and Efficiency (Numerical).

3.6 Braking methods of DC motor – Regenerative braking, Counter current braking, Dynamic braking.

3.7 Applications of different types of DC motor.

TOPIC:

- CONCEPT OF DC MOTOR
- APPLICATION OF DC MOTOR
- TYPES OF DC MOTOR
- BASIC CONSTRUCTION OF DC MOTOR
- WORKING PRINCIPLE OF DC MOTOR

INTRODUCTION TO DC MOTOR

Almost every mechanical development that we see around us is accomplished by an electric motor. Electric machines are a method of converting energy. Motors take electrical energy and produce mechanical energy. Electric motors are utilized to power hundreds of devices we use in everyday life.

A DC motor is an electric motor that runs on direct current power. In an electric motor, the operation is dependent upon simple electromagnetism. A current-carrying conductor generates a magnetic field, when this is then placed in an external magnetic field, it will encounter a force proportional to the current in the conductor and to the strength of the external magnetic field. It is a device which converts electrical energy to mechanical energy. It works on the fact that a current-carrying conductor placed in a magnetic field experiences a force which causes it to rotate with respect to its original position.

APPLICATIONS OF DC MOTOR

SERIES MOTORS

The series DC motors are used where high starting torque is required, and variations in speed are possible. For example – the series motors are used in **Traction system, Cranes, air compressors, Vacuum Cleaner, Sewing machine**, etc.

SHUNT MOTORS

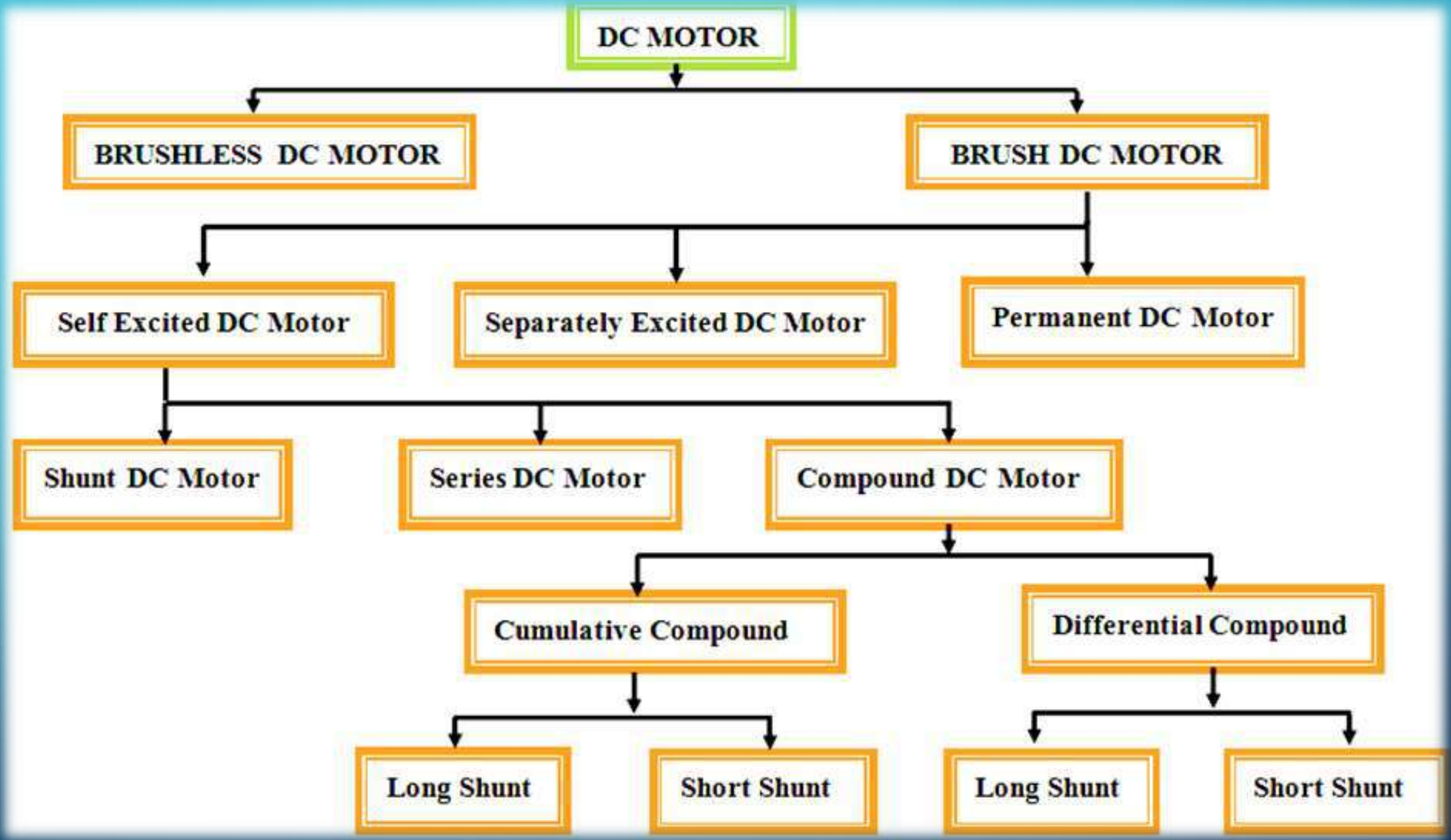
The shunt motors are used where constant speed is required and starting conditions are not severe. The various applications of DC shunt motor are in **Lathe Machines, Centrifugal Pumps, Fans, Blowers, Conveyors, Lifts, Weaving Machine, Spinning machines**, etc.

COMPOUND MOTORS

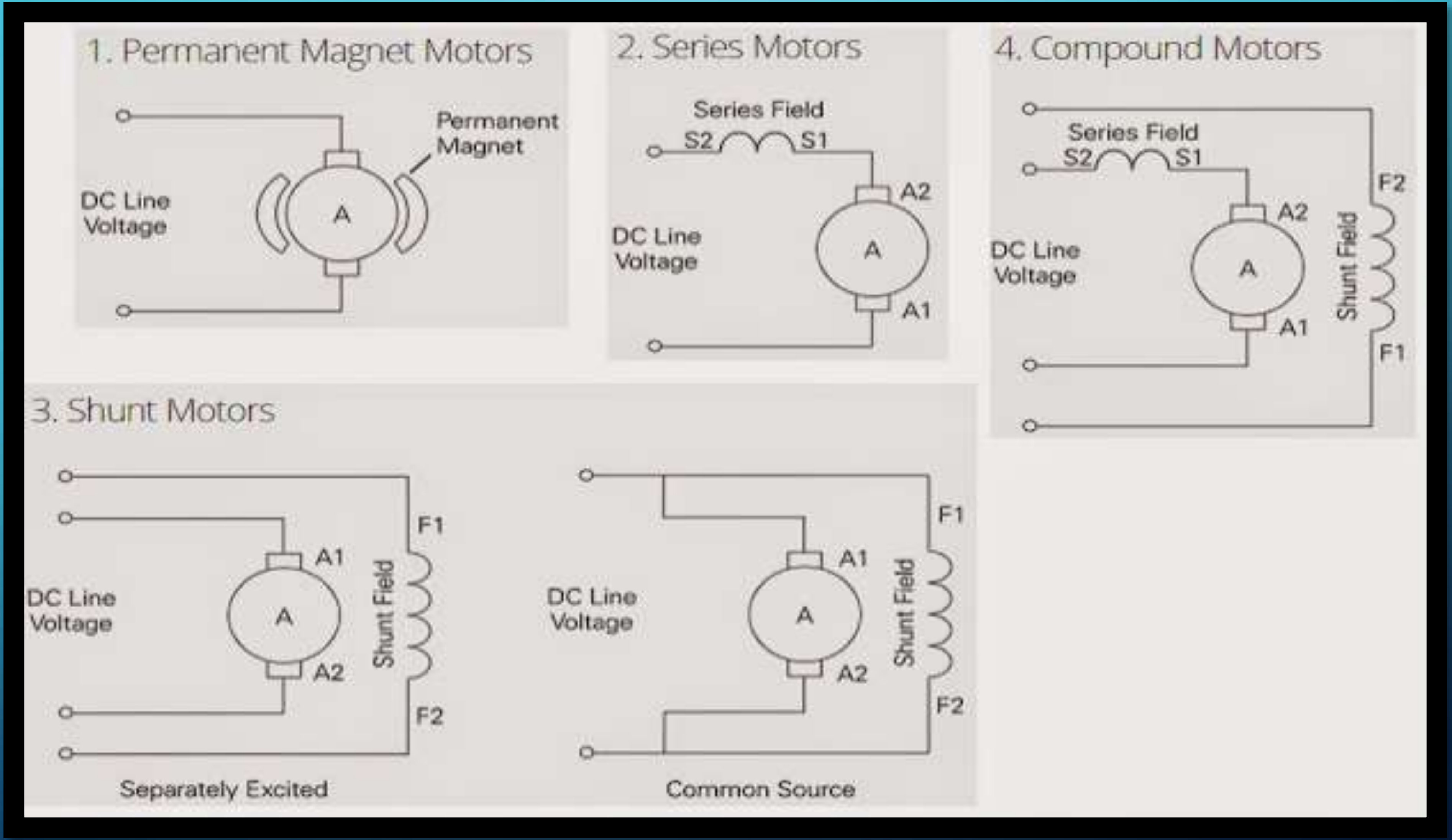
The compound motors are used where higher starting torque and fairly constant speed is required. The examples of usage of compound motors are in **Presses, Shears, Conveyors, Elevators, Rolling Mills, Heavy Planners**, etc.

The small DC machines whose ratings are in fractional kilowatt are mainly used as control device such in Techno generators for speed sensing and in Servo motors for positioning and tracking.

TYPES OF DC MOTOR



TYPES OF DC MOTOR



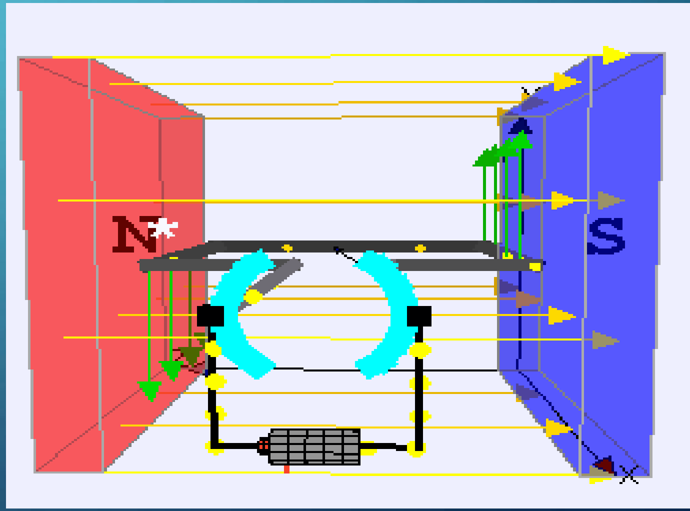
WORKING PRINCIPLE OF A DC MOTOR

An electric motor is an electrical machine which converts electrical energy into mechanical energy. The basic working principle of a DC motor is: "whenever a current carrying conductor is placed in a magnetic field, it experiences a mechanical force". The direction of this force is given by Fleming's left-hand rule and its magnitude is given by F = BIL. Where, B = magnetic flux density, I = current and L = length of the conductor within the magnetic field.

Fleming's left hand rule: If we stretch the first finger, second finger and thumb of our left hand to be perpendicular to each other, and the direction of magnetic field is represented by the first finger, direction of the current is represented by the second finger, then the thumb represents direction of the force experienced by the current carrying conductor.

When armature windings are connected to a DC supply, an electric current sets up in the winding. Magnetic field may be provided by field winding (electromagnetism) or by using permanent magnets. In this case, current carrying armature conductors experience a force due to the magnetic field, according to the principle stated above.

Commutator is made segmented to achieve unidirectional torque. Otherwise, the direction of force would have reversed every time when the direction of movement of conductor is reversed in the magnetic field.



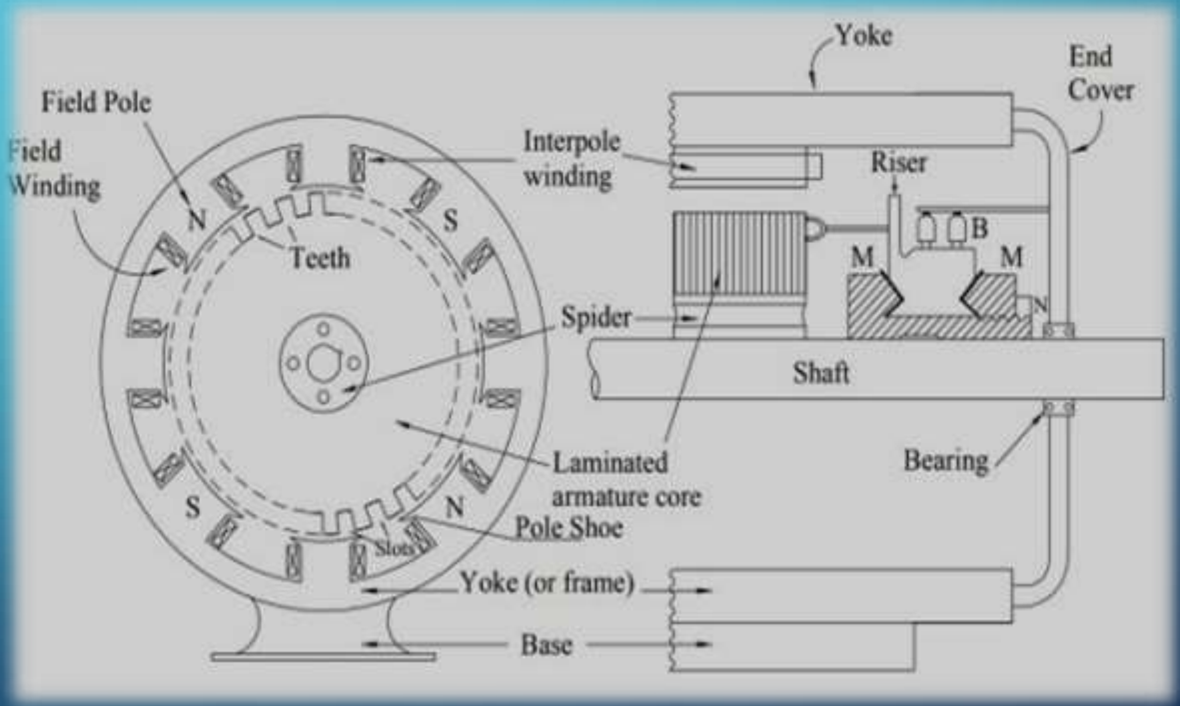
CONSTRUCTION OF DC MOTOR

DC motor is an electromagnetic device which converts electrical energy into mechanical energy. DC power input is converted into mechanical power at the shaft motor.

There is no difference in the construction of DC Motor and Generator. A DC Motor can also be used as DC generator without any constructional change. Similarly, a DC generator can also be used as DC Motor. They are broadly termed as DC machine.

Main parts of dc machine are:

1. Field magnet frame or yoke
2. Pole cores and pole shoes
3. Pole coil or field coils
4. Armature core
5. Armature winding
6. Commutator
7. Brushes
8. Brush holder
9. Bearing
10. Shaft
11. Terminal Box
12. Eye Bolt



CONSTRUCTION OF DC MOTOR

FIELD MAGNET FRAME OR YOKE

The yoke or outer frame is the covering provided to dc generator and it serves the following purpose It provides a mechanical support for the poles. It act as a protective cover against mechanical damage It provide a passage for the magnetic flux produced by the poles.

POLE CORE AND POLE SHOES

The pole core itself may be made of solid piece of cast iron or cast steel, but pole shoe is laminated and is screwed to the pole face by means of counter sunk screw. The pole cores may be made of thin laminations of steel, riveted together. This type of pole is held in position with the frame by means of bolts. The pole shoe serves the two purpose as under. It support the pole coils. Being of larger cross section, it spread the flux and also reduces the reluctance of the magnetic path.

FIELD WINDING OR EXCITING WINDING:

The pole is excited by a winding wound around the pole core. This winding is called the Field Winding or Exciting Winding and made from copper. The number of turns and cross-sectional of filed winding depends on the type of DC machine as below:

- ❑ Large number of turns of small cross-sectional area is used for DC Shunt machine.
- ❑ For DC Series machine, small number of turns of large cross-sectional area is used.
- ❑ Both series and shunt field winding is applied for DC Compound machine.

FIELD WINDINGS: SERIES FIELD WINDINGS

The field winding connected in series with the armature are made with relatively few windings turns of very large wire and have a very low resistance usually found in large horsepower machines wound with square or rectangular wire. The use of square wire permits the windings to be laid closer together, which increases the number of turns that can be wound in a particular space Square and rectangular wire can also be made physically smaller than round wire and still contain the same surface area Square wire contains more surface than round wire. Square wire permits more turns than round wire in the same area.

CONSTRUCTION OF DC MOTOR

FIELD WINDINGS: SHUNT FIELD WINDINGS

It is constructed with relatively many turns of small wire, thus, it has a much higher resistance than the series field is intended to be connected in parallel with, or shunt, the armature. High resistance is used to limit current flow through the field.

BOTH SERIES AND SHUNT FIELD WINDINGS ARE CONTAINED IN EACH POLE PIECE

When a DC machine uses both series and shunt fields, each pole piece will contain both windings. The windings are wound on the pole pieces in such a manner that when current flows through the winding it will produce alternate magnetic polarities. Both series and shunt field windings are contained in each pole piece
S – series field
F – shunt field

ARMATURE

The armature core is cylindrical in shape. It is rotating part of the machine. Its body is made up of soft iron stamping or laminations to reduce the eddy current losses. The lamination are keyed to the shaft. These are insulated from each other by varnish. At the outer periphery slots are cut. The armature conductors (winding)are placed in these slots. The armature core serves the following purpose. It provides a path of low reluctance to the magnetic flux. It house armature conductors.

CONSTRUCTION OF DC MOTOR

ARMATURE WINDINGS

The armature coil are usually former wound. The conductor are placed in the armature slots which are lined with tough insulating material. The slot insulation is folded over the armature conductors placed in the slots and is secured firmly by bamboo or fiber wedges. The armature winding are usually of conductors covered with single cotton cover, double cotton cover or enameled wire.

On the basis of connection these are of two types:

Lap winding

Wave winding

ARMATURE WINDINGS LAP WOUND ARMATURES

It is used in machines designed for low voltage and high current. Armatures are constructed with large wire because of high current. Example: The starter motor of almost all automobiles. The windings of a lap wound armature are connected in parallel. This permits the current capacity of each winding to be added and provides a higher operating current. No of current path, C=p ; p=no of poles Lap wound armatures.

ARMATURE WINDINGS WAVE WOUND ARMATURE

Wave Wound Armatures are used in machines designed for high voltage and low current their windings connected in series. When the windings are connected in series, the voltage of each winding adds, but the current capacity remains the same are used is in the small generator. No of current path, C=2Wave wound armatures

CONSTRUCTION OF DC MOTOR

COMMUTATOR

The Commutator is cylindrical in structure and is built up of wedge shaped hard drawn copper segments. The segment are insulated from each other by a thin sheet of high quality mica. To prevent them from flying out under the action of centrifugal forces, the segments are provided with “v”-grooves, which are insulated by conical mica-nite ring. The function of the Commutator is to facilitate the collection of current from the armature and to rectify the A.C. induced in the armature into D.C.

BRUSH HOLDER AND BRUSHES

The function of brushes is to collect current from the Commutator and supply it to the external load circuit. These are usually made of carbon and are rectangular in shapes. These brushes are housed in brush holders. These are held in position under spring tension , the pressure of the spring can be adjusted by altering the position of lever in the notches. Copper brushes are only used for machine delivering large current at low voltages.

BEARING

These are supported in end cover, because of reliability, ball bearing are usually employed .Though for heavy duty, roller bearing are employed. These are used to reduce friction and have less wear and tear.

COMPENSATING WINDING

Theses windings are placed in the slots cut in the pole faces of DC machine. Compensating winding is also connected in series with the armature winding.

CONSTRUCTION OF DC MOTOR

INTERPOLES

Interpole are fixed to the Yoke in between the main poles of DC machine. The Interpole winding is made of copper and consists of few turns of thick wire. This winding is connected in series with the armature winding.

SHAFT

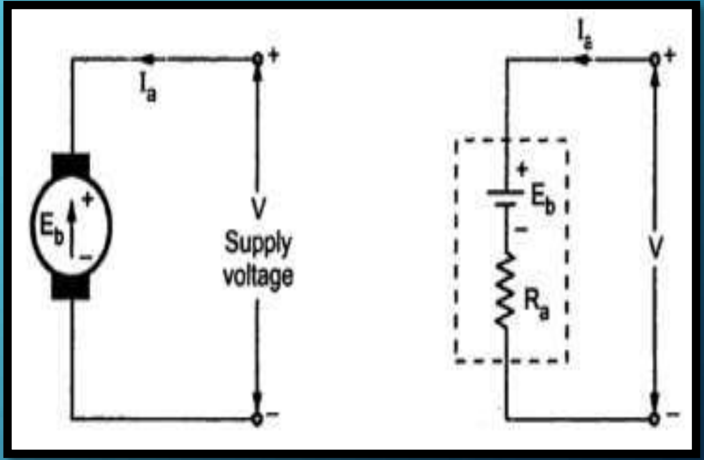
Shaft of DC Motor is coupled to the load to transfer mechanical power. For DC Generator, shaft is coupled to prime mover to convert mechanical input energy into electrical output. Armature core, bearing, Commutator etc. are mounted on the Shaft.

MACHINE WINDINGS OVERVIEW

1. Armature field
2. Separately Excited
3. Self excited
4. Series
5. Shunt
6. Compound
Wave Winding C=2
Lap Winding C=2p

BACK EMF

According to fundamental laws of nature, no energy conversion is possible until there is something to oppose the conversion. In case of generators this opposition is provided by magnetic drag, but in case of dc motors there is back emf. When the armature of a motor is rotating, the conductors are also cutting the magnetic flux lines and hence according to the Faraday's law of electromagnetic induction, an emf induces in the armature conductors. The direction of this induced emf is such that it opposes the armature current (I_a). The circuit diagram below illustrates the direction of the back emf and armature current. Magnitude of the Back emf can be given by emf equation of a DC generator.



SIGNIFICANCE OF BACK EMF:

Magnitude of back emf is directly proportional to speed of the motor. Consider the load on a dc motor is suddenly reduced. In this case, required torque will be small as compared to the current torque. Speed of the motor will start increasing due to the excess torque. Hence, being proportional to the speed, magnitude of the back emf will also increase. With increasing back emf armature current will start decreasing. Torque being proportional to the armature current, it will also decrease until it becomes sufficient for the load. Thus, speed of the motor will regulate. On the other hand, if a dc motor is suddenly loaded, the load will cause decrease in the speed. Due to decrease in speed, back emf will also decrease allowing more armature current. Increased armature current will increase the torque to satisfy the load requirement. Hence, presence of the back emf makes a dc motor ‘self-regulating’.

RELATION BETWEEN MECHANICAL POWER (PM), SUPPLY VOLTAGE (VT) AND BACK EMF (EB)

The back emf in the dc motor is expressed as

$$E_b = V_t - I_a R_a$$

Where
E_b – Back Emf
I_a – Armature Current
V_t – Terminal Voltage
R_a – Resistance of Armature

The maximum power developed on the motor is expressed by

$$P_m = VI_a - 2I_a R_a$$

On differentiating the above equation we get

$$\frac{dP_m}{dI_a} = VI_a - 2I_a R_a$$

$$VI_a - 2I_a R_a = 0$$

$$V = 2I_a R_a$$

$$\frac{V}{2} = I_a R_a$$

From the back emf equation, we get

$$V = E_b + I_a R_a$$

On substituting the $I_a R_a$ in the above equation, we get

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

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

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

The above equation shows that the maximum power develops in the motor when the back emf is equal to half of the supply voltage.

ADVANTAGES OF BACK EMF IN DC MOTOR

1. The back emf opposes the supply voltage. The supply voltage induces the current in the coil which rotates the armature. The electrical work required by the motor for causing the current against the back emf is converted into the mechanical energy. And that energy is induced in the armature of the motor. Thus, we can say that energy conversion in DC motor is possible only because of the back emf. The mechanical energy induced in the motor is the product of the back emf and the armature current, i.e., $E_b I_a$.

2. The back emf makes the DC motor self-regulating machine, i.e., the back emf develops the armature current according to the need of the motor. The armature current of the motor is calculated as,

$$I = \frac{V - E_b}{R_a}$$

BACK EMF MAKES MOTOR SELF-REGULATING

1. Consider the motor is running at no load condition. At no load, the DC motor requires small torque for controlling the friction and windage loss. The motor withdraws less current. As the back emf depends on the current their value also decreases. The magnitude of the back EMF is nearly equal to the supply voltage.

2. If the sudden load is applied to the motor, the motor becomes slow down. As the speed of the motor decreases, the magnitude of their back emf also falls down. The small back emf withdraw heavy current from the supply. The large armature current induces the large torque in the armature, which is the need of the motor. Thus, the motor moves continuously at the new speed.

3. If the load on the motor is suddenly reduced, the driving torque on the motor is more than the load torque. The driving torque increases the speed of the motor which also increases their back emf. The high value of back emf decreases the armature current. The small magnitude of armature current develops less driving torque, which is equal to the load torque. And the motor will rotate uniformly at the new speed.

FEATURES OF DC MOTORS

1. Encoder/potentiometer determines the accuracy and resolution of the servo motor

2. A servo motor has 5-10 times rated torque for short periods

3. Stays cool because the current draw is proportional to load

4. Maintains usable high speed torque of 90% of NL RPM

3. performs quietly at high speeds silently

4. Has a resonance-free and vibration-free operation

5. High Torque to Inertia Ratio can rapidly accelerate loads

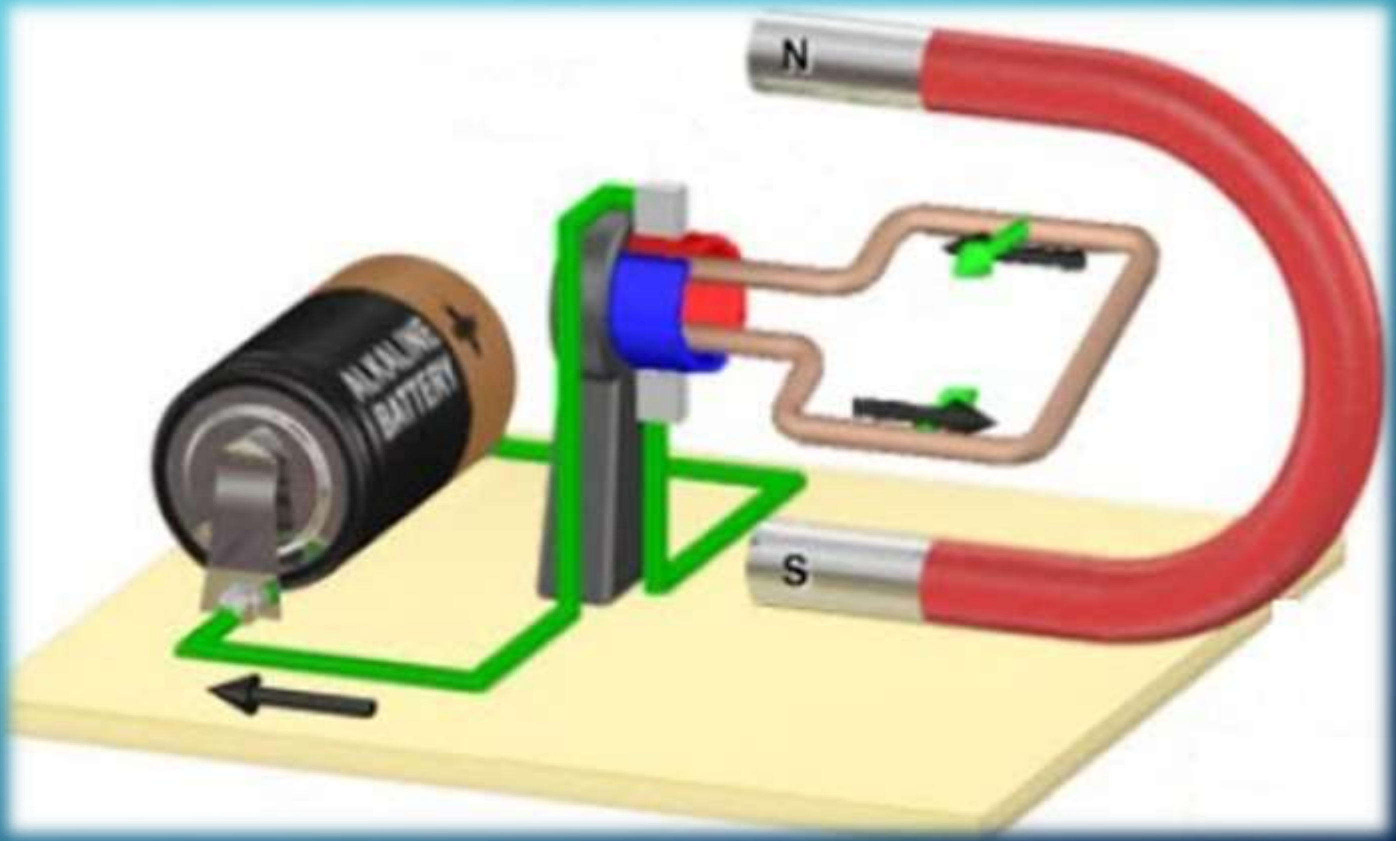
6. The servo motor can approach 90% efficiency at light loads

DISADVANTAGES AND PROBLEMS OF BRUSHED DC MOTOR:

1. The brushes eventually wear out.
2. Because the brushes are making/breaking connections, you get sparking and electrical noise.
3. The brushes limit the maximum speed of the motor.
4. Having the electromagnet in the center of the motor makes it harder to cool.
5. The use of brushes puts a limit on how many poles the armature can have.

MODULE:3

DC MOTOR



TOPIC:

- CONCEPT OF DC MOTOR STARTER
- NECESSITY OF STARTER
- TYPES OF DC MOTOR STARTER
- TWO POINT STARTING METHOD
- THREE POINT STARTING METHOD
- FOUR POINT STARTING METHOD

STARTING OF DC MOTOR

A starter is a device to start and accelerate a motor. A controller is a device to start the motor, control and reverse the speed of the DC motor and stop the motor. While starting the DC motor, it draws the heavy current which damages the motor. The starter reduces the heavy current and protects the system from damage.

The starting of DC motor is somewhat different from the starting of all other types of electrical motors. This difference is credited to the fact that a DC motor unlike other types of motor has a very high starting current that has the potential of damaging the internal circuit of the DC motor if not restricted to some limited value. This limitation to the starting current of DC motor is brought about by means of the starter. Thus the distinguishing fact about the starting methods of DC motor is that it is facilitated by means of a starter. Or rather a device containing a variable resistance connected in series to the armature winding so as to limit the starting current of DC motor to a desired optimum value taking into consideration the safety aspect of the motor.

WHY DOES A DC MOTOR HAVE SUCH A HIGH STARTING CURRENT

Let us take into consideration the basic operational voltage equation of the DC motor which is given by,

$$E = E_b + I_a R_a$$

Where,
E is the supply voltage,
I_a is the armature current,
R_a is the armature resistance.
And the back emf is given by E_b.

Now the back emf, in case of a DC motor, is very similar to the generated emf of a DC generator as it's produced by the rotational motion of the current carrying armature conductor in presence of the field. This back emf of DC motor is given by

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

It has a major role to play in case of the starting of DC motor.

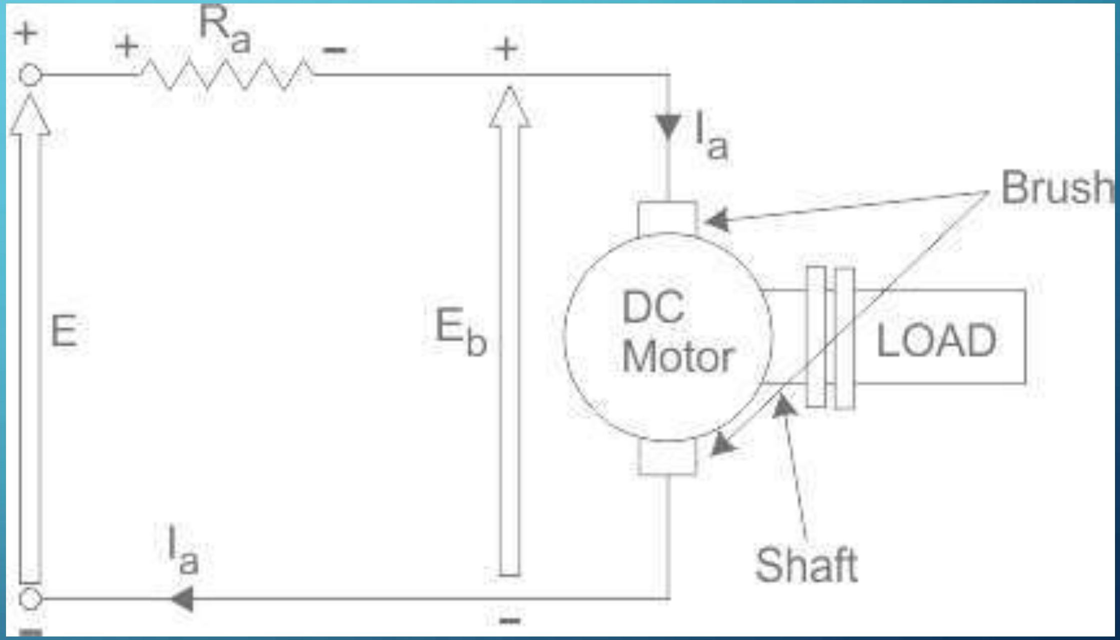
From this equation we can see that E_b is directly proportional to the speed N of the motor.

WHY DOES A DC MOTOR HAVE SUCH A HIGH STARTING CURRENT

Now since at starting N = 0, E_b is also zero, and under this circumstance the voltage equation is modified to

$$E = 0 + E_b R_a$$

For all practical practices to obtain optimum operation of the motor the armature resistance is kept very small usually in the order of 0.5 Ω and the bare minimum supply voltage being 220 volts. Even under these circumstance the starting current, I_a is as high as 220/0.5 amp = 440 amp.



$$Therefore,\ I_a = \frac{E}{R_a}$$

EFFECT OF HIGH STARTING CURRENT

High starting current of DC motor creates two major problems.

1. Firstly, current of the order of 400 A has the potential of damaging the internal circuit of the armature winding of DC motor at the very onset.

2. Very high electromagnetic **starting torque of DC motor** is produced by virtue of the high starting current, which has the potential of producing huge centrifugal force capable of flying off the rotor winding from the slots.

$$Therefore,\ I_a = \frac{E}{R_a}$$

STARTING METHODS OF DC MOTOR

As a direct consequence of the two above mentioned facts i.e high starting current and high starting torque of DC motor, the entire motoring system can undergo a total disarray and lead towards into an engineering massacre and non-functionality. To prevent such an incidence from occurring several starting methods of DC motor has been adopted. The main principal of this being the addition of external electrical resistance R_{ext} to the armature winding, so as to increase the effective resistance to $R_a + R_{ext}$, thus limiting the armature current to the rated value. The new value of starting armature current is desirably low and is given by.

$$Therefore,\ I_a = \frac{E}{R_a + R_{ext}}$$

Now as the motor continues to run and gather speed, the back emf successively develops and increases, countering the supply voltage, resulting in the decrease of the net working voltage. Thus now,

$$Therefore,\ I_a = \frac{E - E_b}{R_a + R_{ext}}$$

TYPES OF DC MOTOR STARTER

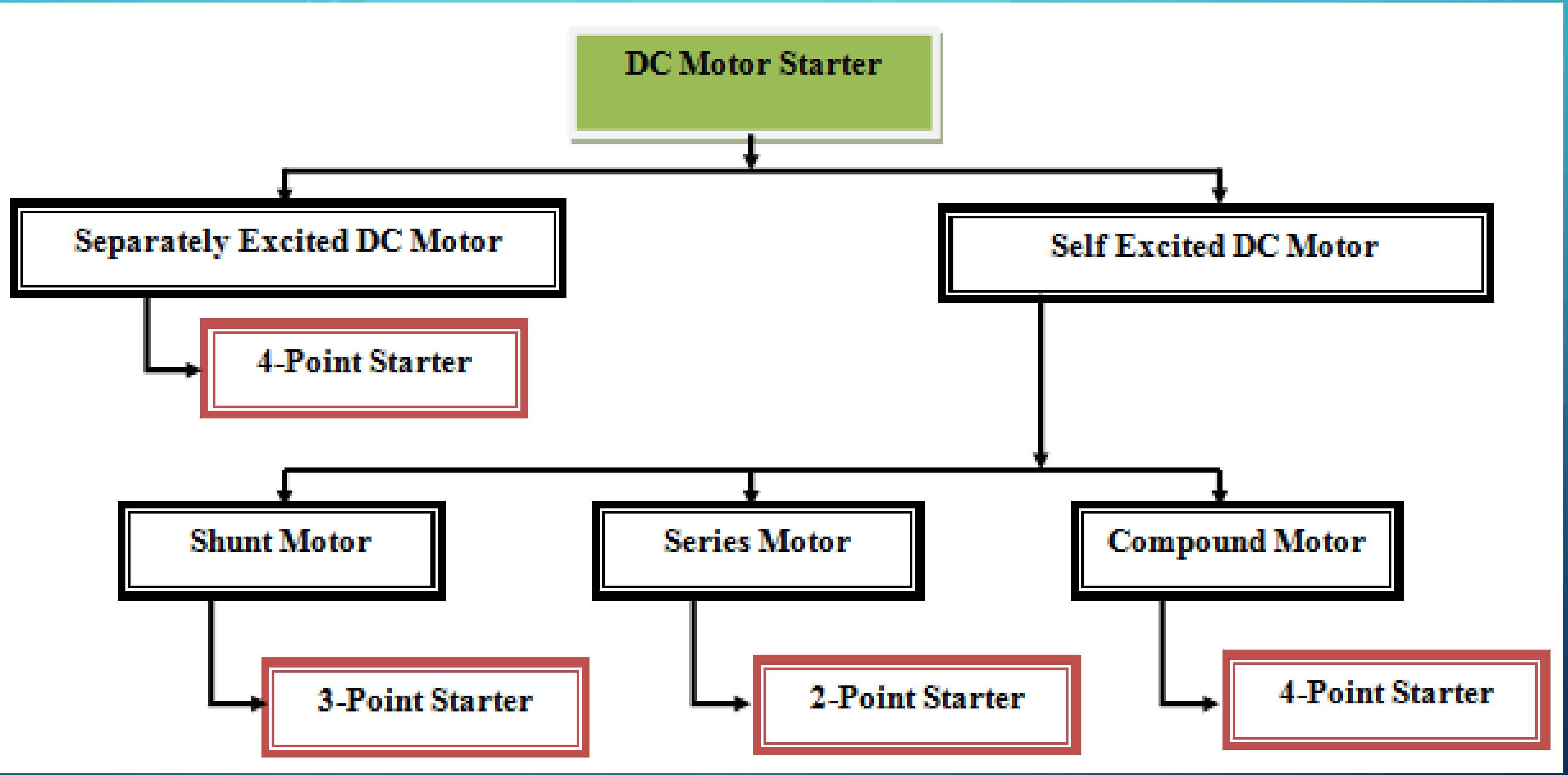
At this moment to maintain the armature current to its rated value, R_{ext} is progressively decreased unless its made zero, when the back emf produced is at its maximum. This regulation of the external electrical resistance in case of the starting of DC motor is facilitated by means of the starter.

Starters can be of several types and requires a great deal of explanation and some intricate level understanding. But on a brief over-view the main types of starters used in the industry today can be illustrated as:-

Common Four Starting Methods of DC Motor

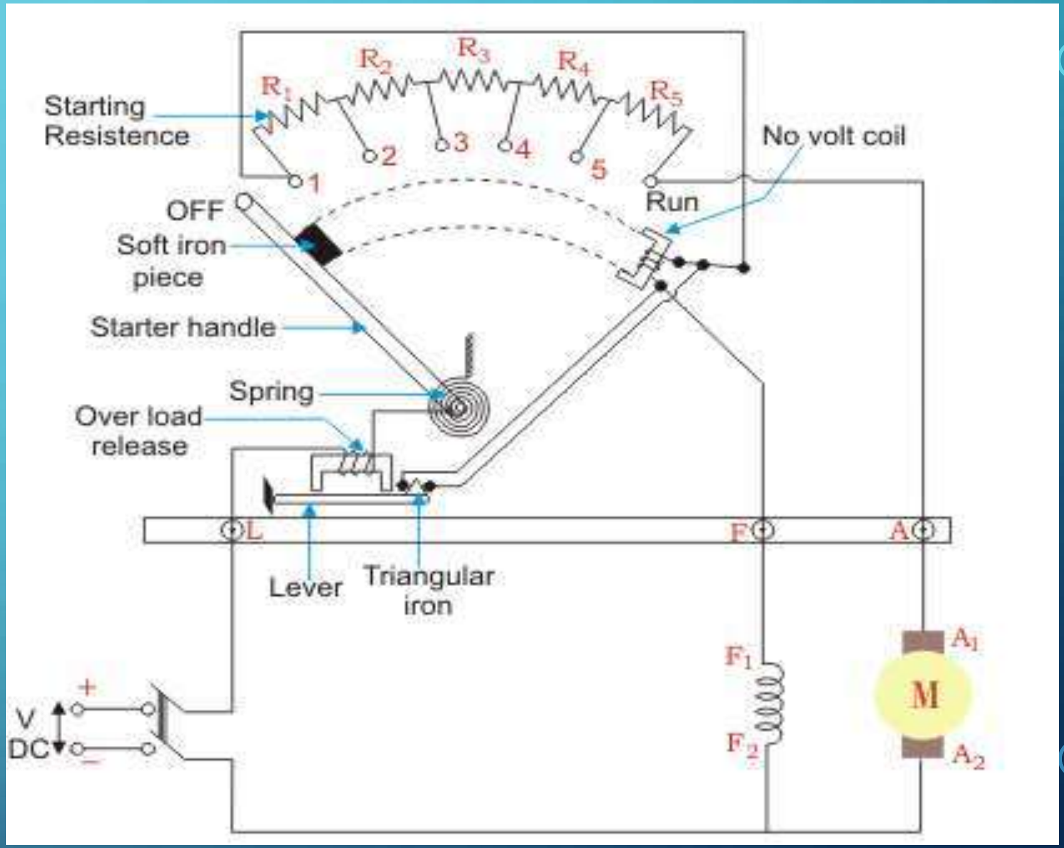
1. **Two Point Starting Method**
2. **Three Point Starting Method**
3. **Four Point Starting Method**
4. **Automatic Starting Method**
5. **Electronic Starting Method**

TYPES OF DC MOTOR STARTER'S



THREE POINT STARTING METHOD OF DC SHUNT MOTOR

Three Point Starter is a device whose main function is starting and maintaining the speed of the DC shunt motor. The 3 point starter connects the resistance in series with the circuit which reduces the high starting current and hence protects the machines from damage. Mainly there are three main points or terminals in 3 point starter of DC motor. They are as follows

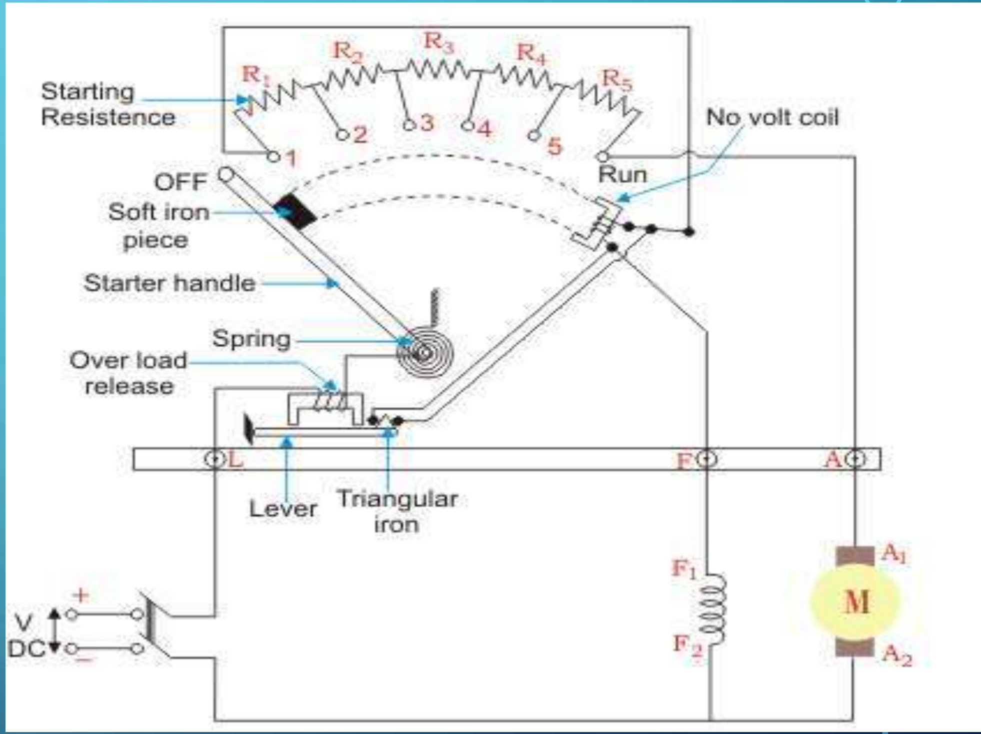


L is known as Line terminal, which is connected to the positive supply.
A is known as the armature terminal and is connected to the armature windings.
F is known as the field terminal and is connected to the field terminal windings.

STARTING METHOD OF DC SHUNT MOTOR WITH THREE POINT STARTER

The starter handle is now moved from stud to stud, and this builds up the speed of the motor until it reaches the **RUN** position. The Studs are the contact point of the resistance. In the RUN position, three main points are considered. They are as follows.

1. The motor attains the full speed.
2. The supply is direct across both the windings of the motor.
3. The resistance R is completely cut out.

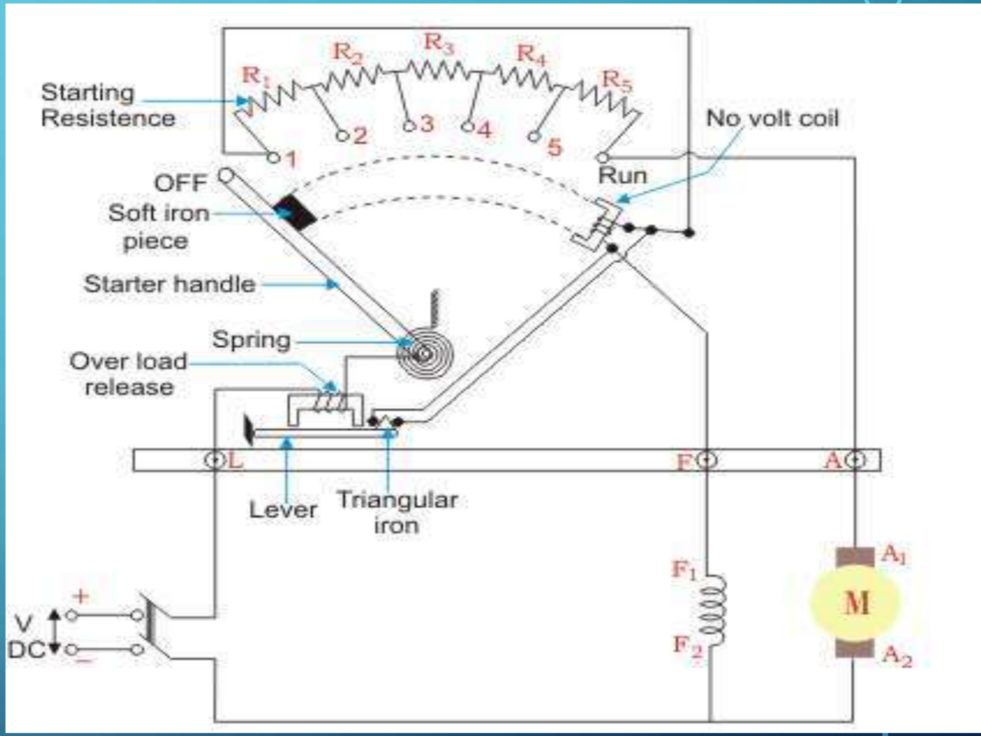


The handle H is held in RUN position by an electromagnet energized by a **no volt trip coil (NVC)**. This no volt trip coil is connected in series with the field winding of the motor. In the event of switching OFF, or when the supply voltage falls below a predetermined value, or the complete failure of supply while the motor is running, NVC is energized. The handle is released and pulled back to the OFF position by the action of the spring. The current to the motor is cut off, and the motor is not restarted without a resistance R in the armature circuit. The no voltage coil also provides protection against an open circuit in the field windings.

The No Voltage Coil (NVC) is called NO-VOLT or UNDERVOLTAGE protection of the motor. Without this protection, the supply voltage might be restored with the handle in the RUN position. The full line voltage is directly applied to the armature. As a result, a large amount of current is generated.

STARTING METHOD OF DC SHUNT MOTOR WITH THREE POINT STARTER

The other protective device incorporated in the starter is the overload protection. The Over Load Trip Coil (OLC) and the No Voltage Coil (NVC) provide the overload protection of the motor. The overload coil is made up of a small electromagnet, which carries the armature current. The magnetic pull of the Overload trip coil is insufficient to attract the strip P, for the normal values of the armature current.



When the motor is overloaded, that is the armature current exceeds the normal rated value, P is attracted by the electromagnet of the OLC and closes the contact aa thus, the No Voltage Coil is short-circuited, shown in the figure of 3 Point Starter. As a result, the handle H is released, which returns to the OFF position, and the motor supply is cut off.

To stop the motor, the starter handle should never be pulled back as this would result in burning the starter contacts. Thus, to stop the motor, the main switch of the motor should be opened.

DRAWBACKS OF A THREE POINT STARTER

The following drawbacks of a 3 point starter are as follows

1. The 3 point starter suffers from a serious drawback for motors with a large variation of speed by adjustment of the field rheostat.

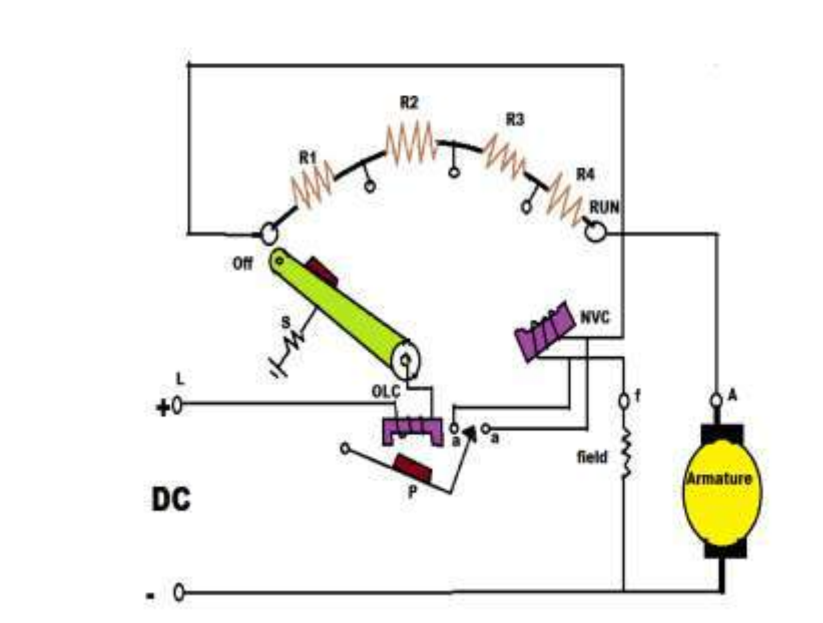
2. To increase the speed of the motor, the field resistance should be increased. Therefore, the current through the shunt field is reduced.

3. The field current may become very low because of the addition of high resistance to obtain a high speed.

4. A very low field current will make the holding electromagnet too weak to overcome the force exerted by the spring.

5. The holding magnet may release the arm of the starter during the normal operation of the motor and thus, disconnect the motor from the line. This is not a desirable action.

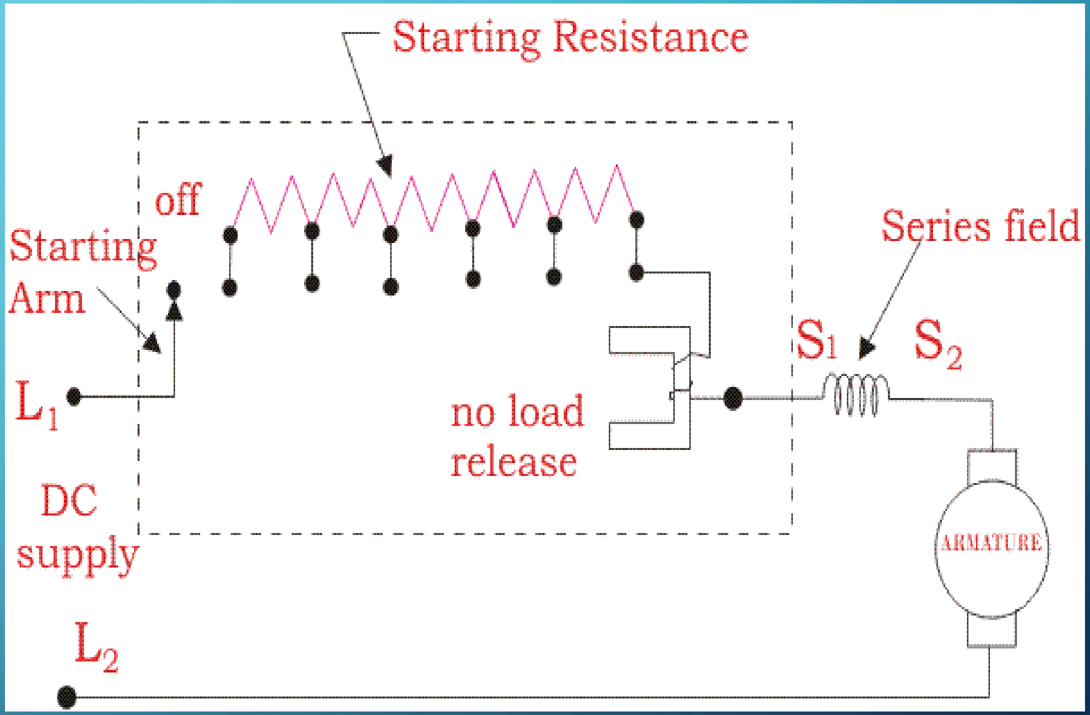
Hence, to overcome this difficulty, the 4 Point Starter is used.



TWO POINT STARTING METHOD OF DC SERIES MOTOR

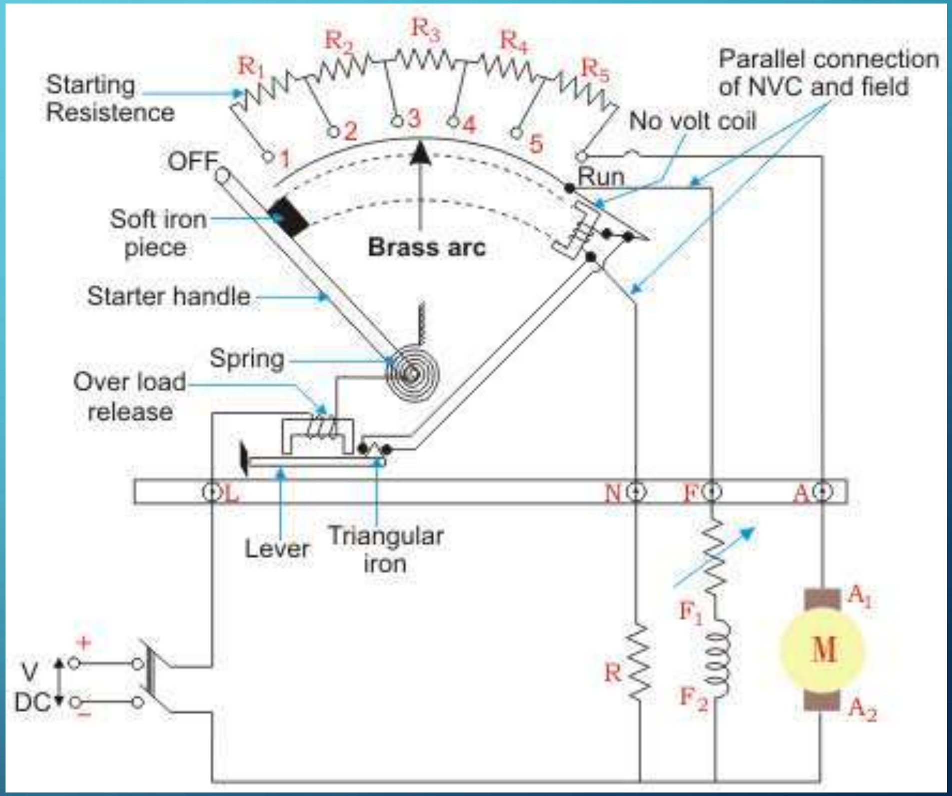
Construction of DC series motor starters is very basic as shown in the figure. The start arm is simply moved towards right to start the motor. Thus, maximum resistance is connected in series with the armature during starting and then gradually decreased as the start arm moves towards right. This starter is sometimes also called as a 2 point starter.

The no load release coil holds the start arm to the run position and leaves it when the voltage is lost.



FOUR POINT STARTING METHOD OF DC COMPOUND MOTOR

A 4 Point Starter is almost similar in functional characteristics like 3 Point Starter. In the absence of back EMF, the 4 Point Starter acts as a current limiting device while starting of the DC motor. 4 Point Starter also acts a protecting device.



The basic difference in 4 Point Starter as compared to 3 Point Starter is that in this a holding coil is removed from the shunt field circuit. This coil after removing is connected across the line in series with a current limiting resistance R. The studs are the contact points of the resistance represented by 1, 2, 3, 4, 5

The above arrangement forms three parallel circuits. They are as follows:-

1. Armature, starting the resistance and the shunt field winding.

2. A variable resistance and the shunt field winding.

3. Holding coil and the current limiting resistance.

DRAWBACKS OF A FOUR POINT STARTER

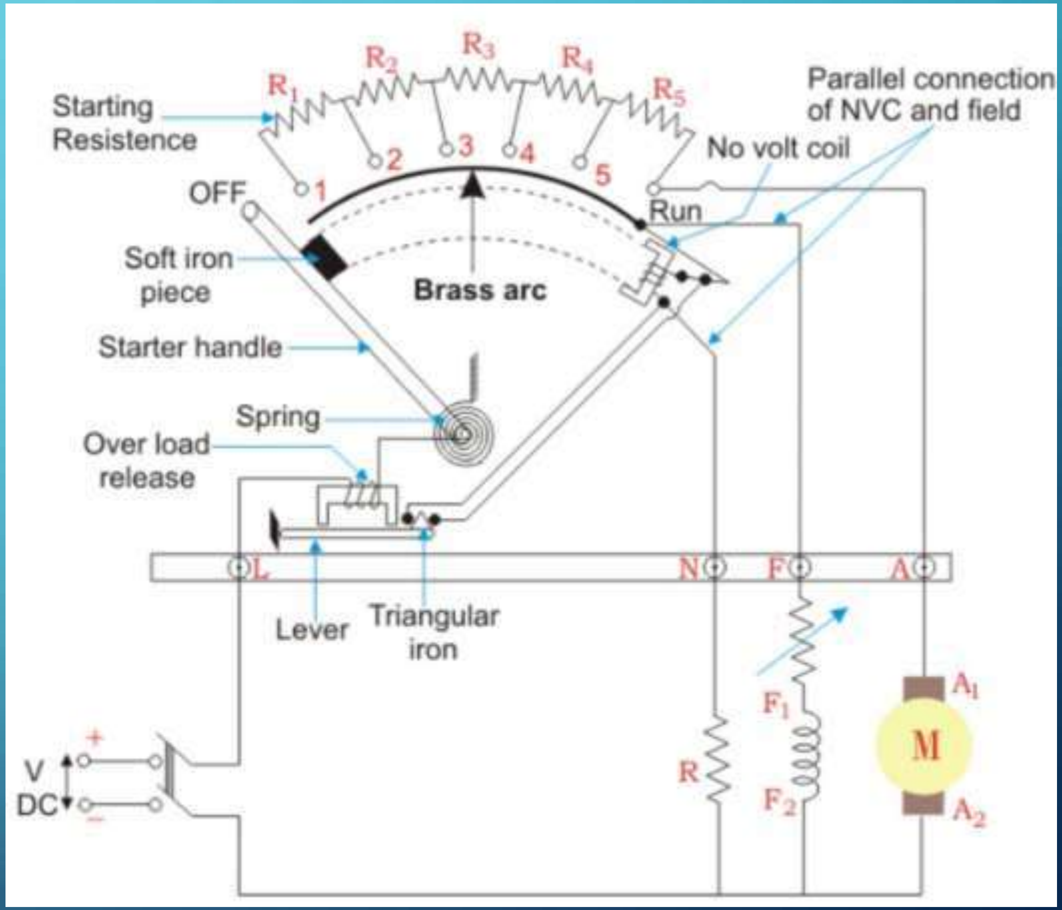
The only limitation or the drawback of the 4 point starter is that it cannot limit or control the high current speed of the motor. If the field winding of the motor gets opened under the running condition, the field current automatically reduces to zero. But as some of the residual flux is still present in the motor, and we know that the flux is directly proportional to the speed of the motor. Therefore, the speed of the motor increases drastically, which is dangerous and thus protection is not possible. This sudden increase in the speed of the motor is known as High-Speed Action of the Motor.

Nowadays automatic push button starters are also used. In the automatic starters, the ON push button is pressed to connect the current limiting starting resistors in series with the armature circuit. As soon as the full line voltage is available to the armature circuit, this resistor is gradually disconnected by an automatic controlling arrangement.

The circuit is disconnected when the OFF button is pressed. Automatic starter circuits have been developed using electromagnetic contactors and time delay relays. The main advantage of the automatic starter is that it enables even the inexperienced operator to start and stop the motor without any difficulty.

FOUR POINT STARTING METHOD OF SEPARETELY DC MOTOR

The diagram shows the field connected to the DC source through a variable resistor. That would be considered to be a separate source. The starting lever connects the field to the source through the brass arc at the same time it is moved to the "1" terminal. If that arrangement is not suitable for the field, the field could be connected directly to some other source, but there should be some provision to assure that the field is energized when the armature is energized. If the field is not energized when the armature is energized, the motor could run to a high speed if the load is light. That could cause the motor to be damaged.



AUTOMATIC STARTING METHOD

The starting methods discussed up till now are the manual starting methods. It becomes inconvenient when the DC motor is to be started and stopped frequently. In such a case, the automatic starting method is used.

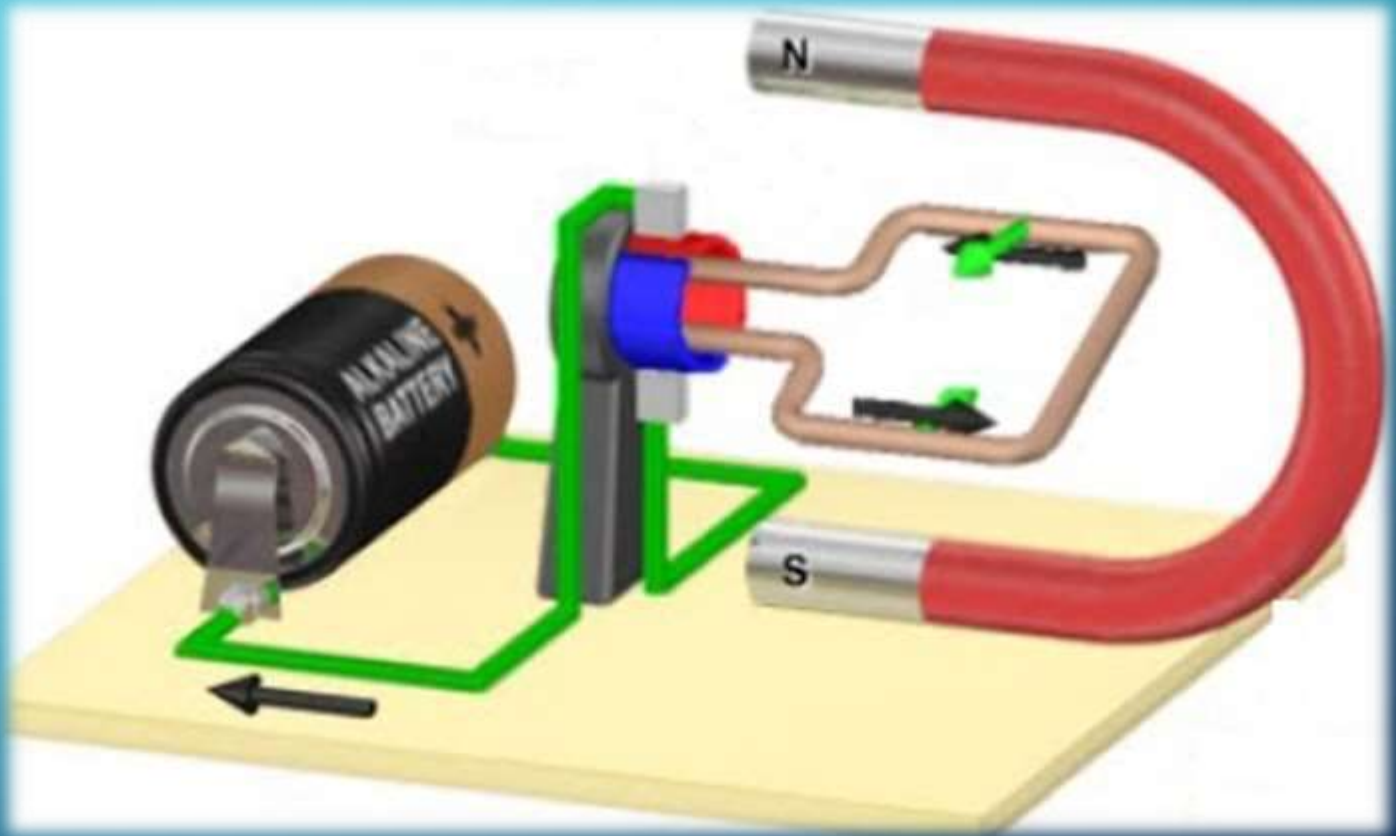
The automatic starter uses the automatic switches called contactors which is a device whose operation depends on the solenoidal coil controlled electromagnetically. When the main supply is ON, the field winding gets supply as it gets directly connected across the supply which provides the required working flux.

ELECTRONIC STARTING METHOD

The thyristor's is an electronic device that can work as a switch. It acts as a closed switch when conducts and becomes open when it is not conducting. Thus, the contactors in the automatic starter can be replaced by the thyristor's due to which it is called an electronic starter.

MODULE:3

DC MOTOR



TOPIC:

- TYPES OF DC MOTOR

- LOSSES OF DC MOTOR

TYPES OF DC MOTOR

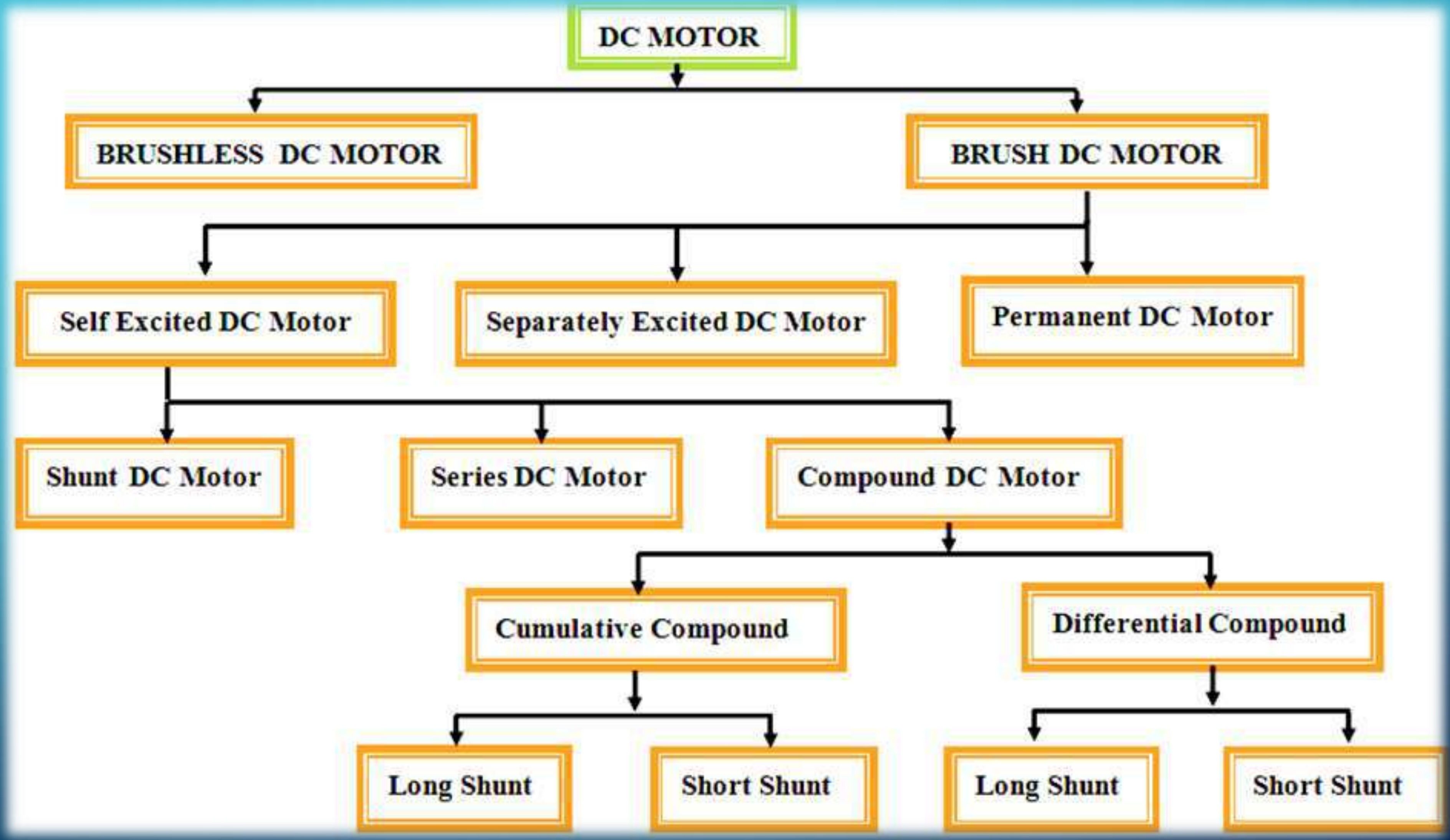
The dc motor converts the electrical power into mechanical power is known as dc motor. The construction of the dc motor and generator are same. But the dc motor has the wide range of speed and good speed regulation which in electric traction. The working principle of the dc motor is based on the principle that the current carrying conductor is placed in the magnetic field and a mechanical force experience by it.

The DC motor is generally used in the location where require protective enclosure, for example, drip-proof, the fireproof, etc. according to the requirements. A Direct Current Motor, DC is named according to the connection of the field winding with the armature.

The types of DC motor include:

- Permanent Magnet DC Motor (PMDC Motor)
- Separately Excited DC Motor
- Self Excited DC Motor
    - Shunt Wound DC Motor
    - Series Wound DC Motor
    - Compound Wound DC Motor
        - Short shunt DC Motor
        - Long shunt DC Motor
    - Differential Compound DC Motor

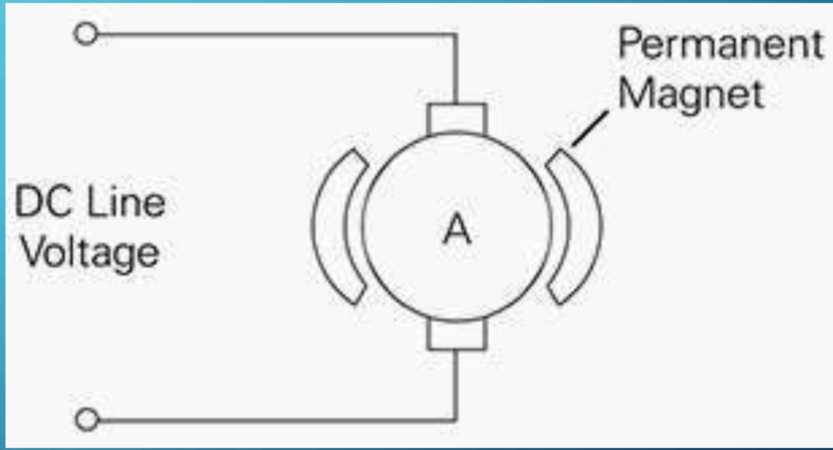
TYPES OF DC MOTOR



TYPES OF DC MOTOR

1. Permanent Magnet DC Motors

The permanent magnet motor uses a magnet to supply field flux. Permanent magnet DC motors have excellent starting torque capability with good speed regulation. A disadvantage of permanent magnet DC motors is they are limited to the amount of load they can drive. These motors can be found on low horsepower applications.



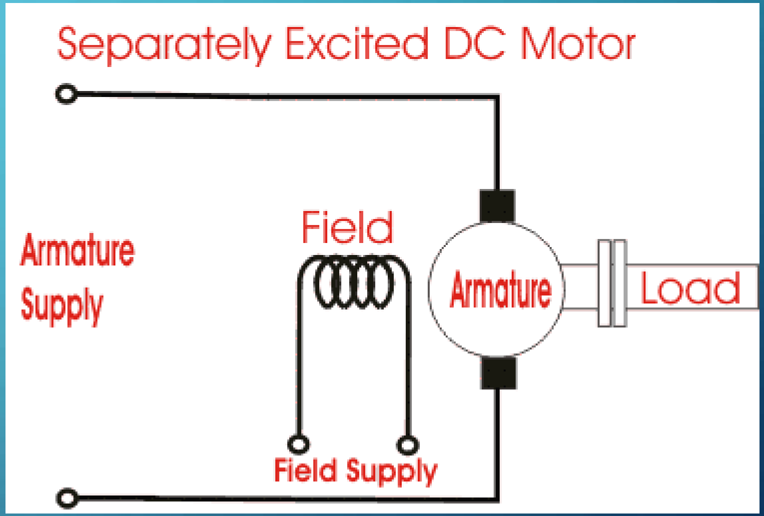
It works on the same principle as that of a normal type. The difference between the normal type and PMDC is the usage of permanent magnets for the production of the magnetic field instead of using a field coil in series with the armature winding. The permanent magnet produces the field flux and the flux produced by the armature interacts with each other to produce a resultant magnetic flux. This resultant flux is considered to be as the armature reaction. This enables the coils to produce a Uni-directional torque.

Another disadvantage is that torque is usually limited to 150% of rated torque to prevent demagnetization of the permanent magnets.

TYPES OF DC MOTOR

2. Separately excited DC Motor

As the name suggests, in case of a separately excited DC motor the supply is given separately to the field and armature windings. The main distinguishing fact in these types of DC motor is that, the armature current does not flow through the field windings, as the field winding is energized from a separate external source of DC current as shown in the figure beside.



The voltage equation of separately excited type machine is given as

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

We can neglect brush loss, then we get

$$V = E_b + I_a R_a$$

From the torque equation of DC motor we know $T_g = K_a \varphi I_a$ So the torque in this case can be varied by varying field flux φ, independent of the armature current I_a.

TYPES OF DC MOTOR

3. Self excited DC Motor

The field winding of the machine does not require any separate source. It feeds the supply on its own by the use of armature. The supply to the field winding is received from the armature voltage. In case of self excited DC motor, the field winding is connected either in series or in parallel or partly in series, partly in parallel to the armature winding.

Based on this, self excited DC Motors can be classified as:

i. Shunt wound DC motor

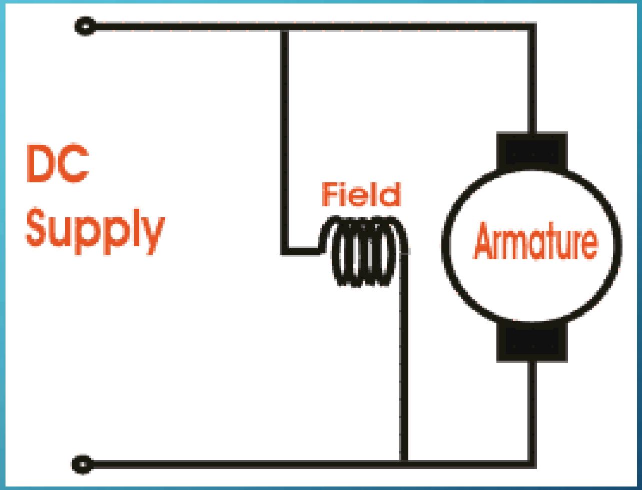
ii. Series wound DC motor

iii. Compound wound DC motor

TYPES OF DC MOTOR

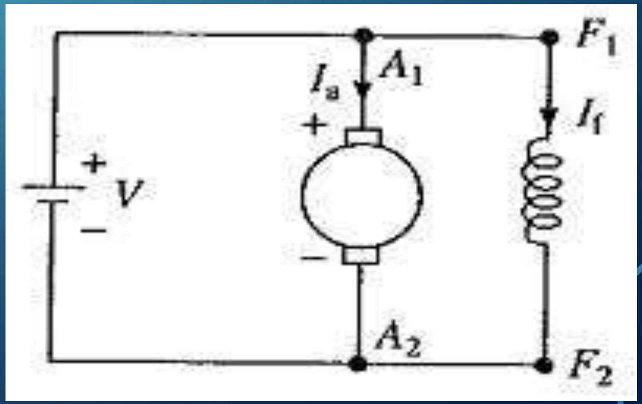
3. Self excited DC Motor

i. Shunt wound DC Motor



Here, the field is connected with the armature windings in parallel or also known as a shunt. The shunt field can be separately excited from the armature windings and that is the reason it can be used for greater speed regulation and can also offer very simplified reverse control.

$$V = E_b + I_a R_a + V_{brush}$$
$$I_l = I_a + I_f$$
$$I_f = V_s / R_{sh}$$



The flux in this type is directly proportional to the field current I_f a relationship is expressed as

$$\Phi \alpha I_f$$

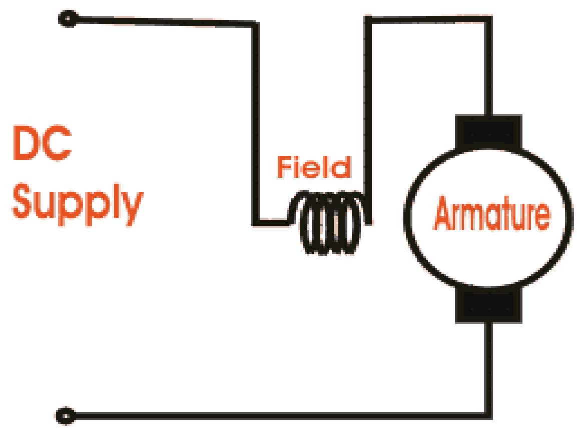
In case of a shunt wound DC motor or more specifically shunt wound self excited DC motor, the field windings are exposed to the entire terminal voltage as they are connected in parallel to the armature winding

TYPES OF DC MOTOR

3. Self excited DC Motor

ii. Series wound DC Motor

Here, a large wire carrying the full armature current winds the field with few turns. This kind of motor generates a large amount of starting torque but the speed cannot be regulated here. If they are run with no load then it might face damage. These are not the ideal option for variable speed applications.



The voltage and current equation association is given as

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

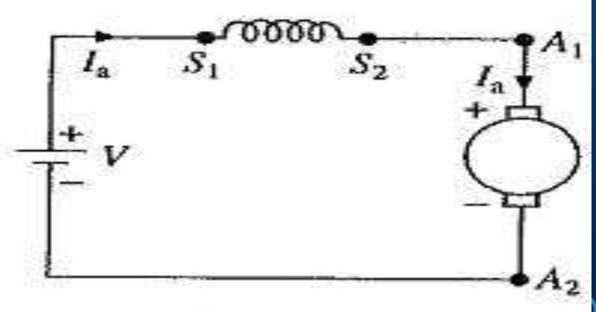
$$V = E_b + I_{a\,+}(R_a + R_{se}) + V_{brush}$$

The brush losses can be neglected then the equation obtained is as follows

$$V = E_b + I_{a\,+}(R_a + R_{se})$$

The current in the series type connection is as follows

$$I_a = I_l = I_{se}$$



$$T = K_e \Phi I_a$$

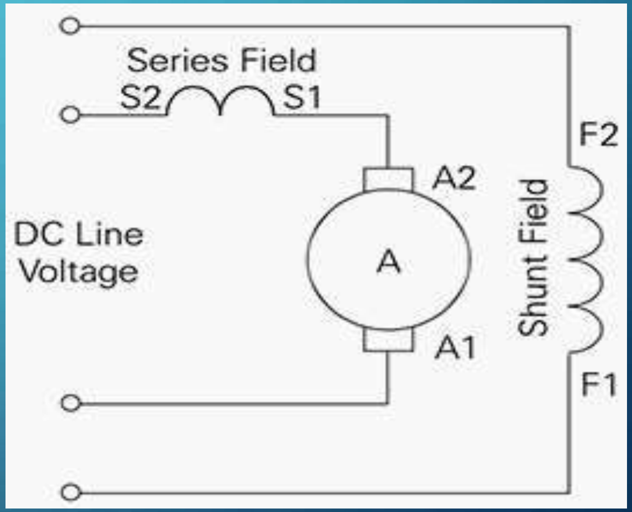
A characteristic of series motors is the motor develops a large amount of starting torque. However, speed varies widely between no load and full load. Series motors cannot be used where a constant speed is required under varying loads.

TYPES OF DC MOTOR

3. Self excited DC Motor

iii. Compound wound DC motor

These have a shunt field which is separately excited. They have a good starting torque but might face problems in variable speed application.



The compound excitation characteristic in a DC motor can be obtained by combining the operational characteristic of both the shunt and series excited DC motor. The compound wound self excited DC motor or simply compound wound DC motor essentially contains the field winding connected both in series and in parallel to the armature winding.

The excitation of compound wound DC motor can be of two types depending on the nature of compounding.

Compound motors have a field connected in series with the armature and a separately excited shunt field. The series field provides better starting torque and the shunt field provides better speed regulation.

TYPES OF DC MOTOR

3. Self excited DC Motor

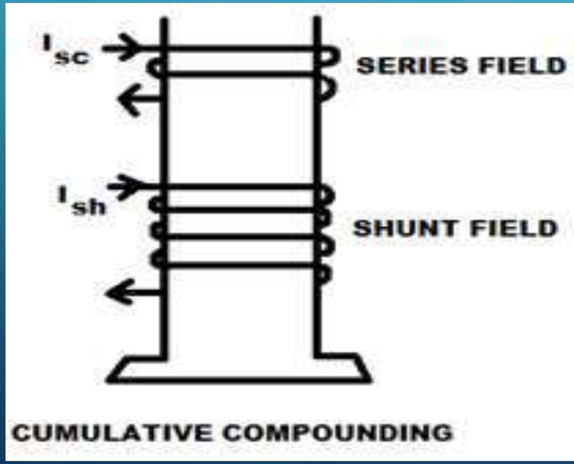
iii. Compound wound DC motor

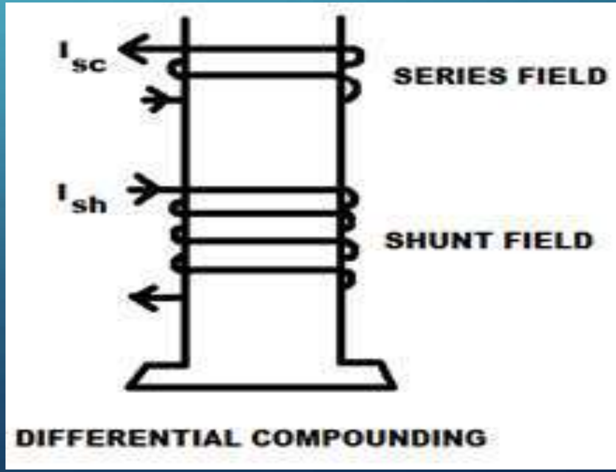
Cumulative Compound DC Motor

Here, the flux produced by the shunt field windings enhances the effect of the main field flux which is produced by series winding.

Differentially Compound DC Motor

In this type of compound wound DC motor, the flux produced due to the shunt field windings reduces the effect of the main series windings.





TYPES OF DC MOTOR

3. Self excited DC Motor

iii. Compound wound DC motor

Short Shunt DC Motor

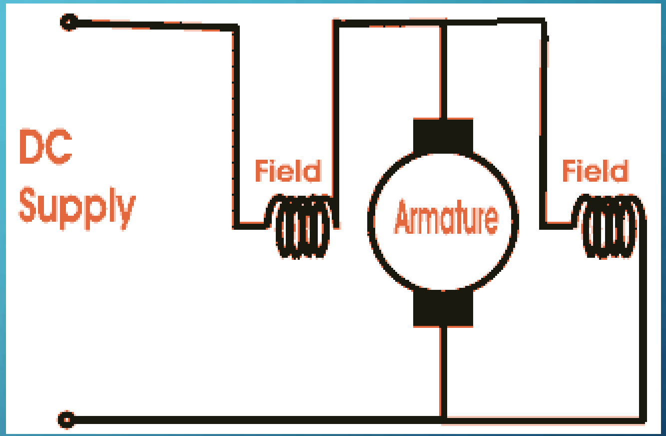
If the shunt field winding is only parallel to the armature winding and not the series field winding then its known as short shunt DC motor or more specifically short shunt type compound wound DC motor.

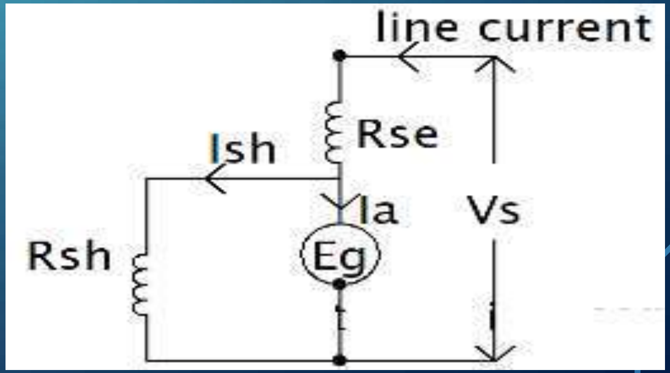
The relationship between and current and voltage is expressed as

$$V = E_b + I_a R_a + I_l R_{se} + V_{brush}$$

The brush drops can be neglected, then we get

$$V = E_b + I_a R_a + I_l R_{se}$$
$$I_a = I_l - I_{sh}$$
$$I_{sh} = V - I_l R_{se} / R_{sh}$$





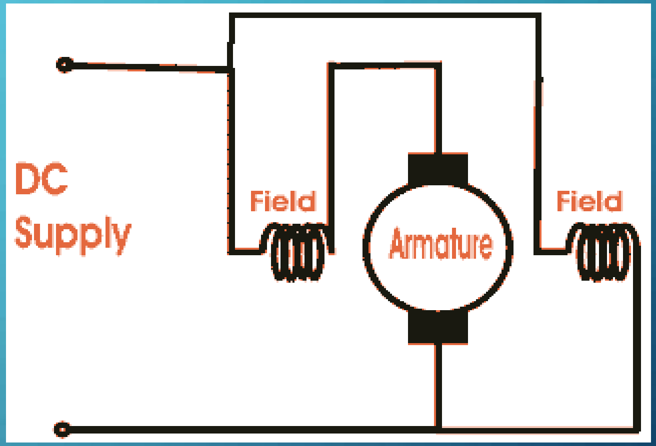
TYPES OF DC MOTOR

3. Self excited DC Motor

iii. Compound wound DC motor

Long Shunt DC Motor

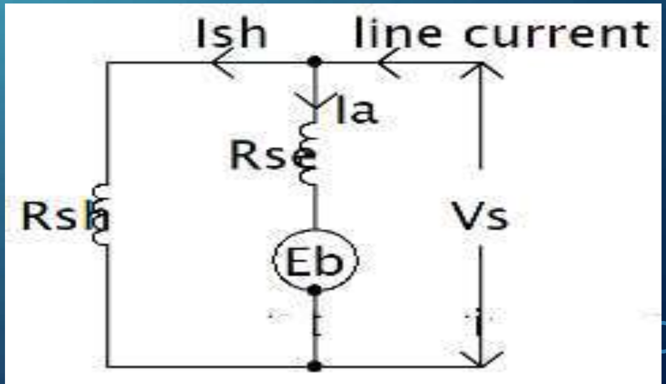
If the shunt field winding is parallel to both the armature winding and the series field winding then it's known as long shunt type compounded wound DC motor or simply long shunt DC motor.



In here, the shunt field winding is connected in parallel with both series field coil and armature which are again connected with each other in series.

The association between and current and voltage is expressed as

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



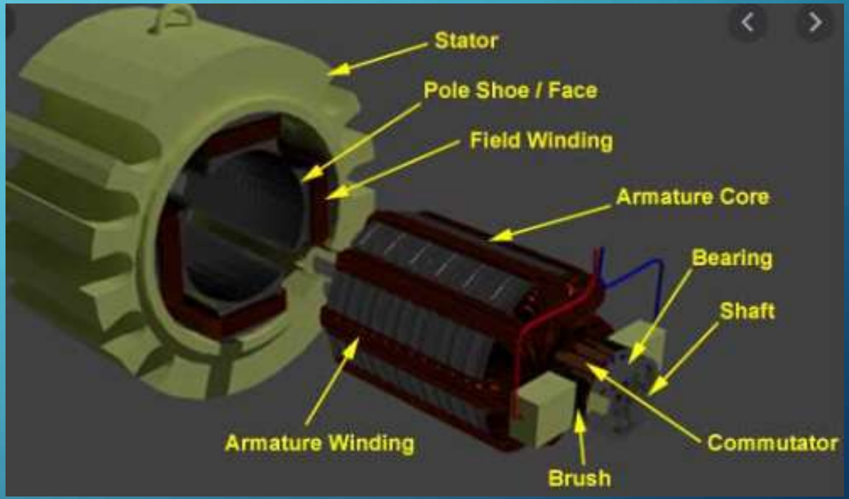
The brush drops can be neglected, then we get

$$V = E_b + I_{a\,+}(R_a + R_{se})$$
$$I_a = I_l - I_{sh}$$
$$I_{sh} = V / R_{sh}$$

LOSSES OF DC MOTOR

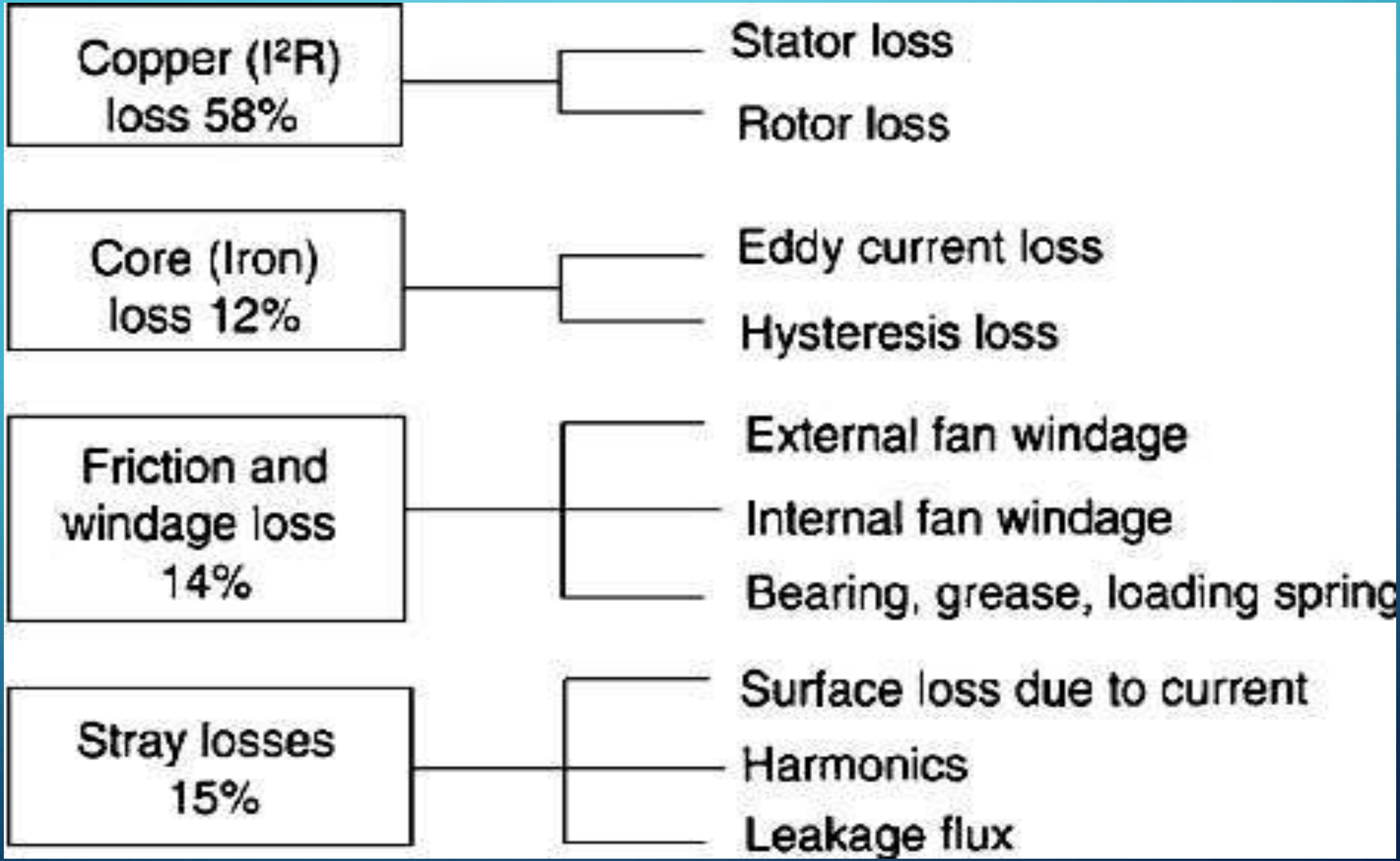
The losses can be divided into three types in a dc machine (Generator or Motor). They are

1. Copper losses
2. Iron or core losses
3. Mechanical losses.



All these losses seem as heat and therefore increase the temperature of the machine. Further the efficiency of the machine will reduce.

LOSSES OF DC MOTOR



LOSSES OF DC MOTOR

Copper Losses in DC Machine

These losses are also known as Winding losses as the copper loss occurs because of the resistance of the windings. The ohmic loss is produced by the current flowing in the windings. The windings that are present in addition to the armature windings are the field windings, Interpoles and compensating windings.

Armature copper losses = $I_a^2R_a$ where I_a is armature current, and Ra is the armature resistance. These losses are about 30 percent of the total full load losses.

In shunt machine, the Copper loss in the shunt field is $I^2_{sh}R_{sh}$, where I_{sh} is the current in the shunt field, and R_{sh} is the resistance of the shunt field windings. The shunt regulating resistance is included in R_{sh}.

In a series machine, the copper loss in the series windings is $I^2_{se}R_{se}$, where, I_{se} is the current through the series field windings, and R_{se} is the resistance of the series field windings.

In a **Compound machine**, both the shunt and the series field losses occur. These losses are almost 20 percent of the full load losses.

Copper losses in the Interpoles windings are written as $I_a^2R_i$ where R_i is the resistance of the Interpoles windings.

Copper loss in the compensating windings if any is $I_a^2R_c$ where R_c is the resistance of compensating windings.

LOSSES OF DC MOTOR

Core Losses or Iron Losses

The core losses are the **hysteresis** and **eddy current** losses. These losses are considered almost constant as the machines are usually operated at constant flux density and constant speed. These losses are about 20 percent of the full load losses.

Mechanical Losses

The losses that take place because of the mechanical effects of the machines are known as mechanical losses. Mechanical losses are divided into bearing friction loss and windage loss. The losses occurring in the moving parts of the machine and the air present in the machine is known as Windage losses. These losses are very small.

Brush Losses

Brush losses are the losses taking place between the commutator and the carbon brushes. It is the power loss at the brush contact point. The brush drop depends upon the brush contact voltage drop and the armature current Ia.

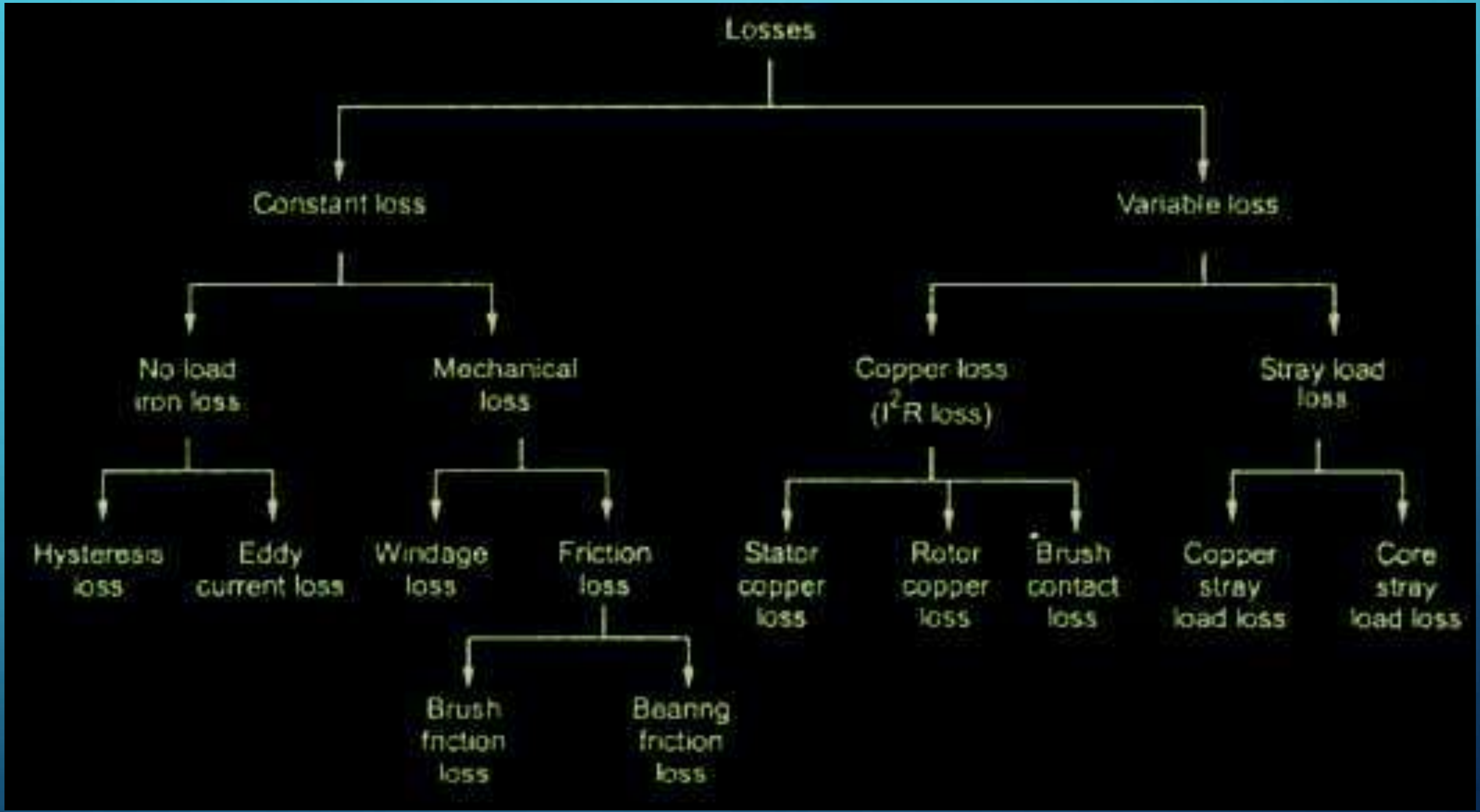
Stray Losses

These losses are the miscellaneous type of losses. The following factors are considered in stray load losses.

- The distortion of flux because of armature reaction.
- Short circuit currents in the coil, undergoing commutation.

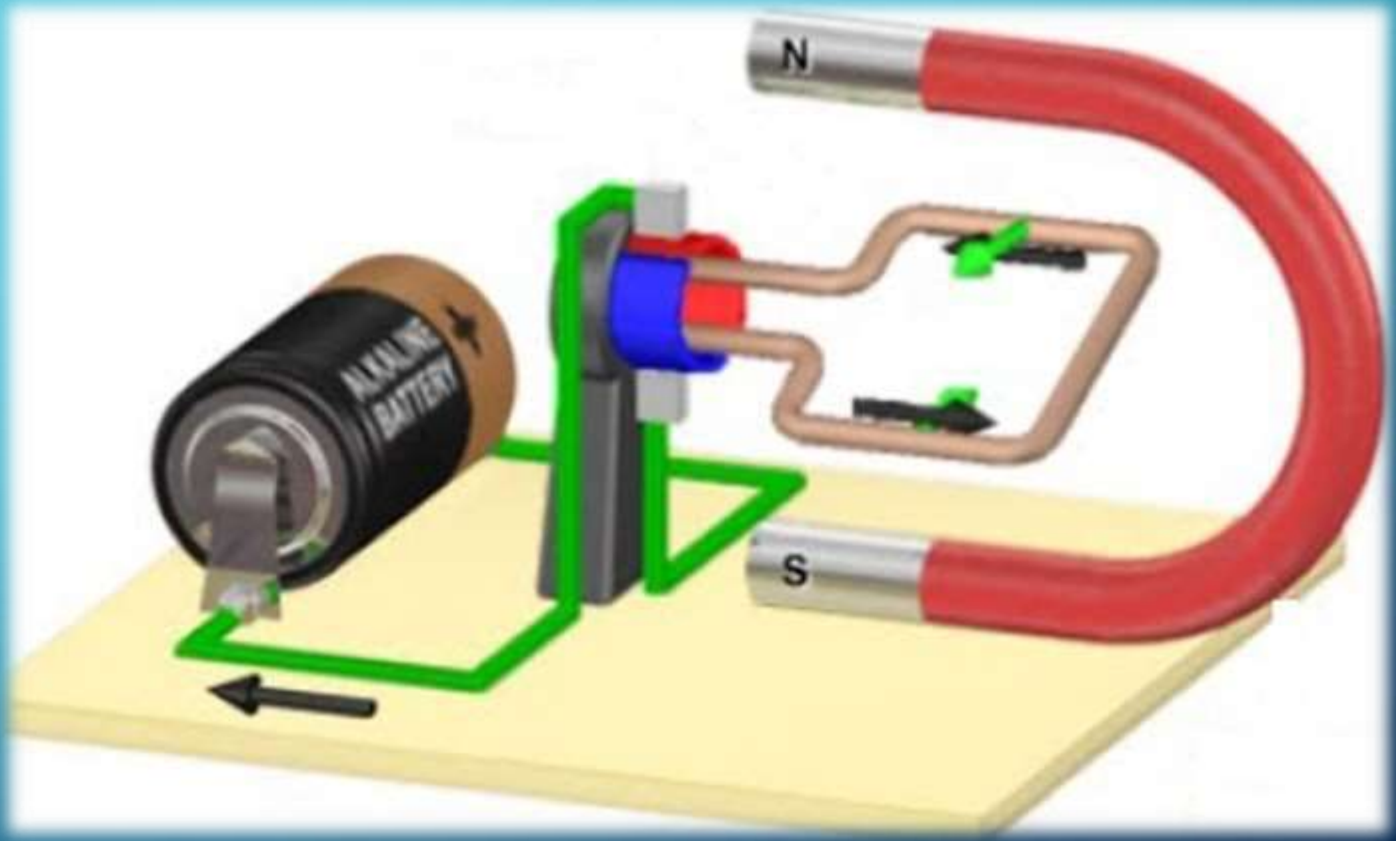
These losses are very difficult to determine. Therefore, it is necessary to assign the reasonable value of the stray loss. For most machines, stray losses are taken by convention to be one percent of the full load output power.

LOSSES OF DC MOTOR



MODULE:3

DC MOTOR



TOPIC:

- SPEED CONTROL OF DC MOTOR

❑ SEPARETELY EXCITED DC MOTOR

❑ SELF EXCITED DC MOTOR

  ➢ SHUNT WOUND DC MOTOR

  ➢ SERIES WOUND DC MOTOR

  ➢ COMPOUND WOUND DC MOTOR

SPEED CONTROL OF DC MOTOR

DC motor speed control is one of the most useful features of the motor. By controlling the speed of the motor, you can vary the speed of the motor according to the requirements and can get the required operation.

The speed control mechanism is applicable in many cases like controlling the movement of robotic vehicles, movement of motors in paper mills and the movement of motors in elevators where different types of DC motors are used.

Often we want to control the speed of a DC motor on demand. This intentional change of drive speed is known as speed control of a DC motor.

Speed control of a DC motor is either done manually by the operator or by means of an automatic control device. This is different to speed regulation – where the speed is trying to be maintained (or ‘regulated’) against the natural change in speed due to a change in the load on the shaft.

The term speed control is different from the speed regulation. The speed regulation means that, to maintain a speed of shaft constant against the change in load.

SPEED CONTROL OF DC MOTOR

Back emf E_b of a DC motor is nothing but the induced emf in armature conductors due to rotation of the armature in magnetic field. Thus, the magnitude of E_b can be given by EMF equation of a DC generator.

$$E_b = {}^{P\text{Ø}NZ}/_{60A}$$

where,
P = no. of poles
Ø = flux/pole
N = speed in rpm
Z = no. of armature conductors
A = parallel paths)

E_b can also be given as $\quad E_b = V- I_aR_a$

Thus, from the above equations $\quad N = {}^{E_b\,60A}/_{P\text{Ø}Z}$

But, for a DC motor A, P and Z are constants

Therefore, $\quad N \propto K\, {}^{E_b}/_{\text{Ø}}$ (where, K=constant)

This shows the **speed of a dc motor** is directly proportional to the back emf and inversely proportional to the flux per pole.

SPEED CONTROL OF DC MOTOR

The relationship given below gives the speed of a D.C. motor

$$N = \frac{V - I_a R_a}{k\phi}$$

The above equation shows that the speed depends upon the supply voltage V, the armature circuit resistance R_a, and the field flux Φ, which is produced by the field current. In practice, the variation of these three factors is used for speed control. Thus, there are three general methods of speed control of D.C. Motors.

1. Resistance variation in the armature circuit: This method is called armature resistance control or Rheostat control.

2. Variation of field flux Φ
This method is called field flux control.

3. Variation of the applied voltage.
This method is also called armature voltage control.

TYPES OF SPEED CONTROL OF DC MOTOR

Speed of a DC motor can be varied by varying flux, armature resistance or applied voltage. Different speed control methods for different DC shunt and series methods are there.

Speed Control of Shunt Motors

1. **Flux control method**
2. **Armature and Rheostatic control method**
3. **Voltage control method**
   - **Multiple voltage control**
   - **Ward Leonard system**

Speed Control of Series Motors

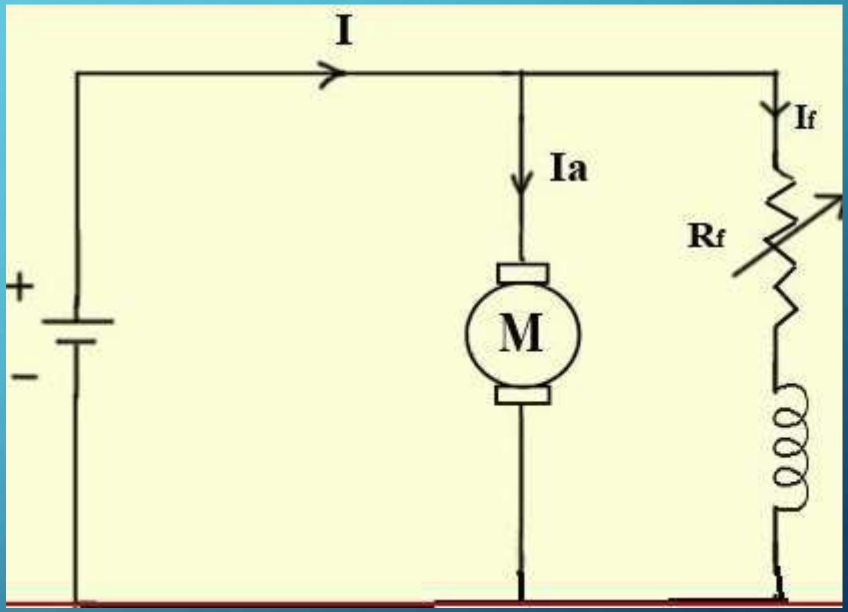
1. **Flux control method**
   - **Field diverter**
   - **Armature diverter**
   - **Trapped field control**
   - **Paralleling field coils**
2. **Variable Resistance in series with motor**
3. **Series -parallel control method**

SPEED CONTROL METHODS OF DC MOTOR

SPEED CONTROL OF SHUNT MOTOR

1. Flux control method

It is already explained above that the speed of a dc motor is inversely proportional to the flux per pole. Thus by decreasing the flux, speed can be increased and vice versa.



To control the flux, a rheostat is added in series with the field winding, as shown in the circuit diagram. Adding more resistance in series with the field winding will increase the speed as it decreases the flux. In shunt motors, as field current is relatively very small, I_{sh}^2R loss is small. Therefore, this method is quite efficient. Though speed can be increased above the rated value by reducing flux with this method, it puts a limit to maximum speed as weakening of field flux beyond a limit will adversely affect the commutation.

SPEED CONTROL METHODS OF DC MOTOR

SPEED CONTROL OF SHUNT MOTOR

1. Flux control method

Advantages of flux control method

(i) This is an easy and convenient method.

(ii) It is an inexpensive method since very little power is wasted in the shunt field rheostat due to a relatively small value of Ish.

(iii) The speed control exercised by this method is independent of the load on the machine.

Disadvantages of flux control method

(i) Only speeds higher than the normal speed can be obtained since the total field circuit resistance cannot be reduced below Rsh—the shunt field winding resistance.

(ii) There is a limit to the maximum speed obtainable by this method. It is because if the flux is too much weakened, commutation becomes poorer.

SPEED CONTROL METHODS OF DC MOTOR

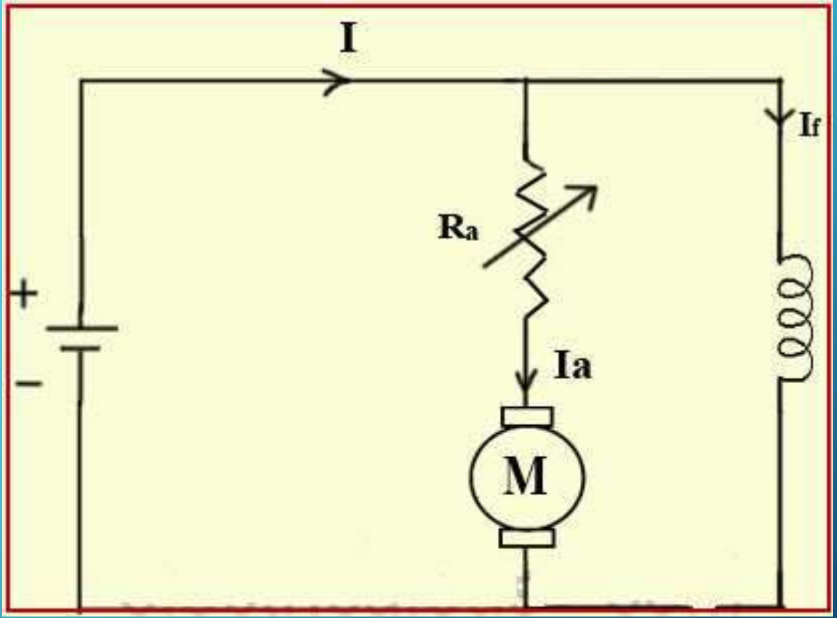
SPEED CONTROL OF SHUNT MOTOR

2. Armature control method

Speed of a dc motor is directly proportional to the back emf E_b

$$E_b = V - I_a R_a.$$

That means, when supply voltage V and the armature resistance R_a are kept constant, then the speed is directly proportional to armature current I_a. Thus, if we add resistance in series with the armature, I_a decreases and, hence, the speed also decreases. Greater the resistance in series with the armature, greater the decrease in speed.



Disadvantages of Armature Control Method

(i) A large amount of power is wasted in the controller resistance since it carries full armature current Ia.

(ii) The speed varies widely with load since the speed depends upon the voltage drop in the controller resistance and hence on the armature current demanded by the load.

(iii) The output and efficiency of the motor are reduced.

(iv) This method results in poor speed regulation.

SPEED CONTROL METHODS OF DC MOTOR

SPEED CONTROL OF SHUNT MOTOR

3.Voltage Control Method

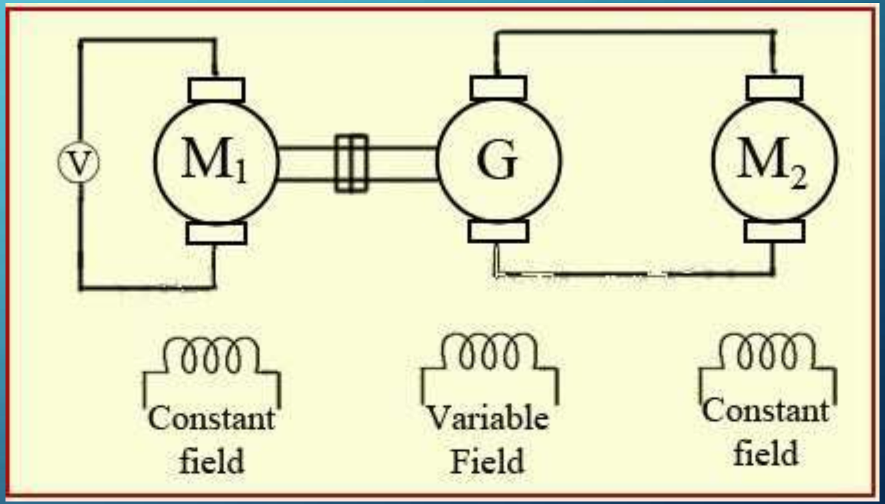
a) **Multiple voltage control**

In this method, the shunt field is connected to a fixed exciting voltage and armature is supplied with different voltages. Voltage across armature is changed with the help of suitable switchgear. The speed is approximately proportional to the voltage across the armature.

b) **Ward-Leonard System**

This Ward –Leonard system is used where very sensitive speed control of the motor is required (e.g. electric excavators, elevators, etc.).

M2 is the motor, it controls the speed of the generator. M1 may be any AC motor or DC motor with constant speed. G is the generator directly coupled to M1. In this method the output from the generator G is fed to the armature of the motor M2 whose speed is to be controlled. The generator output voltage can be connected to the motor M2 and it can be varied from zero to its maximum value, and hence the armature voltage of the motor M2 is varied very smoothly. Hence very smooth speed control of motor can be obtained by this method.



SPEED CONTROL METHODS OF DC MOTOR

SPEED CONTROL OF SHUNT MOTOR

Advantages of Ward Leonard Method

The advantages of this method are summarized below;

1. The speed of a motor can be controlled over a wide range.
2. The operation of the motor is very smooth.
3. The speed regulation of the motor is good.
4. A motor can run with uniform acceleration.
5. It has an inherent breaking capacity.
6. Easy to reverse the direction of rotation and speed can be controlled in both directions.

Disadvantages of Ward Leonard Method

The disadvantages of this method are summarized below;

1. It needs two additional machines (motor-generator set) with the same rating of the main motor. 2.Therefore, the overall cost of this arrangement is very high.
3. It produces more noise.
4. Frequent maintenance required.
5. This arrangement needs more space to install.
6. Overall efficiency is low if the motor runs with light load conditions for a long period of time.

Application of Ward Leonard Method

This method is used where the motor to be controlled over a wide speed range. The application of the motor is very sensitive to speed, in this condition this method is very useful.

This method is used in the application like; cranes, excavator, elevator, mine hoists, paper machine, steel rolling mills, etc.

SPEED CONTROL METHODS OF DC MOTOR

SPEED CONTROL OF SERIES MOTOR

1. Flux control method

Field diverter:
A variable resistance is connected parallel to the series field as shown in fig (a). This variable resistor is called as a diverter, as the desired amount of current can be diverted through this resistor and, hence, current through field coil can be decreased. Thus, flux can be decreased to the desired amount and speed can be increased.

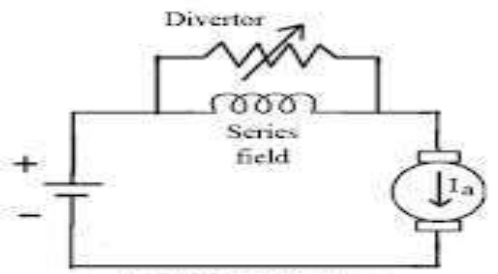


fig (a) Field Divertor

Armature diverter:
Diverter is connected across the armature as shown in fig (b).
For a given constant load torque, if armature current is reduced then the flux must increase, as $T_a \propto \O I_a$
This will result in an increase in current taken from the supply and hence flux Ø will increase and subsequently speed of the motor will decrease.

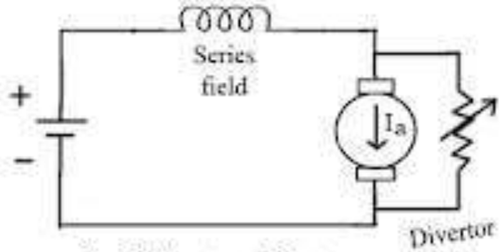


fig (b) Armature Divertor

Tapped field control:
As shown in fig (c) field coil is tapped dividing number of turns. Thus we can select different value of Ø by selecting different number of turns.

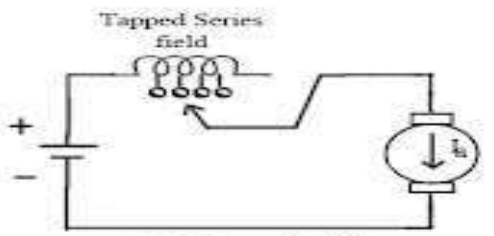


fig (c) Tapped field

Paralleling field coils:
In this method, several speeds can be obtained by regrouping coils as shown in fig (d).

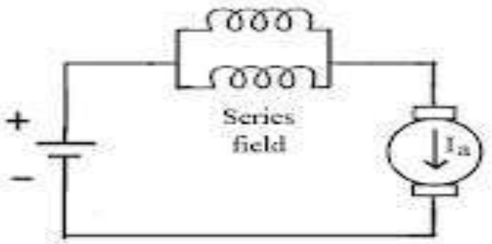


fig (d) Paralleling Field coils

SPEED CONTROL METHODS OF DC MOTOR

SPEED CONTROL OF SERIES MOTOR

2. Variable resistance in series with armature

By introducing resistance in series with the armature, voltage across the armature can be reduced. And, hence, speed reduces in proportion with it.

3. Series-parallel control

This system is widely used in electric traction, where two or more mechanically coupled series motors are employed. For low speeds, the motors are connected in series, and for higher speeds, the motors are connected in parallel.

When in series, the motors have the same current passing through them, although voltage across each motor is divided. When in parallel, the voltage across each motor is same although the current gets divided.

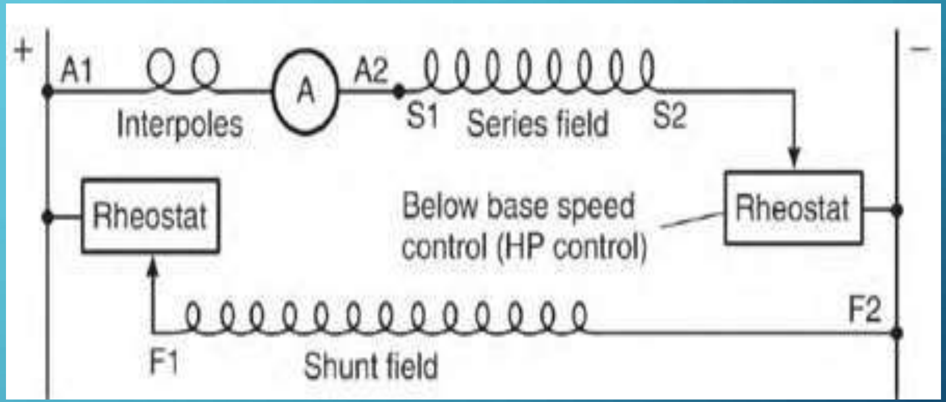
SPEED CONTROL METHODS OF DC MOTOR

SPEED CONTROL OF COMPOUND MOTOR

The motor's nameplate shows the base speed of the motor.

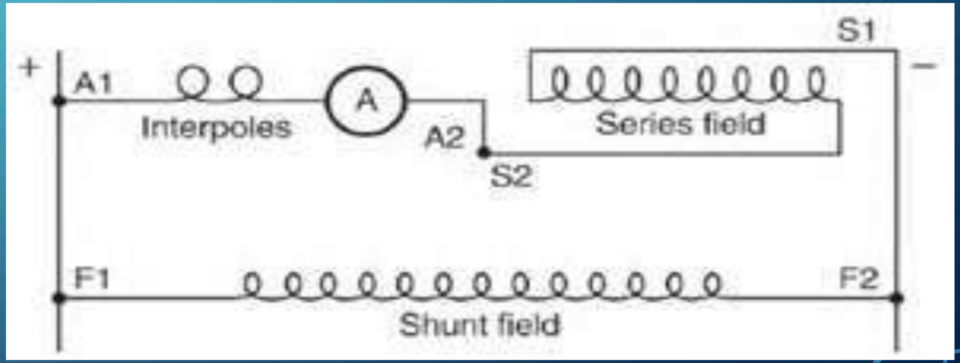
Armature Control for Starting and for Below Base Speed

Full voltage should be applied to the shunt field when the armature control is used. Full voltage to the shunt field will give the motor constant torque (from zero to base speed). The armature control allows enough amperes through the armature to give it breakaway torque. The resistance is lowered gradually as the motor starts to accelerate. The motor accelerates to the RPM required by the load. Full voltage is applied to the armature at base speed.



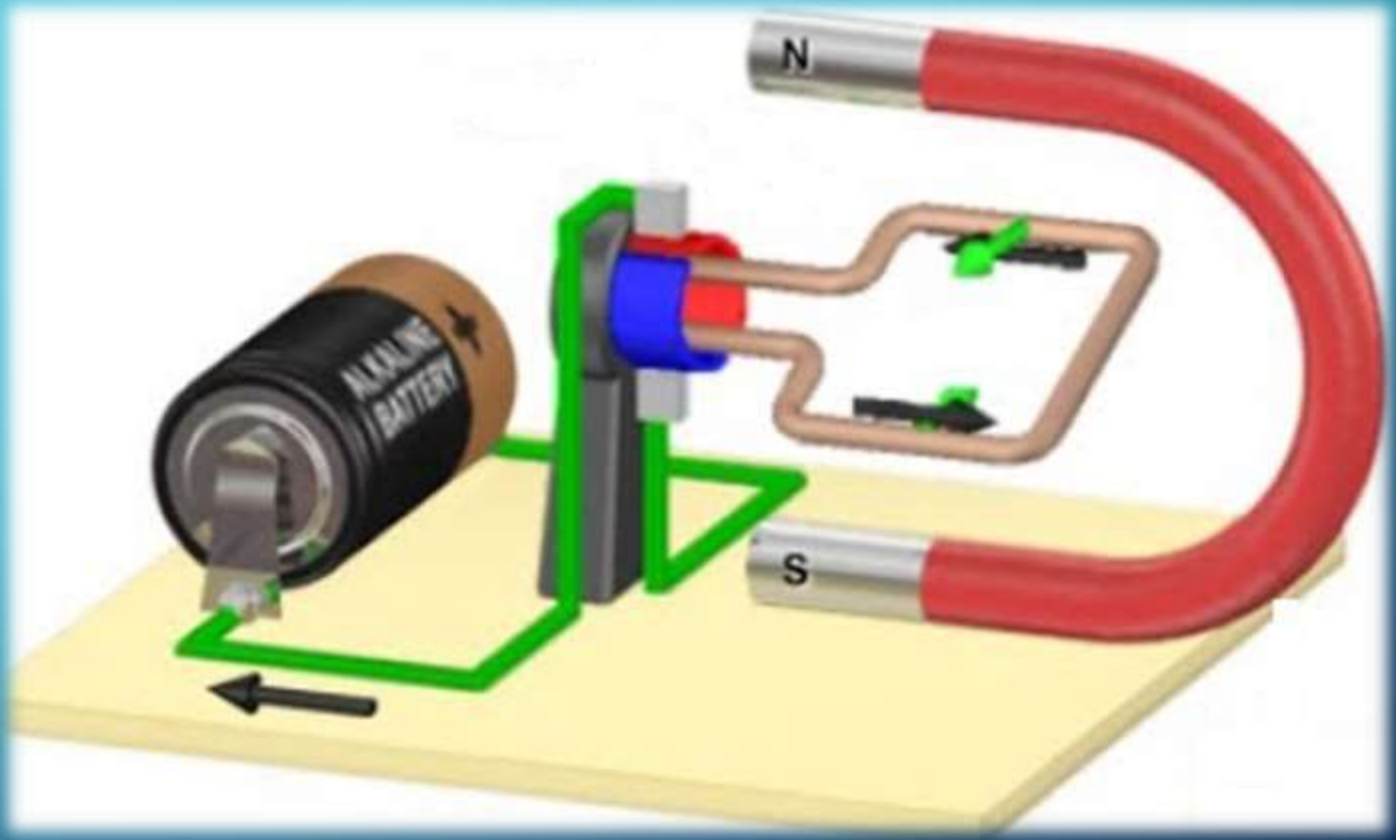
Shunt Field Control for Starting and for Above Base Speed

The shunt field control applies full voltage to the shunt field when the motor starts. The motor accelerates until the RPM is stabilized at base speed. At this RPM the lines of force furnished by the shunt field are at maximum. The amperes flowing in the armature are limited by counter voltage to a value needed for the load and the motor's internal losses.



MODULE:3

DC MOTOR



TOPIC:

- **ARMATURE CONTROL OF DC SHUNT MOTOR**

SPEED OF A DCMOTOR

$$E_b = V - I_a R_a$$

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

$$\frac{P\phi Z N}{60\, A} = V - I_a R_a$$

$$N = \frac{(V - I_a R_a)}{\phi} \frac{60\, A}{P Z}$$

$$N = K \frac{(V - I_a R_a)}{\phi} \quad \text{where} \quad K = \frac{60 A}{PZ}$$

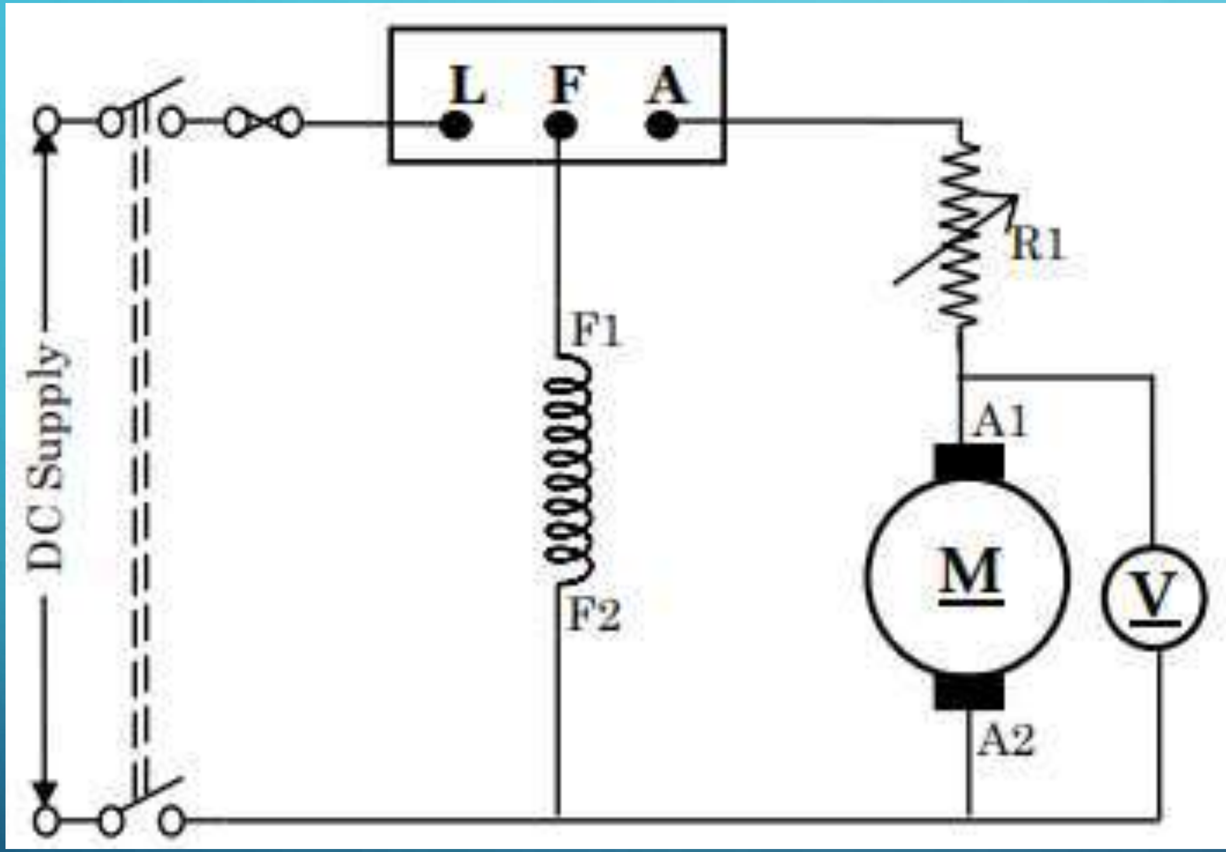
$$V - I_a R_a = E_a$$

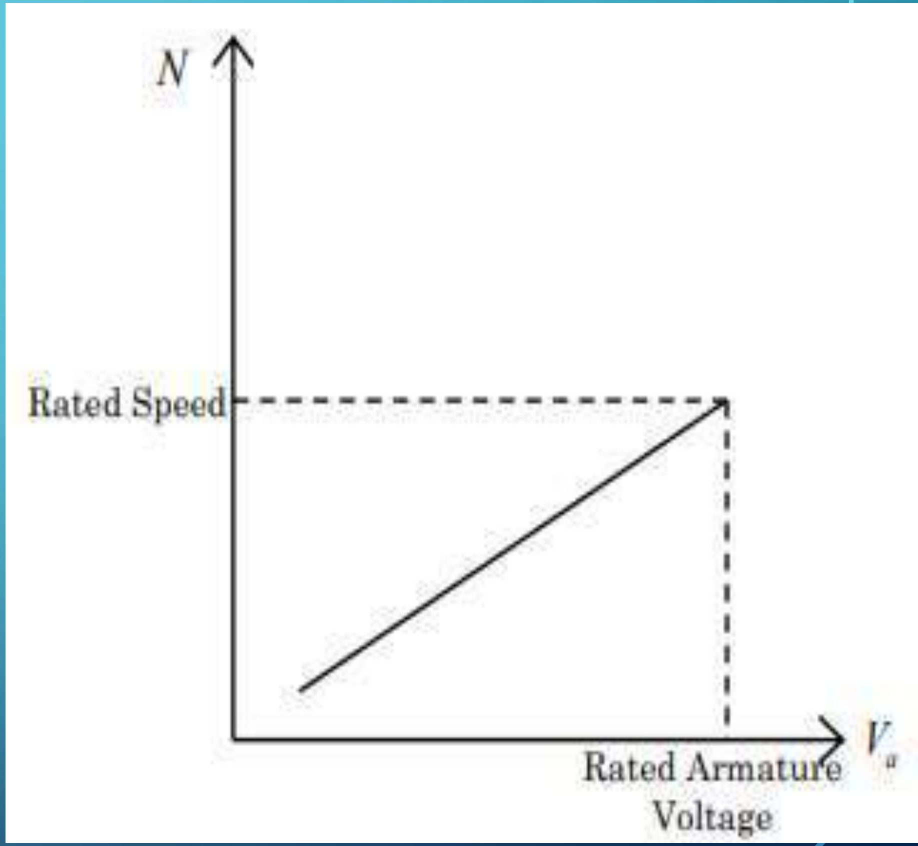
$$N = K \frac{E_b}{\phi}$$

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

Therefore, in a DC Motor speed is directly proportional to back EMF and inversely proportional to flux.

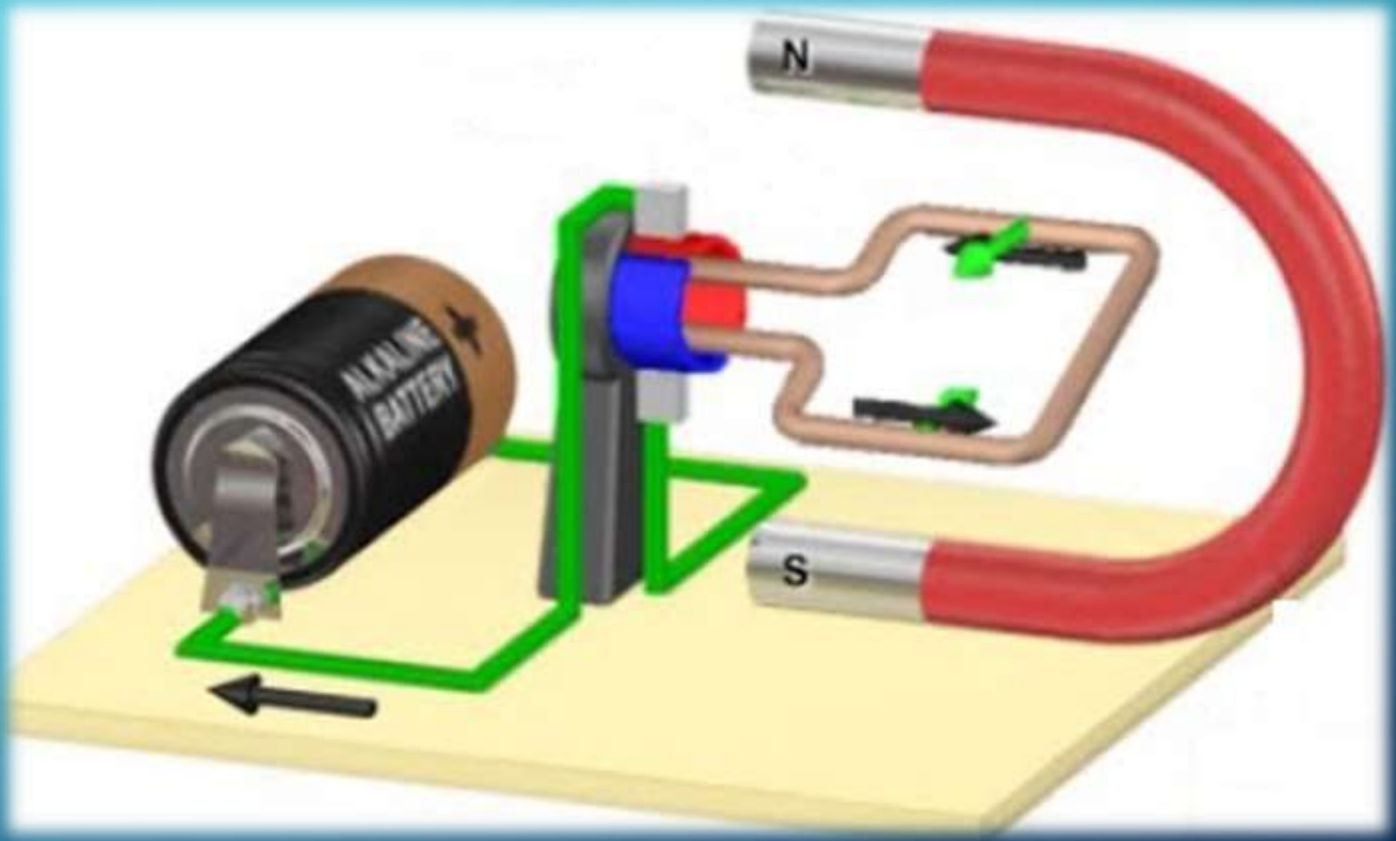
ARMATURE CONTROL METHOD





MODULE:3

DC MOTOR



TOPIC:

- FIELD CONTROL OF DC SHUNT MOTOR

SPEED OF A DCMOTOR

$$E_b = V - I_a R_a$$

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

$$\frac{P\phi Z N}{60\ A} = V - I_a R_a$$

$$N = \frac{(V - I_a R_a)}{\phi} \frac{60\ A}{P Z}$$

$$N = K \frac{(V - I_a R_a)}{\phi} \quad \text{where} \quad K = \frac{60A}{PZ}$$

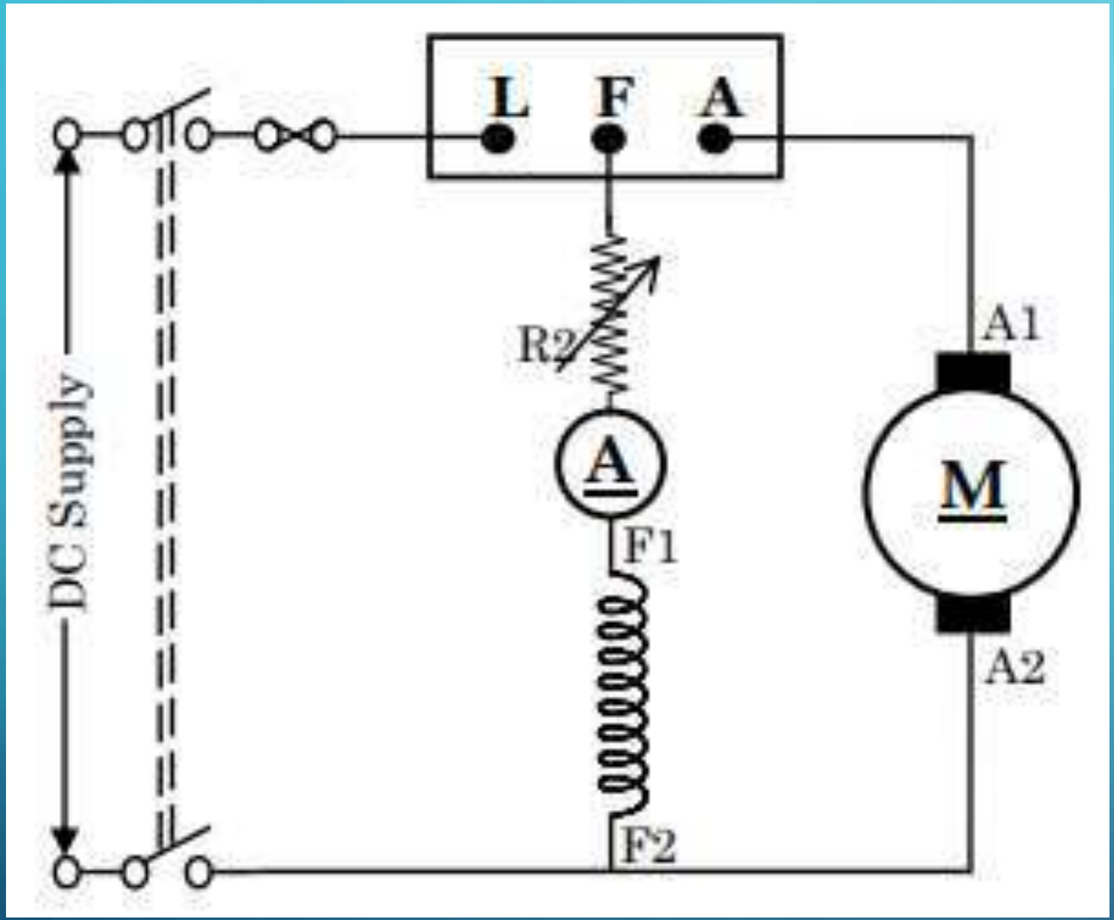
$$V - I_a R_a = E_a$$

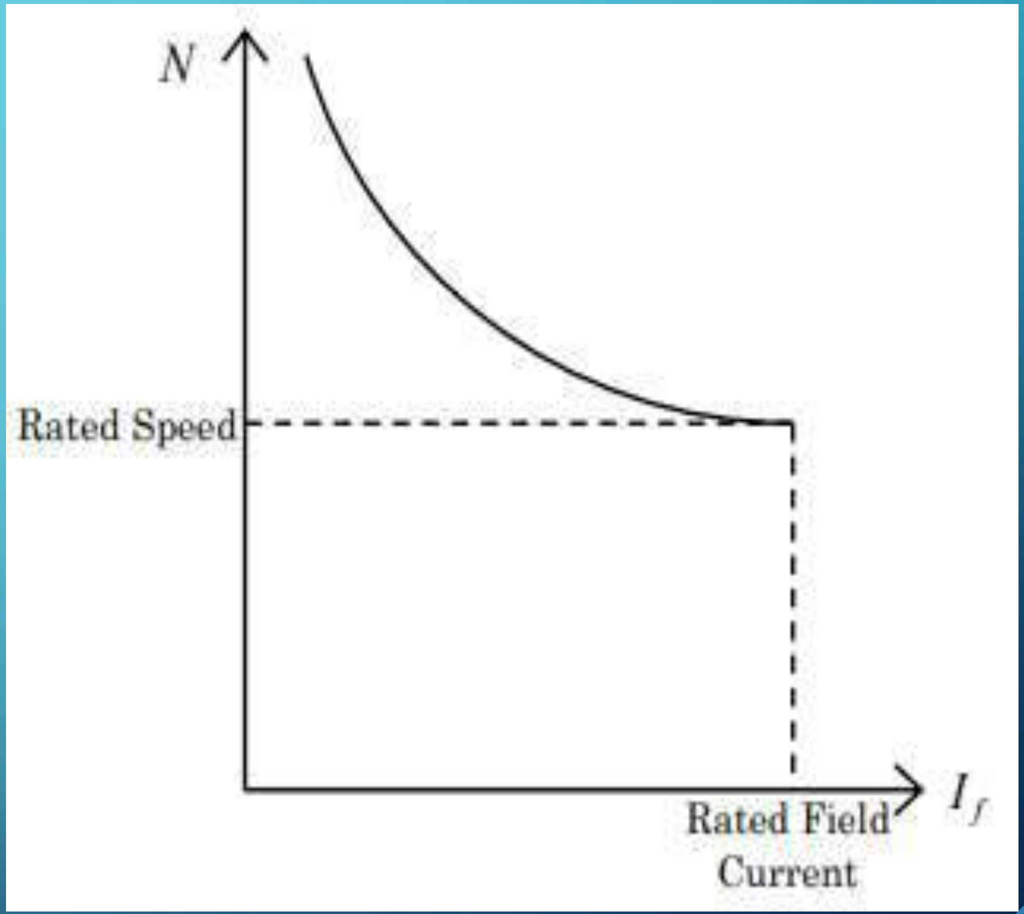
$$N = K \frac{E_b}{\phi}$$

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

Therefore, in a DC Motor speed is directly proportional to back EMF and inversely proportional to flux.

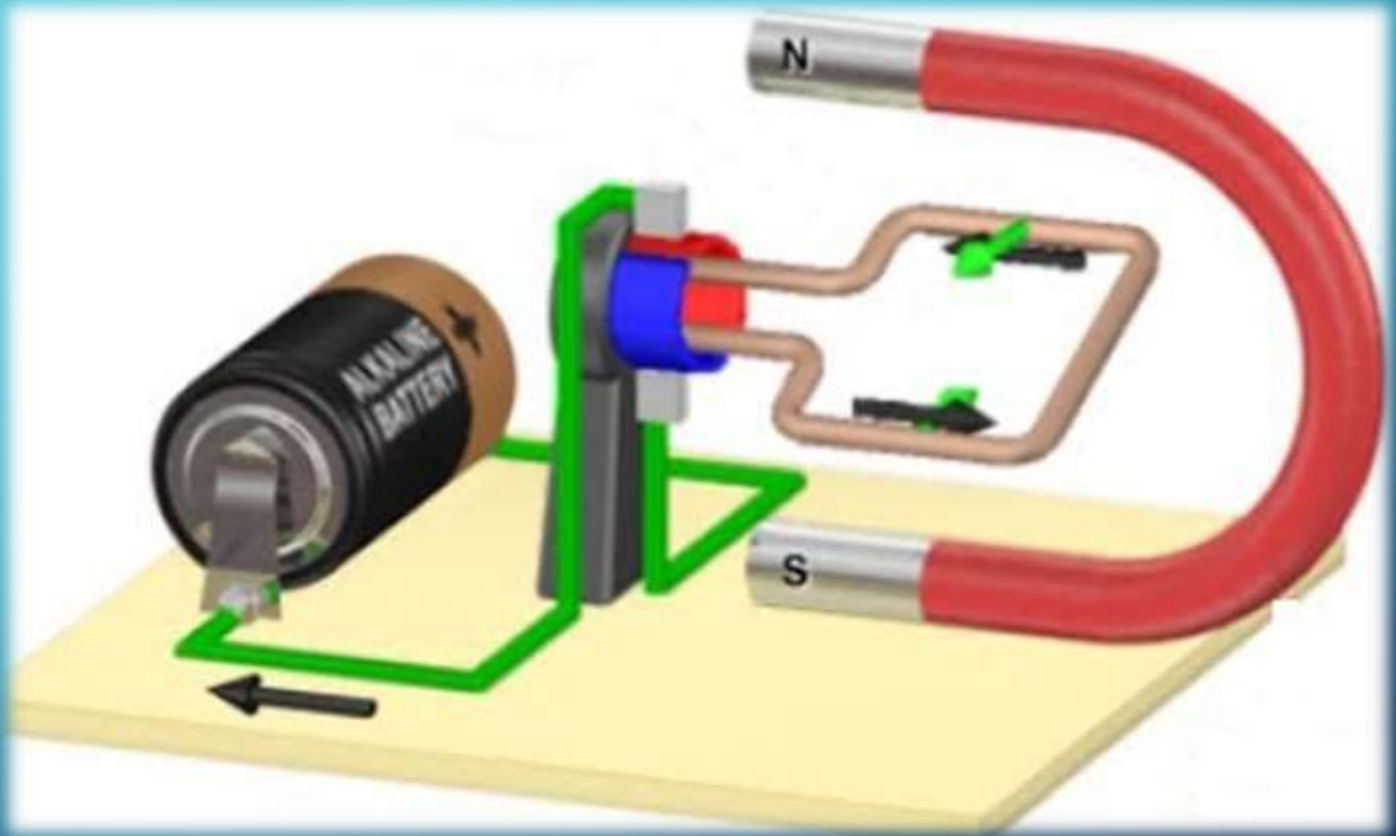
FIELD CONTROL METHOD





MODULE:3

DC MOTOR



TOPIC:

- **CHARACTERISTICS OF DC MOTOR**
  - **SEPARATELY EXCITED DC MOTOR**
  - **SHUNT DC MOTOR**
  - **SERIES DC MOTOR**
  - **COMPOUND DC MOTOR**
    - **CUMULATIVE COMPOUND**
    - **DIFFERENTIAL COMPOUND**

CHARACTERISTICS OF DC MOTORS

According to the Excitation D.C Motor may be classified as

(i) Separately excited motor
(ii) Self excited motor

Self excited generator may be classified as

(i) Shunt motor
(ii) Series motor
(iii) Compound motor

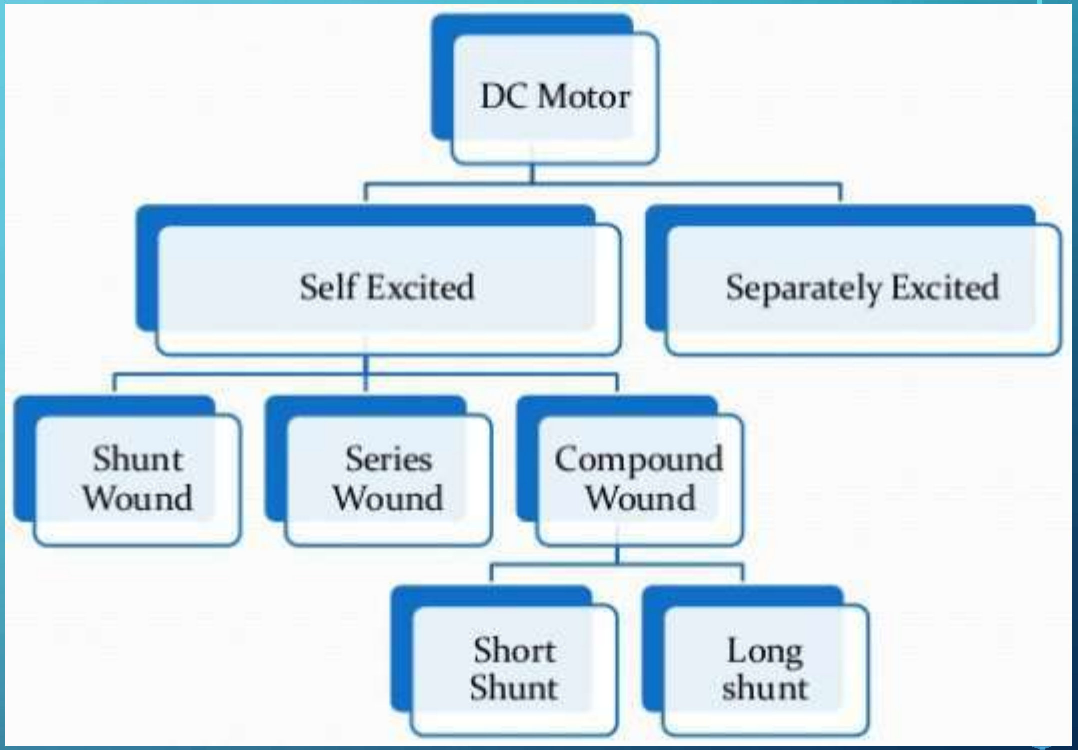
In a separately excited motor field winding is energized from a separate voltage source in order to produce flux in the machine. So long the machine operates in unsaturated condition the flux produced will be proportional to the field current.

In order to implement shunt connection, the field winding is connected in parallel with the armature. It will be shown that subject to fulfillment of certain conditions, the machine may have sufficient field current developed on its own by virtue of its shunt connection.

CHARACTERISTICS OF DC MOTORS

In series d.c motor, there is one field winding wound over the main poles with fewer turns and large cross sectional area. Series winding is meant to be connected in series with the armature and naturally to be designed for rated armature current. Obviously there will be practically no voltage or very small voltage due to residual field under no load condition (Ia = 0)

A compound motor has two separate field coils wound over the field poles. The coil having large number of turns and thinner cross sectional area is called the shunt field coil and the other coil having few number of turns and large cross sectional area is called the series field coil. Series coil is generally connected in series with the armature while the shunt field coil is connected in parallel with the armature. If series coil is left alone without any connection, then it becomes a shunt machine with the other coil connected in parallel.



CHARACTERISTICS OF DC MOTORS

Generally, three characteristic curves are considered important for DC motors which are,

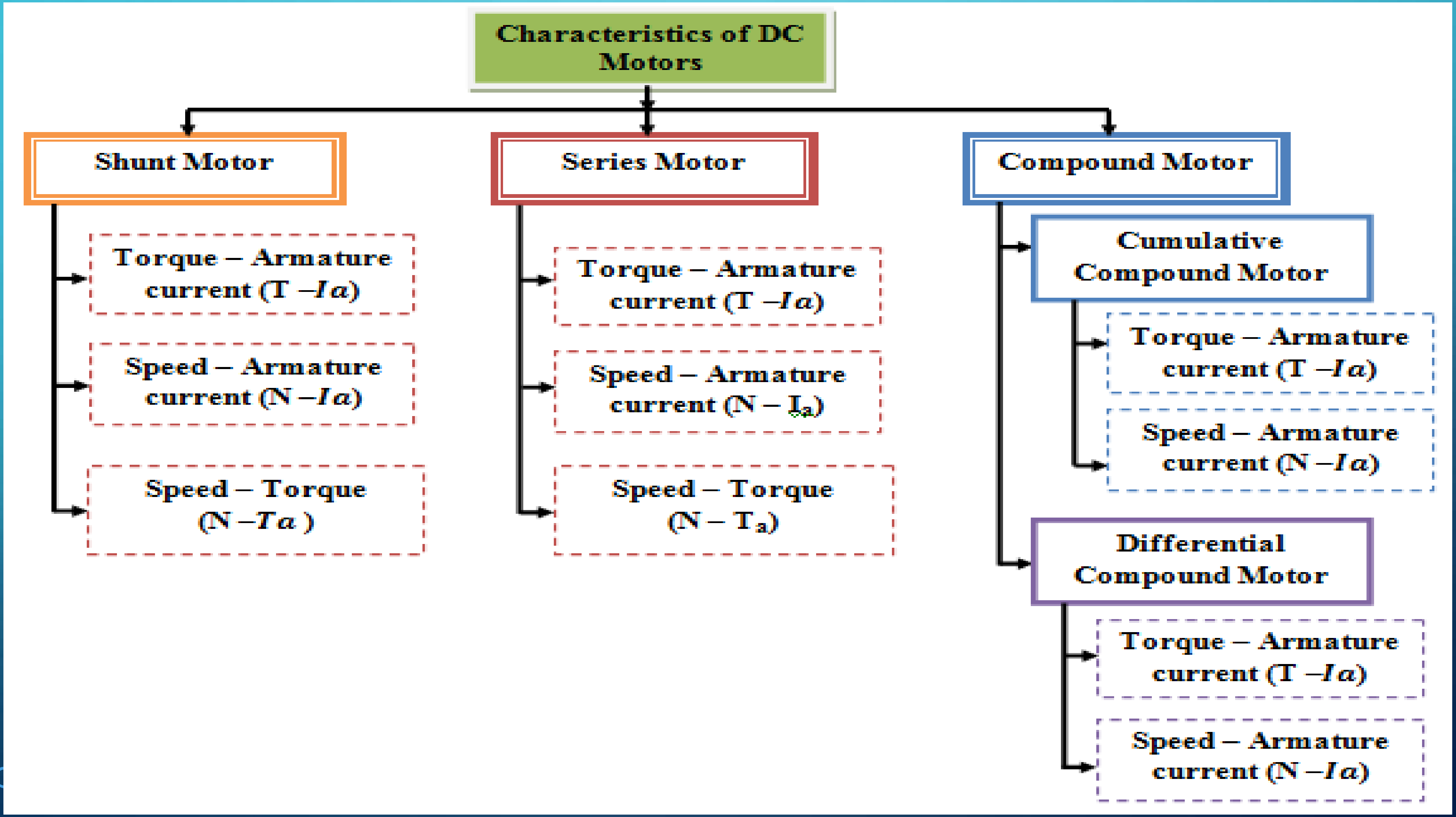
1. Torque vs. armature current,
2. Speed vs. armature current
3. Speed vs. torque.

These characteristics are determined by keeping the following two relations in mind.

1. $T_a \propto \emptyset I_a$
2. $N \propto E_b / \emptyset$
3. $E_b = V - I_a R_a$

These above equations can be studied at - emf, torque equation and voltage equation of dc machine. For a DC motor, magnitude of the back emf is given by the same emf equation of a dc generator i.e. $E_b = P\phi NZ / 60A$. For a machine, P, Z and A are constant, therefore, $N \propto E_b/\phi$

TYPES OF CHARACTERISTICS OF DC MOTORS



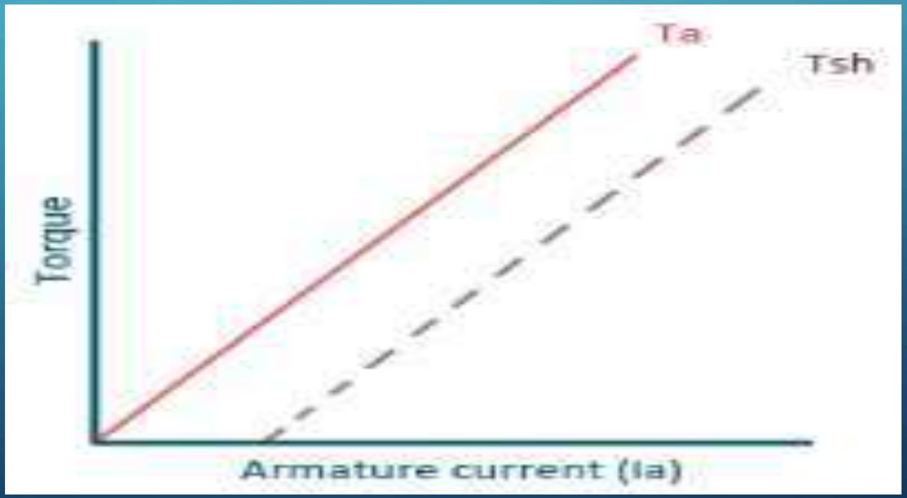
CHARACTERISTICS OF SHUNT MOTORS

1. Torque vs. armature current (Ta-Ia)

If the supply voltage is kept constant, the field flux remains constant.

Ta α ΦIa
Therefore, Ta α Ia

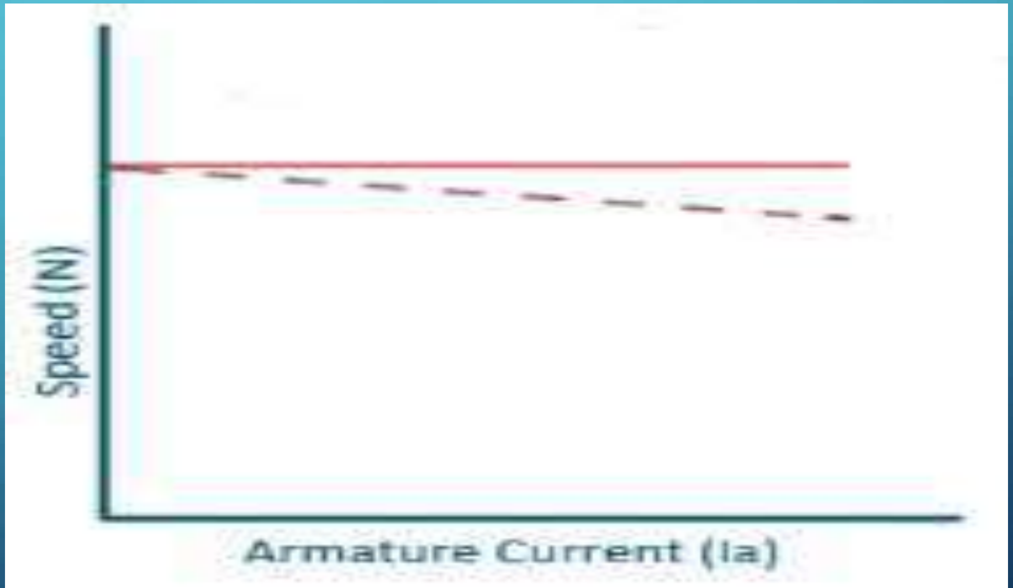
The characteristic of torque – armature current is straight line from the origin.
The shaft torque is always less than the gross torque because of stray losses.
It should be noted that the heavy starting load requires heavy starting current therefore the DC shunt motor never starts against heavy load.
The shunt flux does not remain constant at any load condition but it decreases slight at heavy load due to effect of armature reaction.



CHARACTERISTICS OF SHUNT MOTORS

2. Speed vs. armature current (N-Ia)

As flux ϕ is assumed to be constant, we can say N ∝ Eb. But, as back emf is also almost constant, the speed should remain constant. But practically, ϕ as well as Eb decreases with increase in load. Back emf Eb decreases slightly more than ϕ, therefore, the speed decreases slightly. Generally, the speed decreases only by 5 to 15% of full load speed. Therefore, a shunt motor can be assumed as a constant speed motor. In speed vs. armature current characteristic in the following figure, the straight horizontal line represents the ideal characteristic and the actual characteristic is shown by the dotted line.



CHARACTERISTICS OF SHUNT MOTORS

3. Speed vs. torque (N-Ta)

This curve is drawn between the speed of the motor and armature current with various amps as shown in the fig. From the curve it is understood that the speed reduces when the load torque increases.

With the above three characteristic it is clearly understood that when the shunt motor runs from no load to full load there is slight change in speed. Thus, it is essentially a constant speed motor. Since the armature torque is directly proportional to the armature current, the starting torque is not high.

$$N = \frac{V - I_a R_a}{\phi Z} \times \frac{60A}{P} = K_1 \frac{V - I_a R_a}{\phi} = K_1 \frac{E_b}{\phi}$$

∵ Z, A and P are constant for a particular machine

$$T = \frac{\phi}{2\pi} \times Z \times \frac{P}{A} I_a = K_2 \phi I_a$$

$$N = K_1 \frac{V}{\phi} - K_1 \frac{\frac{T}{K_2 \phi} R_a}{\phi} = K_1 \frac{V}{\phi} - \frac{K_1}{K_2} \frac{T R_a}{\phi^2}$$

CHARACTERISTICS OF SERIES MOTORS

1. Torque vs. armature current (Ta-Ia)

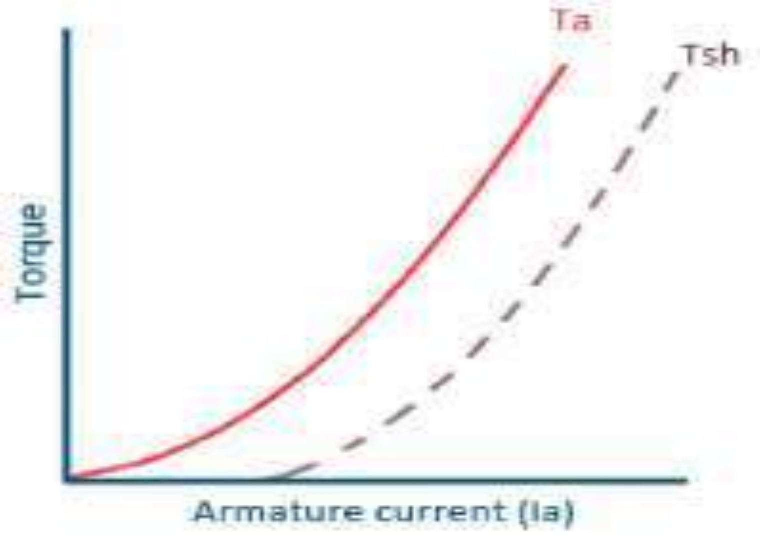
This characteristic is also known as electrical characteristic. We know that torque is directly proportional to the product of armature current and field flux, $T_a \propto \phi.I_a$. In DC series motors, field winding is connected in series with the armature, i.e. $I_a = I_f$. Therefore, before magnetic saturation of the field, flux ϕ is directly proportional to Ia. Hence, before magnetic saturation Ta α Ia^2.

Therefore, the Ta-Ia curve is parabola for smaller values of Ia.

After magnetic saturation of the field poles, flux ϕ is independent of armature current Ia. Therefore, the torque varies proportionally to Ia only, T ∝ Ia. Therefore, after magnetic saturation, Ta-Ia curve becomes a straight line.

The shaft torque (Tsh) is less than armature torque (Ta) due to stray losses. Hence, the curve Tsh vs Ia lies slightly lower.

In DC series motors, (prior to magnetic saturation) torque increases as the square of armature current, these motors are used where high starting torque is required.



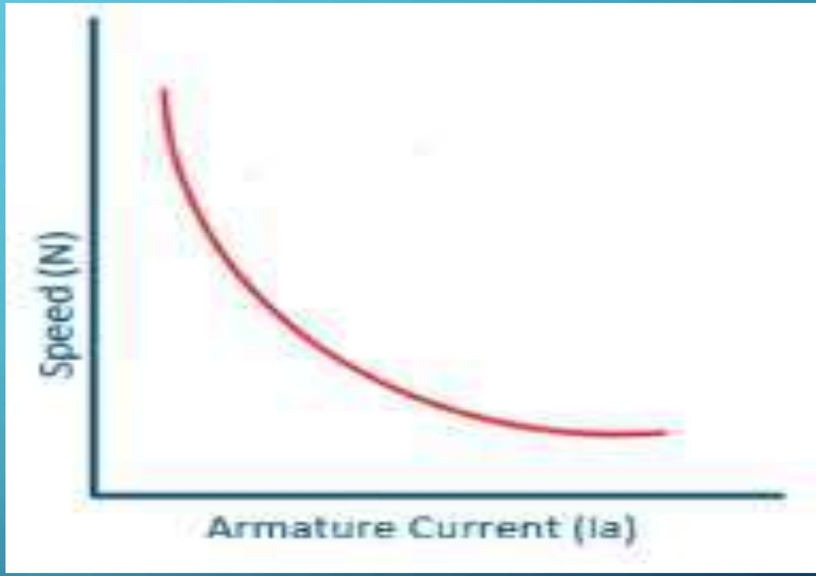
CHARACTERISTICS OF SERIES MOTORS

2. Speed vs. armature current (N-Ia)

We know the relation, $N \propto E_b/\phi$

For small load current (and hence for small armature current) change in back emf Eb is small and it may be neglected. Hence, for small currents speed is inversely proportional to ϕ. As we know, flux is directly proportional to Ia, speed is inversely proportional to Ia. Therefore, when armature current is very small the speed becomes dangerously high. That is why a series motor should never be started without some mechanical load.

But, at heavy loads, armature current Ia is large. And hence, speed is low which results in decreased back emf Eb. Due to decreased Eb, more armature current is allowed.

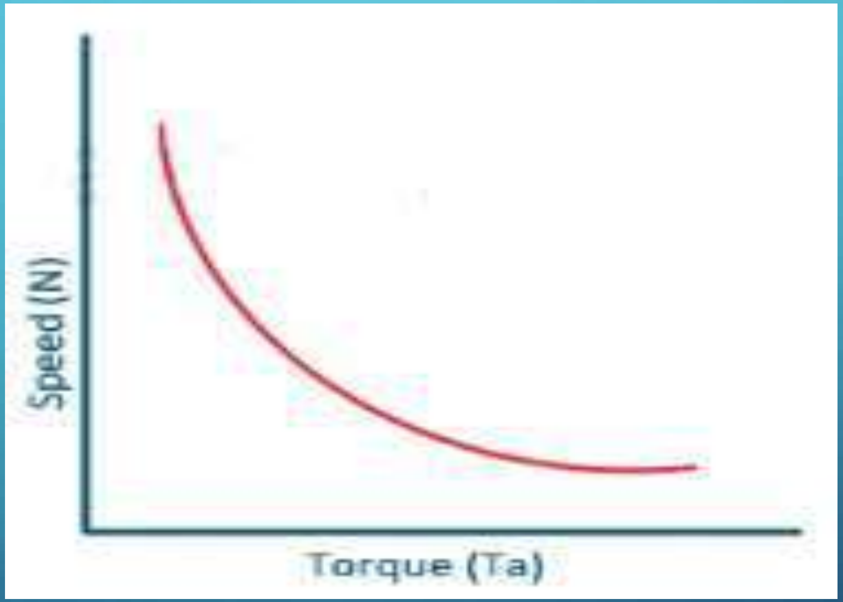


CHARACTERISTICS OF SERIES MOTORS

3. Speed vs. torque (N-Ta)

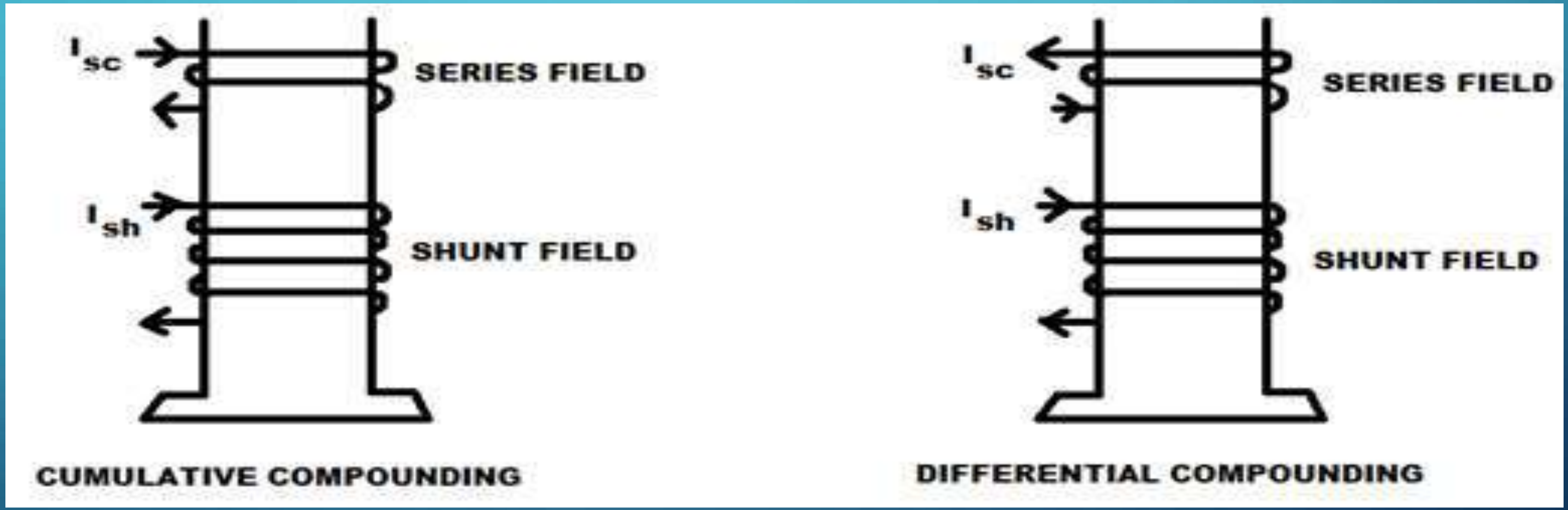
This characteristic is also called as mechanical characteristic.

From the above two characteristics of DC series motor, it can be found that when speed is high, torque is low and vice versa.



CHARACTERISTICS OF COMPOUND MOTORS

DC compound motors have both series as well as shunt winding. In a compound motor, if series and shunt windings are connected such that series flux is in direction as that of the shunt flux then the motor is said to be cumulatively compounded. And if the series flux is opposite to the direction of the shunt flux, then the motor is said to be differentially compounded. Characteristics of both these compound motors are explained below.



CHARACTERISTICS OF COMPOUND MOTORS

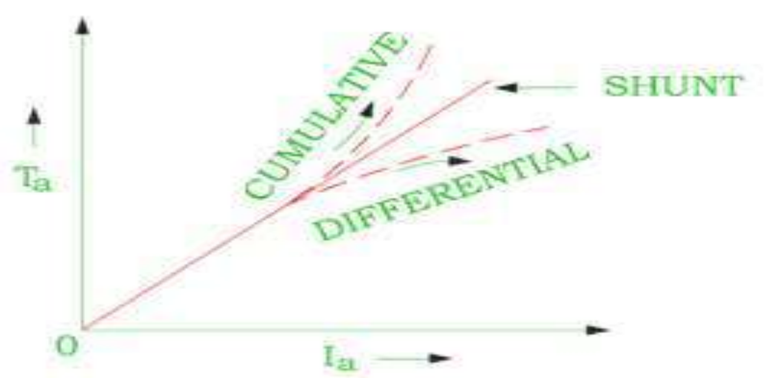
Cumulative compound motor

Cumulative compound motors are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors have generally employed a flywheel, where sudden and temporary loads are applied like in rolling mills.

1. Torque vs. armature current (Ta-Ia)

The series flux is in the same direction as that of shunt flux therefore the net flux increases as the load current increases in the compound motor.

As the load current increases, the flux due to series field winding also increases result in greater torque obtained that of DC Shunt motor for same load current.

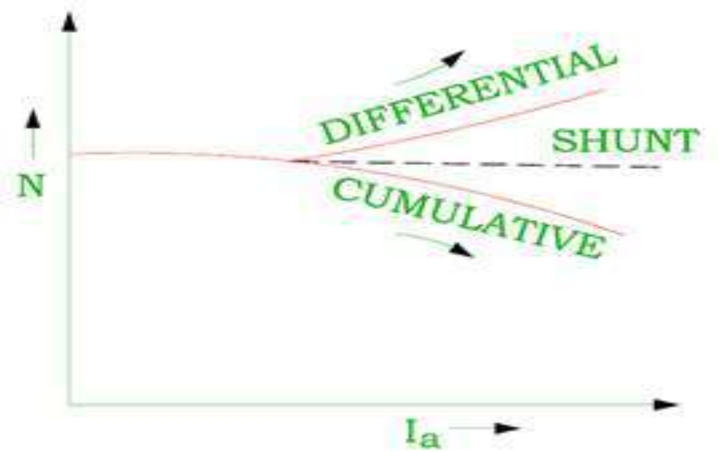


2. Speed vs. armature current (N-Ia)

As the load current increases, the flux due to series field winding also increases.

This will result in fall in speed which is more than that of DC Shunt motor for a given armature current.

However the speed does not become dangerous high due to presence of shunt field winding flux.

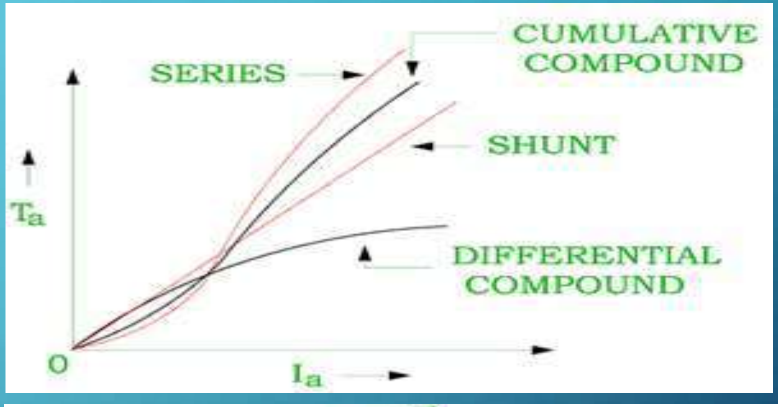


CHARACTERISTICS OF COMPOUND MOTORS

Differential Compound Motor

Since in differential field motors, series flux opposes shunt flux, the total flux decreases with increase in load. Due to this, the speed remains almost constant or even it may increase slightly with increase in load ($N \propto E_b/\phi$). Differential compound motors are not commonly used, but they find limited applications in experimental and research work.

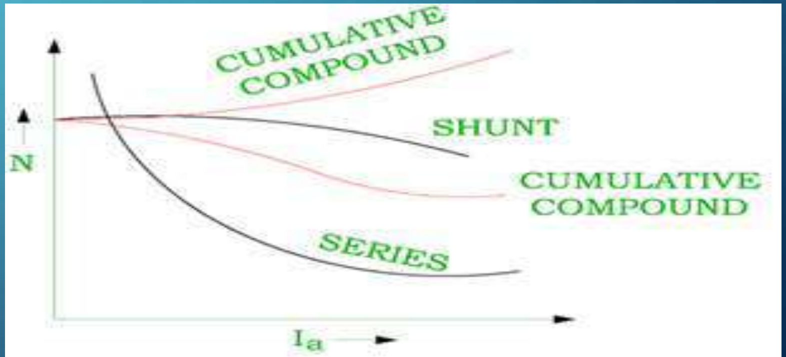
1. Torque vs. armature current (Ta-Ia)



The series flux opposes the shunt flux in the DC Differential compound motor therefore the net flux decreases as the load current increases.

The armature torque increases less than that of DC Shunt motor for a given armature current.

2. Speed vs. armature current (N-Ia)



As the series field flux opposes the shunt field flux, resultant flux decreases with increase in load current.

The back emf decreases as the load current increases but it decrease slightly less than that of flux.

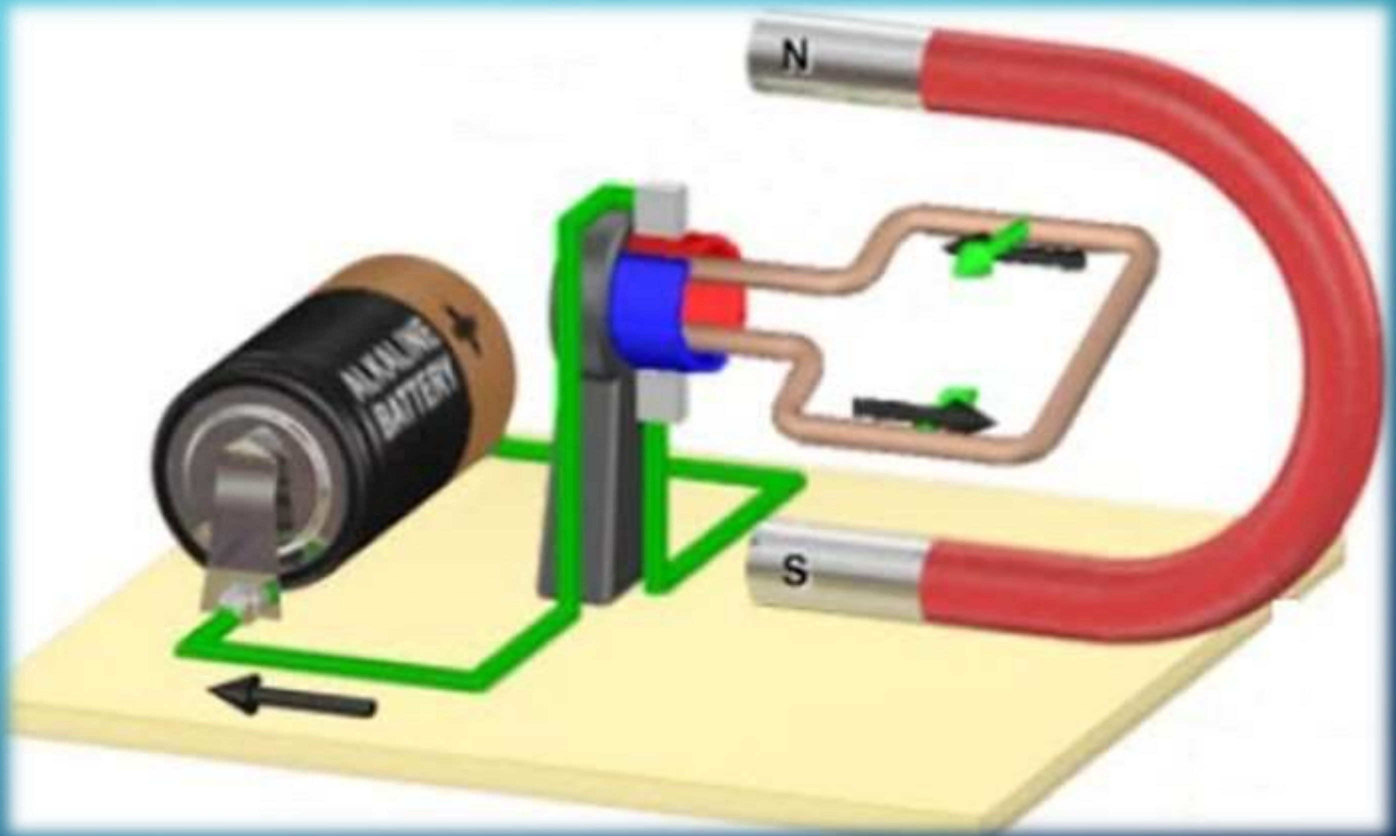
$N \alpha Eb / \Phi$

Therefore the speed of the DC Differential compound motor is slightly higher than the DC Shunt motor for a given armature current. The DC Differential compound motor is useful for constant speed application.

It should be noted any suitable characteristic can be obtained by suitable designing of number of shunt field turns and / or number of series field turns in the DC compound motor.

MODULE:3

DC MOTOR



TOPIC:

- TORQUE EQUATION OF DC MOTOR
- EFFICIENCY OF DC MOTOR
- POWER FLOW IN DC MOTOR
- APPLICATION OF DC MOTOR
- PROBLEM SOLVING

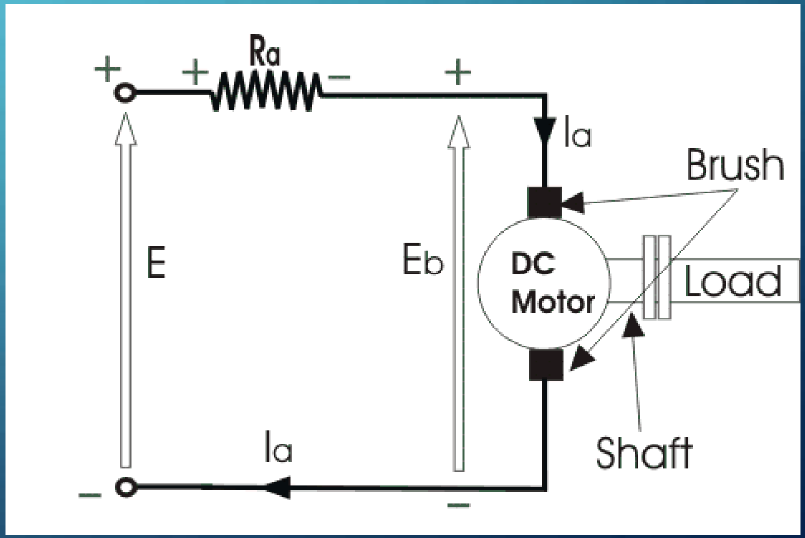
TORQUE EQUATION OF DC MOTOR

Torque equation of DC Motor gives the amount and nature of electrical torque T_e developed whenever it is taken into service. Basically the performance of DC machine centers around two equations. One is **EMF equation** and another is **Torque Equation**. Therefore, understanding of torque equation is a must for performance analysis. In motor operation mode, electrical torque is utilized to drive the load coupled to motor shaft.

Torque in DC Motor depends upon the constructional as well as operational parameters. Constructional parameters include number of poles P, number of conductors Z and number of parallel paths 'a' in armature. Operational parameters include armature current I_a and field excitation.

Referring to the diagram beside, we can see, that if E is the supply voltage, E_b is the back emf produced and I_a, R_a are the armature current and armature resistance respectively then the voltage equation is given by,

$$E = E_b + I_a R_a$$



But keeping in mind that our purpose is to derive the torque equation of DC motor we multiply both sides of above equation by I_a.

$$E I_a = E_b I_a + I_a^2 R_a$$

TORQUE EQUATION OF DC MOTOR

Now $I_a^2.R_a$ is the power loss due to heating of the armature coil, and the true effective mechanical power that is required to produce the desired torque of DC machine is given by,

$$P_m = E_b I_a$$

The mechanical power P_m is related to the electromagnetic torque T_g as,

$$P_m = T_g \omega$$

Where, ω is speed in rad/sec. $w = \frac{2\pi N}{60}$

Now equating above equation, we get, $E_b I_a = T_g \omega$

Now for simplifying the torque equation of DC motor we substitute. $E_b = \frac{P\varphi ZN}{60A}$

$$T_g = \frac{P.Z.\varphi.I_a}{2\pi A}$$

The torque we so obtain, is known as the electromagnetic torque of DC motor, and subtracting the mechanical and rotational losses from it we get the mechanical torque.

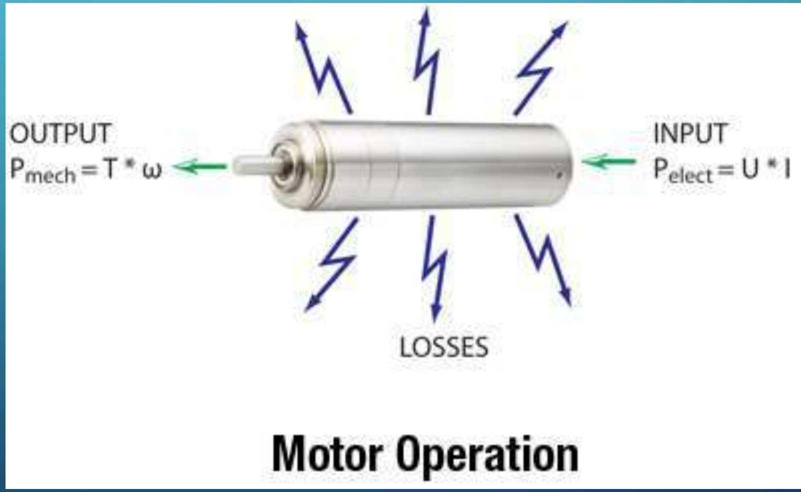
$$T_m = T_g - mechanical\ losses$$

$$T_g = k_a \phi I_A$$

$$Where,\ k_a = \frac{P.Z}{2\pi A}$$

EFFICIENCY OF DC MOTOR

Electric motor efficiency is the ratio between power output (mechanical) and power input (electrical). Mechanical power output is calculated based on the torque and speed required (i.e. power required to move the object attached to the motor), and electrical power input is calculated based on voltage and current supplied to the motor. Mechanical power output is always lower than the electrical power input, as energy is lost during conversion (electrical to mechanical) in various forms, such as heat and friction. Design of an electric motor aims to minimize these losses to improve efficiency.



EFFICIENCY OF DC MOTOR

Consider V is the supply voltage to the dc motor. The motor draws current I from its supply mains during its operation. So the input power to the motor is

$$P_{in} = VI$$

After copper losses, the armature develops mechanical power,

$$P_m = E_b I_a$$

After friction and windage loss the mechanical power appearing at the shaft of the motor for doing the work is

$$P_{out} = P_m - W_c$$

Where W_c is the constant iron loss in the machine. So, the approximate power equation of the motor is

$$P_{out} = VI - {I_a}^2 R_a - W_c$$

Overall Efficiency of DC Motor

The overall efficiency of the dc motor is the ratio of output power to the input power. We also call it as commercial efficiency.

$$\eta_c = \frac{P_{out}}{P_{in}} = \frac{VI - I_a{}^2 R_a - W_c}{VI}$$

Electrical Efficiency of DC Motor

This is the ratio of armature power to the input electrical power.

$$\eta_e = \frac{P_m}{P_{in}} = \frac{E_b I_a}{VI}$$

Mechanical Efficiency of DC Motor

This efficiency determines, how efficiently a motor delivers the armature power to the shaft for doing desired mechanical work by the machine. This is the ratio of output mechanical power to armature power.

$$\eta_m = \frac{P_{out}}{P_m} = \frac{VI_a - I_a{}^2 R_a - W_c}{E_b I_a} \quad [\because \quad I \approx I_a]$$

$$\Rightarrow \eta_m = \frac{VI_a - I_a{}^2 R_a - W_c}{(V - I_a R_a) I_a}$$

$$= \frac{VI_a - I_a{}^2 R_a - W_c}{VI_a - I_a{}^2 R_a}$$

CONDITION OF MAXIMUM EFFICIENCY OF DC MOTOR

The overall efficiency of dc motor as

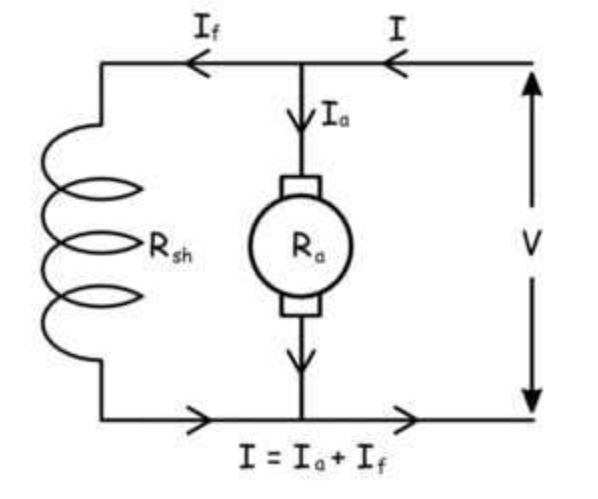
$$\eta_c = \frac{VI_a - {I_a}^2R_a - W_c}{VI_a} = 1 - \left(\frac{I_aR_a}{V} + \frac{W_c}{VI_a}\right)$$

Now the efficiency is maximum when the term under brackets in the above expression is minimum. Again, this condition is satisfied when

$$\frac{\mathrm{d}}{\mathrm{d}I_a}\left(\frac{I_aR_a}{V} + \frac{W_c}{VI_a}\right) = 0$$

$$\Rightarrow \frac{R_a}{V} - \frac{W_c}{V{I_a}^2} = 0$$

$$\Rightarrow W_c = {I_a}^2R_a \Rightarrow I_a = \sqrt{\frac{W_c}{R_a}}$$

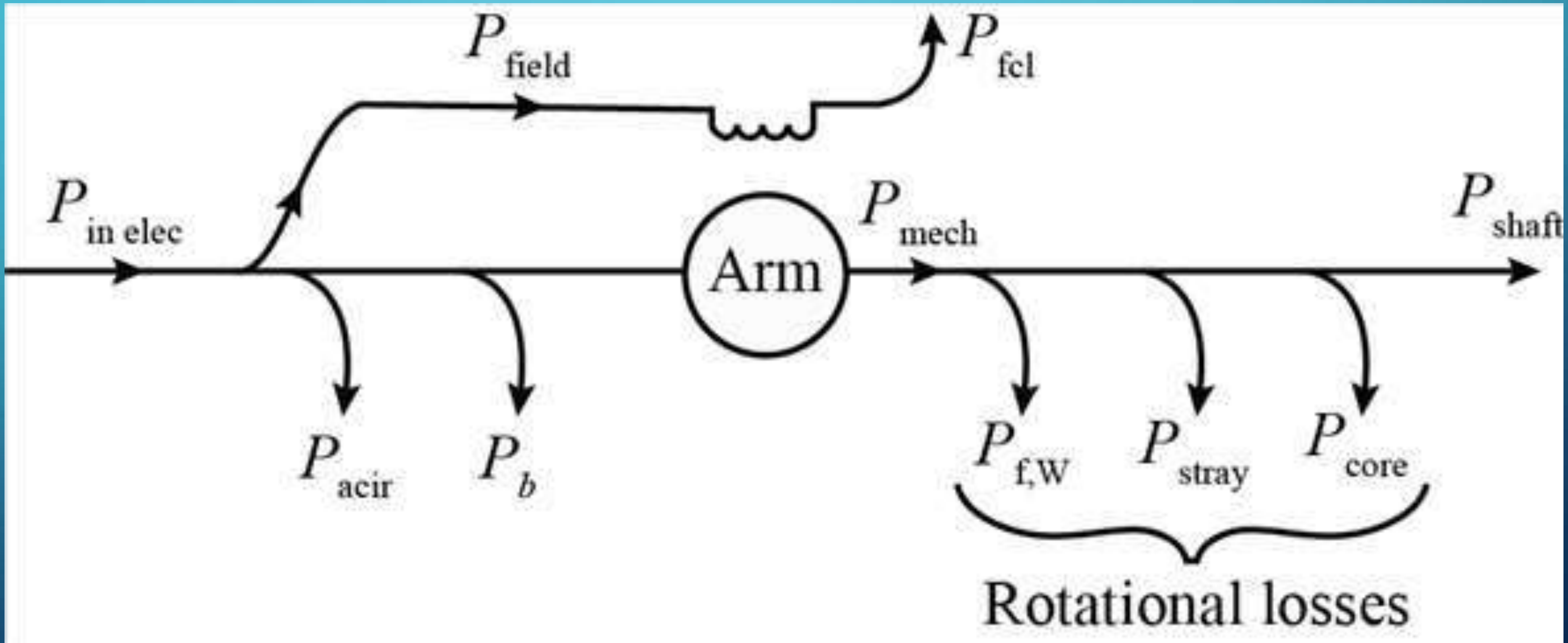


The just above expression shows that the efficiency of a dc motor is maximum when

Copper Loss = Core Loss

POWER FLOW IN DC MOTOR

The motor converts electrical power into the mechanical power. During these power conversions electrical to mechanical, some power losses occur that decrease the quantity of power conversion. Due to these power losses heating produces that affect the operation of dc machines. Due to these power losses the efficiency of machines also decreases. In today's post, we will have a detailed look at these power losses and their effects on machines. Also, discuss how we can reduce these power losses.



APPLICATION OF DC MOTOR

Advantages of DC motors in industrial applications

1. Higher Starting Torque

DC motors have higher starting torque than their AC counterparts, making it easier to get things moving. The only problem with these motors is that you can't start them unless they're already under a load. Without a load to slow them down, DC motors can burn out quickly. For applications that need constant low-speed or variable-speed torque, DC motors are ideal.

2. Linear Speed-Torque Curve

The torque equation of an induction motor — or the curve plotted between the torque and speed of said motor — explains the relationship between how fast the motor spins and how much torque it can generate. DC motors generate a speed-torque curve that's much more linear than AC motors.

3. No Harmonic Effect

AC motors are susceptible to harmonic effects that can damage the equipment or cause the iron or copper components to heat dangerously. In addition to causing excessive noise, harmonic problems can cause the motors to fail prematurely or misfire during use, damaging other equipment or upsetting the manufacturing process. DC motors don't have this problem, effectively eliminating the issue.

4. Improved Speed Control

DC motors are ideal for any job that needs constant low-speed torque or adjustable torque.

5. Easier Installation and Maintenance

DC motors are easier to install than AC motors, require less maintenance and are easier to repair than their AC counterparts. Many industrial systems may already be set up to use DC motors.

APPLICATION OF DC MOTOR

Applications of Dc series motor

DC series motor is the best of Dc motors because it is suitable for both high and low power drives, for fixed and variable speed electric drives, it has a simple construction, it's easy to design and maintenance, and it also has a high starting torque we find it in cheap toys and automotive applications like:

1. Electric traction.
2. Electric footing.
3. Cranes.
4. lifts.
5. Air compressor.
6. Elevators.
7. Winching systems.
8. Versatile electric equipment.
9. Hair drier.
10. Vacuum cleaner, and so on where we also need a variation in speed.
11. Sewing machines and power tools.

APPLICATION OF DC MOTOR

Applications of DC shunt motor

We know that DC shunt motor is a constant speed motor so we use it where we need almost constant speed from no load to full load like in:

1. **Automotive windscreen.**
2. **Wipers.**
3. **Lathes machines.**
4. **Drills.**
5. **Lifts.**
6. **Fans.**
7. **Boring mills.**
8. **Shapers.**
9. **Blowers.**
10. **Centrifugal pumps.**
11. **Conveyors.**
12. **Spinning and weaving machines.**

APPLICATION OF DC MOTOR

Applications of DC Compound motor

We have two types of the compound motor the first is differential compound and we rarely use it because it has poor torque characteristics and the other is the cumulative compound which has a high starting torque and good speed regulation at high speed so it’s the most used in:

1. **Presses.**
2. **Electric shovels.**
3. **Reciprocating machine.**
4. **Conveyors.**
5. **Stamping machine.**
6. **Elevators.**
7. **Compressors.**
8. **Hoist.**
9. **Rolling mills.**
10. **Heavy planners, and so on.**

APPLICATION OF DC MOTOR

Applications of separately excited Dc motor

Separately excited Dc motor or as you remember permanent magnet Dc motor is a special type where we use a permanent magnet to create the required magnetic field and we also know that it doesn't need to control the speed so it's usually used in:

1. **Windshield wipers.**
2. **Washer.**
3. **Automobiles as a starter motor.**
4. **Blowers in heaters and air conditioners.**
5. **Personal computer disc drives.**
6. **Wheelchairs.**
7. **Toys.**

And also in small fractional and sub-fractional KW motors.

APPLICATION OF DC MOTOR

Applications of brushless DC motor

As we said brushless Dc motor is a special motor because it doesn’t contain brushes, has high efficiency, high speed, and electronic control so we use it in many applications like:

1. **In computer peripherals (disk drives, printers).**
2. **Hand-held power tools.**
3. **Consumer electronics.**
4. **Transport.**
5. **Heating and ventilation.**
6. **Vehicles ranging from aircraft to automobiles.**
7. **For Small cooling fans.**
8. **And for gramophone records in direct-drive turntables.**

APPLICATION OF DC MOTOR

Type of Motor	Characteristics	Applications
Shunt	Speed is fairly constant and medium starting torque.	1. Blowers and fans 2. Centrifugal and reciprocating pumps 3. Lathe machines 4. Machine tools 5. Milling machines 6. Drilling machines
Series	High starting torque. No load condition is dangerous. Variable speed.	1. Cranes 2. Hoists, Elevators 3. Trolleys 4. Conveyors 5. Electric locomotives
Cumulative compound	High starting torque. No load condition is allowed.	1. Rolling mills 2. Punches 3. Shears 4. Heavy planers 5. Elevators
Differential compound	Speed increases as load increases.	Not suitable for any practical applications

PROBLEM SOLVING

A 500-V D.C. shunt motor draws a line-current of 5 A on light-load. If armature resistance is 0.15 ohm and field resistance is 200 ohms, determine the efficiency of the machine running as a generator delivering a load current of 40 Amps.

Solution.

No Load, running as a motor :

Input Power = 500 × 5 = 2500 watts

Field copper-loss = 500 × 2.5 = 1250 watts

Neglecting armature copper-loss at no load (since it comes out to be 2.52 × 0.15 = 1 watt), the balance of 1250 watts of power goes towards no load losses of the machine running at rated speed.

These losses are mainly the no load mechanical losses and the core-loss.

As a Generator, delivering 40 A to load :

Output delivered = 500 × 40 = 20 kW

Losses : (a) Field copper-loss = 1250 watts

(b) Armature copper-loss = 42.52 × 0.15 = 271 watts

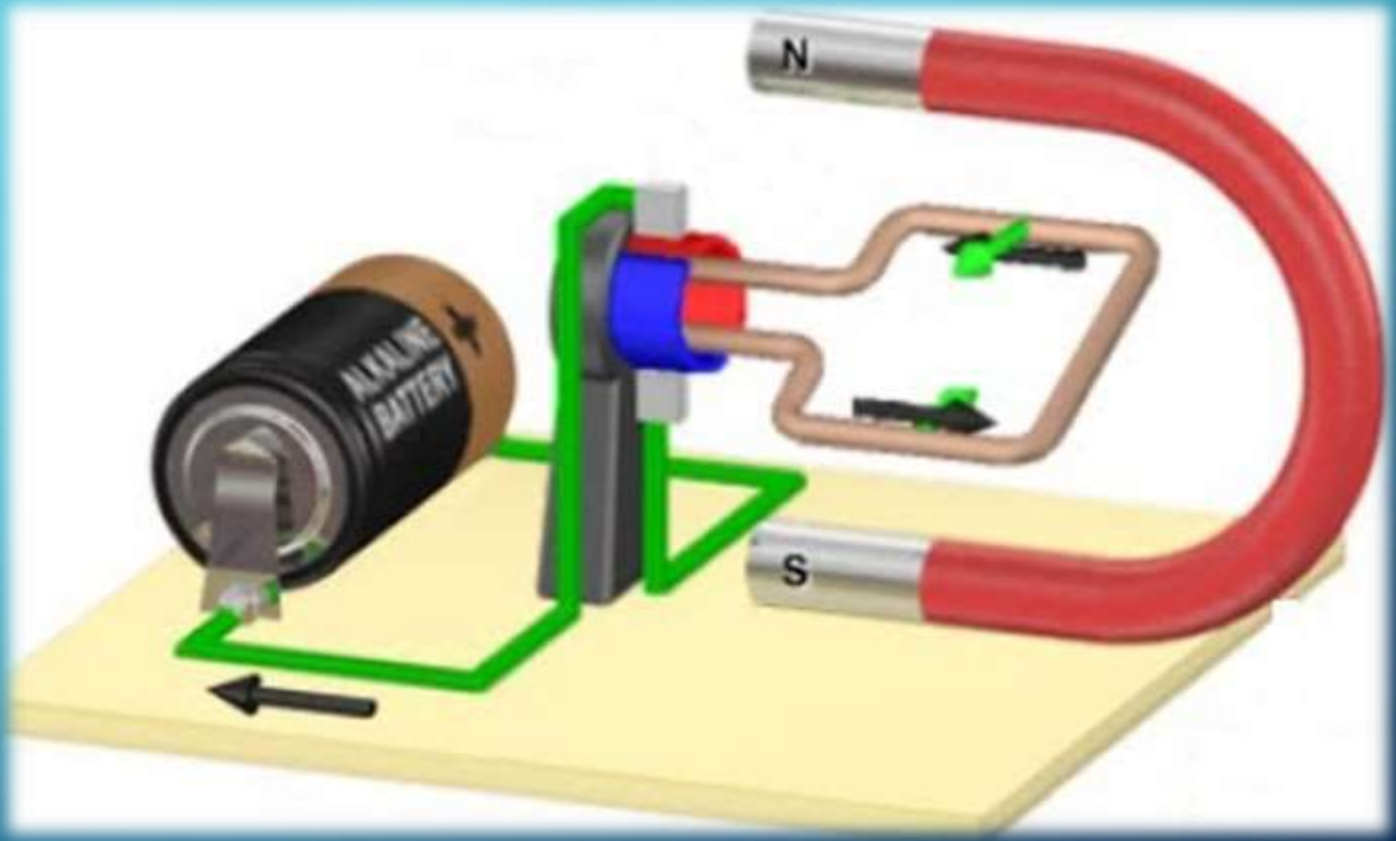
(c) No load losses = 1250 watts

Total losses = 2.771 kW

Generator Efficiency = (20/22.771) × 100 % = 87.83 %

MODULE:3

DC MOTOR



TOPIC:

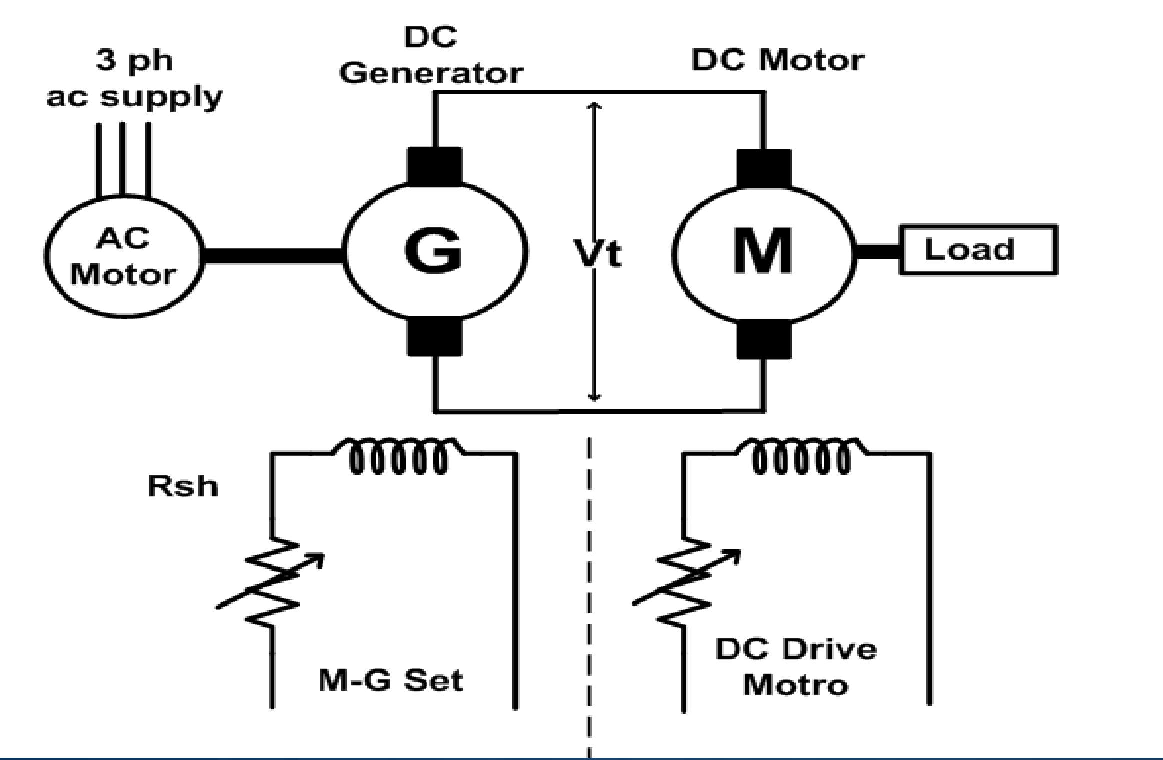
- SPEED CONTROL OF DC MOTOR BY USING WARD- LEONARD METHOD OF SPEED CONTROL

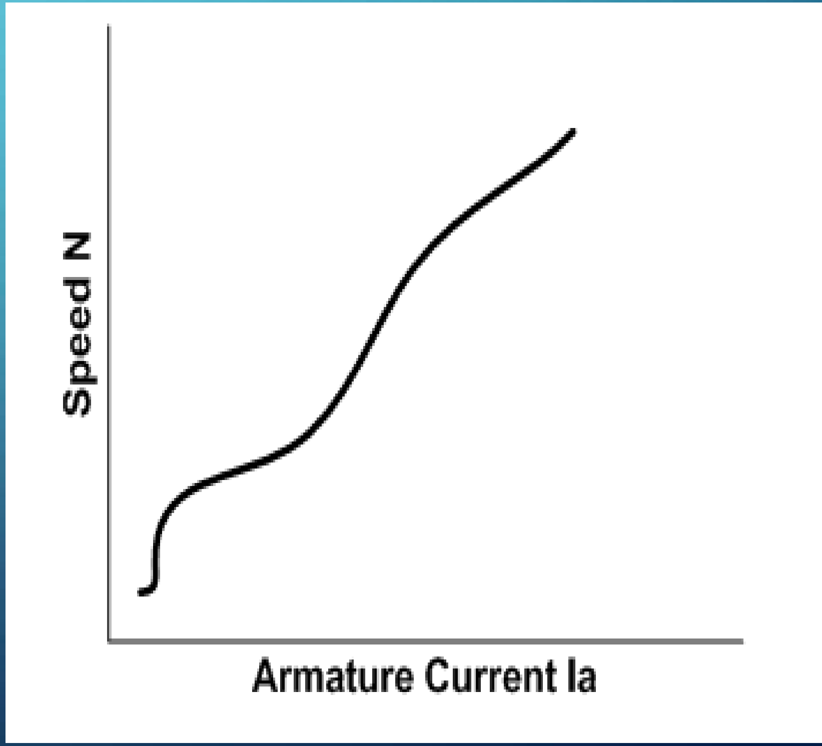
WARD- LEONARD METHOD OF SPEED CONTROL

In the ward-leonard method, the speed control of D.C. motor can be obtained by varying the applied voltage to the armature. In this method M is the main D.C. motor whose speed is to be controlled, and G is a separately excited D.C. generator which is driven by a 3-phase induction motor. The combination of ac driving motor and the dc generator is called the motor-generator set.

The speed of a D.C. motor is directly proportional to the back e.m.f and inversely to the net flux per pole Φ,If brush contact drop is neglected i.e

$$N = (V - I_a R_a)/k\Phi$$





WARD- LEONARD METHOD OF SPEED CONTROL

Ward-Leonard System :

This system is used where unusually wide and very sensitive speed control is required as for colliery winders, electric excavators, elevators and the main drives in steel mills and blooming and paper mills. M1 is the main motor whose speed control is required. The field of this motor is permanently connected across the dc supply lines. A dc or an ac motor M2 directly coupled to generator G. The motor M2 runs at an approximately constant speed. The output voltage of G is directly fed to the main motor M1.

In this method the variable voltage to be applied to the motor armature is obtained from an additional separately excited d.c generator, and the motor under control is also run as a separately excited motor. The above equation shows that if the motor excitation is constant and the applied voltage V is varied the speed will be almost directly proportional to the armature voltage. The system can more be adapted for forward as well as reverse operation of the motor by changing the polarity of the voltage applied to its armature. This condition can be achieved by reversing the direction of the field current of the separately excited variable voltage generator.
The variable voltage generator in Ward Leonard system is driven by a constant speed 3- phase induction motor.

If the constant voltage d.c power for excitation is not available otherwise, the same may be obtained from a constant voltage exciter coupled with the auxiliary motor-generator set. The direction of the field current of the variable voltage generator may be reversed by anyone of the following two methods.

1. By providing a reversing switch in the field circuit

2. By connecting two potentiometer rheostats across generator field across the movable terminals.

WARD- LEONARD METHOD OF SPEED CONTROL

Advantages of Ward Leonard Method

The advantages of this method are summarized below;

1. The speed of a motor can be controlled over a wide range.
2. The operation of the motor is very smooth.
3. The speed regulation of the motor is good.
4. A motor can run with uniform acceleration.
5. It has an inherent breaking capacity.
6. Easy to reverse the direction of rotation and speed can be controlled in both directions.

Disadvantages of Ward Leonard Method

The disadvantages of this method are summarized below;

1. It needs two additional machines (motor-generator set) with the same rating of the main motor. 2.Therefore, the overall cost of this arrangement is very high.
3. It produces more noise.
4. Frequent maintenance required.
5. This arrangement needs more space to install.
6. Overall efficiency is low if the motor runs with light load conditions for a long period of time.

Application of Ward Leonard Method

This method is used where the motor to be controlled over a wide speed range. The application of the motor is very sensitive to speed, in this condition this method is very useful.

This method is used in the application like; cranes, excavator, elevator, mine hoists, paper machine, steel rolling mills, etc.

http://www.vlab.co.in/

MODULE:4

SINGLE PHASE TRANSFORMER

TOPIC:

- BASIC CONCEPTS OF SINGLE PHASE TRANSFORMER
- OPERATING PRICIPLE
- IDEAL TRANSFORMER
- CONSTRUCTIONAL PARTS OF TRANSFORMER
- DIFFERENT TYPES OF TRANSFORMER

SINGLE PHASE TRANSFORMER

A single-phase transformer is an electrical device that accepts single-phase AC power and outputs single-phase AC. This is used in the distribution of power in non-urban areas as the overall demand and costs involved are lower than the 3-phase distribution transformer. They are used as a step-down transformer to decrease the home voltage to a suitable value without a change in frequency.

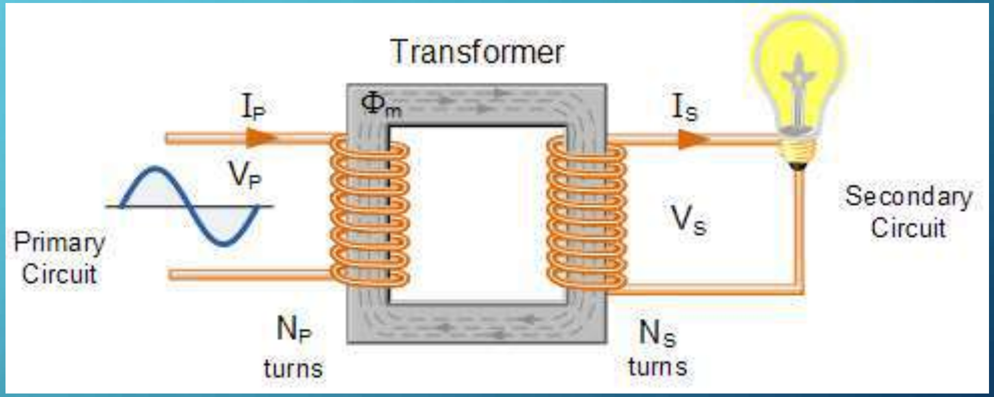
A transformer is a device which converts magnetic energy into electrical energy. It consists of two electrical coils called as a primary winding and secondary winding. The primary winding of a transformer receives power, while the secondary winding delivers power. A magnetic iron circuit called "core" is commonly used to wrap around these coils. Though these two coils are electrically isolated, they are magnetically linked.

An electric current when passed through the primary of a transformer then a magnetic field is created, which induces a voltage across the secondary of a transformer. Based on the type of application, the single-phase transformer is used to either step-up or step-down the voltage at the output. This transformer is typically a power transformer with high-efficiency and low losses.

SINGLE PHASE TRANSFORMER

One of the main reasons that we use alternating AC voltages and currents in our homes and workplace's is that AC supplies can be easily generated at a convenient voltage, transformed (hence the name transformer) into much higher voltages and then distributed around the country using a national grid of pylons and cables over very long distances.

Transformers are capable of either increasing or decreasing the voltage and current levels of their supply, without modifying its frequency, or the amount of electrical power being transferred from one winding to another via the magnetic circuit.



These two coils are not in electrical contact with each other but are instead wrapped together around a common closed magnetic iron circuit called the "core". This soft iron core is not solid but made up of individual laminations connected together to help reduce the core's losses.

The two coil windings are electrically isolated from each other but are magnetically linked through the common core allowing electrical power to be transferred from one coil to the other. When an electric current passed through the primary winding, a magnetic field is developed which induces a voltage into the secondary winding.

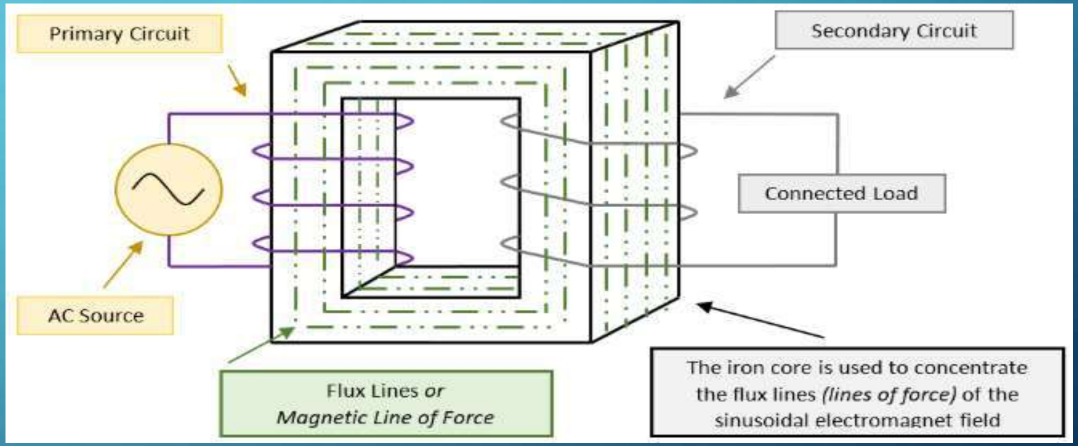
SINGLE PHASE TRANSFORMER

TRANSFORMER ACTION

A transformer is a static device that transfers electric power in one circuit to another circuit of the same frequency. It consists of primary and secondary windings. This transformer operates on the principle of mutual inductance.

When the primary of a transformer is connected to an AC supply, the current flows in the coil and the magnetic field build-up. This condition is known as mutual inductance and the flow of current is as per the Faraday's Law of electromagnetic induction. As the current increases from zero to its maximum value, the magnetic field strengthens and is given by dϕ/dt.

This electromagnet forms the magnetic lines of force and expands outward from the coil forming a path of magnetic flux. The turns of both windings get linked by this magnetic flux. The strength of a magnetic field generated in the core depends on the number of turns in the winding and the amount of current. The magnetic flux and current are directly proportional to each other.



As the magnetic lines of flux flow around the core, it passes through the secondary winding, inducing voltage across it. The Faraday's Law is used to determine the voltage induced across the secondary coil and it is given by:

N. dϕ/dt

SINGLE PHASE TRANSFORMER

CAN DC SUPPLY BE USED FOR TRANSFORMER

The DC Supply can not be used for the Transformer.

Now connect the same transformer to the DC voltage and lets see what happens.

We know that there is no frequency in DC i.e. f = 0. Therefore, the inductive reactance X_L would be zero if we put $f = 0$ in the $X_L = 2\pi f L$.

Thus, current in the primary of a transformer in case of DC source.

I = V / R

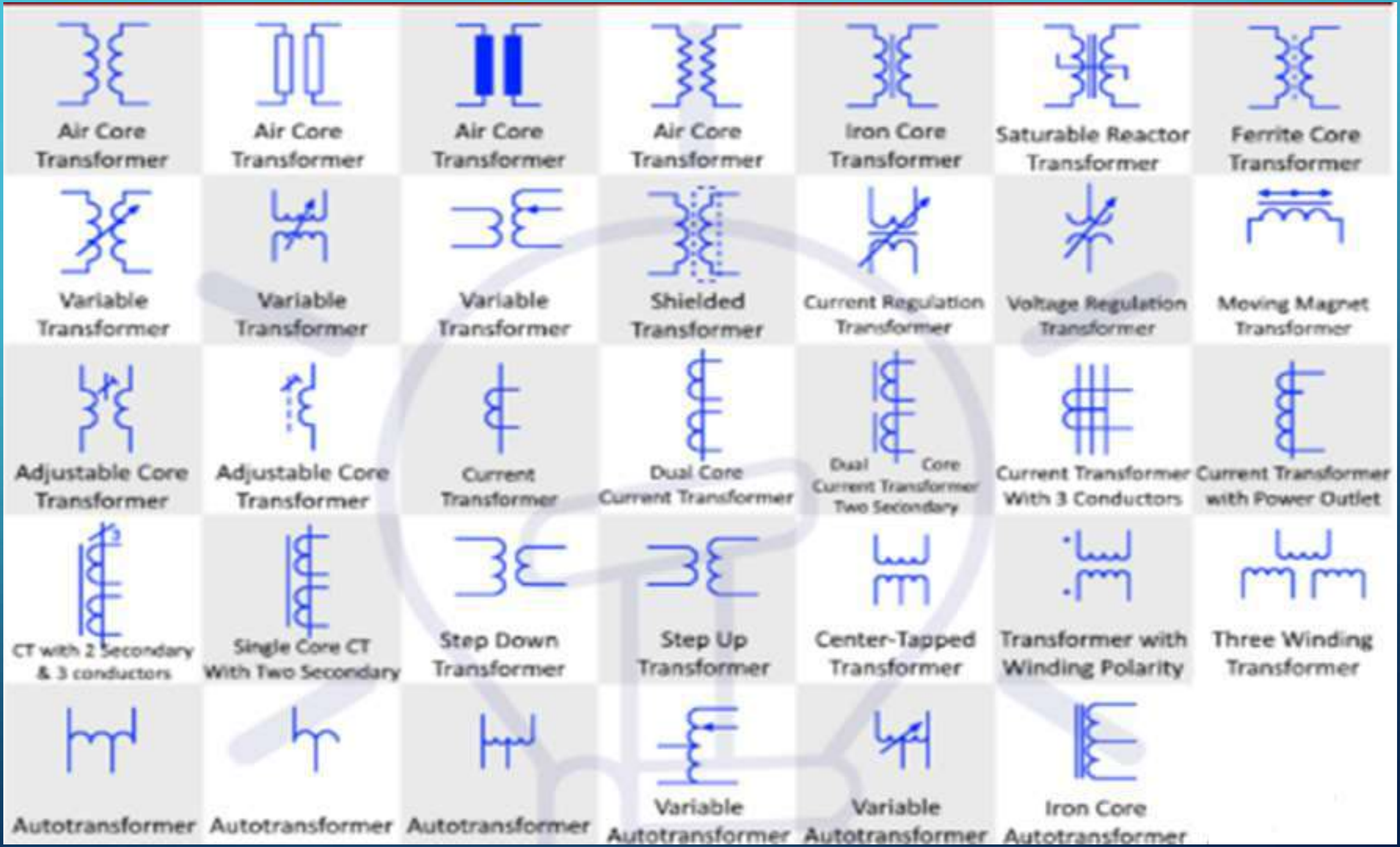
I = 230V / 10Ω
I = 23A

The Primary current in case of DC = 23A

If the primary of a transformer is connected to the DC supply, the primary will draw a steady current and hence produce a constant flux. Consequently, no back EMF will be produced. They primary winding will draw excessive current due to low resistance of the primary because we know that inductive reactance (X_L) is zero due to the inductive reactance formula ($X_L = 2\pi f L$) where frequency of the DC source is zero. Thus result is that the primary winding will overheat and burn out or the fuse and circuit breaker will blow. Care must be taken not to the connect the primary of a transformer across the DC Supply.

SINGLE PHASE TRANSFORMER

TRANSFORMER SYMBOLS – SINGLE LINE TRANSFORMER SYMBOLS



SINGLE PHASE TRANSFORMER

IDEAL TRANSFORMER

A transformer is a fixed electrical device, used to transfer the electrical energy in between two circuits while maintaining stable frequency and also increasing/decreasing the current or voltage. The working principle of a transformer is “Faraday’s law of induction”. When the current in the main winding is changed, then the magnetic flux will be changed, so that an induced EMF can occur within the secondary coil. A practical transformer includes some losses like core losses & copper losses. The copper loss can be defined as, transformer windings which include resistance as well as reactance to cause some loss is called a copper loss. The core loss in the transformer occurs when the transformer is energized; the core loss does not change with load. These losses are caused by two factors like eddy & hysteresis. Because of these losses, the transformer’s output power is less than the input power.

A transformer that doesn’t have any losses like copper and core is known as an ideal transformer. In this transformer, the output power is equivalent to the input power. The efficiency of this transformer is 100%, which means there is no loss of power within the transformer.

SINGLE PHASE TRANSFORMER

IDEAL TRANSFORMER

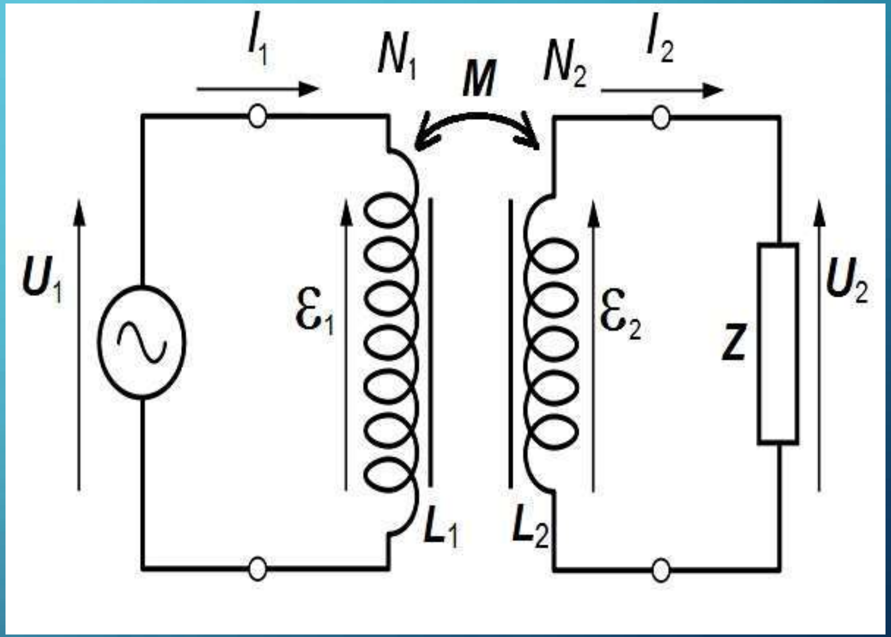
The properties of an ideal transformer include the following.

1. The resistance of their primary and secondary winding becomes zero.

2. The core of the ideal transformer has infinite permeability. The infinite permeable means less magnetizing current requires for magnetizing their core.

3. The leakage flux of the transformer becomes zero, i.e. the whole of the flux induces in the core of the transformer links with their primary and secondary winding.

4. The ideal transformer has 100 percent efficiency, i.e., the transformer is free from hysteresis and eddy current loss.



The above mention properties are not possible in the practical transformer. In an ideal transformer, there is no power loss. Therefore, the output power is equal to the input power.

SINGLE PHASE TRANSFORMER

CONSTRUCTION OF TRANSFORMER

Depending on requirement in the prevailing power system network, a transformer can be single phase or three phase type. Such transformers that are used as components of the power transmission and distribution network are called power transformers and distribution transformers. While such transformers are used for stepping up the voltage or stepping down the voltage as per requirement.

Major construction parts of a transformer can be categorized as:

1. Magnetic parts
2. Electrical parts
3. Insulating parts
4. Mechanical parts & accessories

SINGLE PHASE TRANSFORMER

CONSTRUCTION OF TRANSFORMER

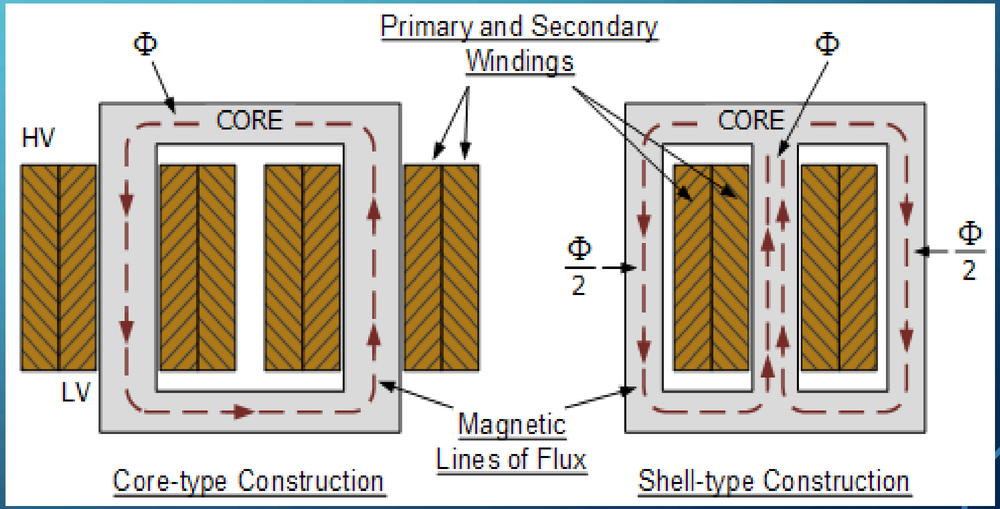
1. Magnetic parts

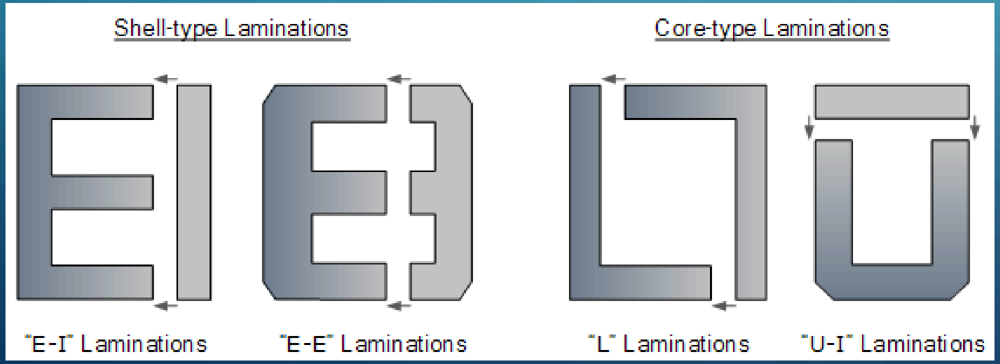
This magnetic circuit, know more commonly as the “transformer core” is designed to provide a path for the magnetic field to flow around, which is necessary for induction of the voltage between the two windings.

The efficiency of a simple transformer construction can be improved by bringing the two windings within close contact with each other thereby improving the magnetic coupling. Increasing and concentrating the magnetic circuit around the coils may improve the magnetic coupling between the two windings, but it also has the effect of increasing the magnetic losses of the transformer core.

Transformer Construction of the Core:

Generally, the name associated with the construction of a transformer is dependant upon how the primary and secondary windings are wound around the central laminated steel core. The two most common and basic designs of transformer construction are the **Closed-core Transformer** and the **Shell-core Transformer**.





SINGLE PHASE TRANSFORMER

CONSTRUCTION OF TRANSFORMER

2. Electrical Parts

Transformer windings form another important part of a transformer construction, because they are the main current-carrying conductors wound around the laminated sections of the core. In a single-phase two winding transformer, two windings would be present. The one which is connected to the voltage source and creates the magnetic flux called the primary winding, and the second winding called the secondary in which a voltage is induced as a result of mutual induction.

If the secondary output voltage is less than that of the primary input voltage the transformer is known as a "Step-down Transformer". If the secondary output voltage is greater then the primary input voltage it is called a "Step-up Transformer".

The type of wire used as the main current carrying conductor in a transformer winding is either copper or aluminum. While aluminum wire is lighter and generally less expensive than copper wire, a larger cross sectional area of conductor must be used to carry the same amount of current as with copper so it is used mainly in larger power transformer applications.

SINGLE PHASE TRANSFORMER

CONSTRUCTION OF TRANSFORMER 3. Insulating parts

Insulation is essential to isolate the energized parts inside a transformer from other energized parts at different potential or from the grounded parts. The desirable properties of an insulation material are:

1. High resistivity
2. High breakdown voltage
3. High dielectric constant
4. Low dissipation factor
5. Thermal stability
6. Chemical stability
7. Mechanical stability

According to the design of transformer insulating materials the allowable temperature rise , there are several insulation class uses such as Y, A, E, B, F, H & C with respect to temperature rise 90, 105,v120, 130, 155, 180 & above 180 degree C
Respectively.

SINGLE PHASE TRANSFORMER

CONSTRUCTION OF TRANSFORMER

4. Mechanical parts & accessories

TANK

The entire core and coil assembly of oil filled transformer is enclosed by metal tank made mostly of Welded mild steel or sometimes aluminum. Purpose of the tank is to hold the oil and to provide a protective casing around the internal parts.

BUSHINGS

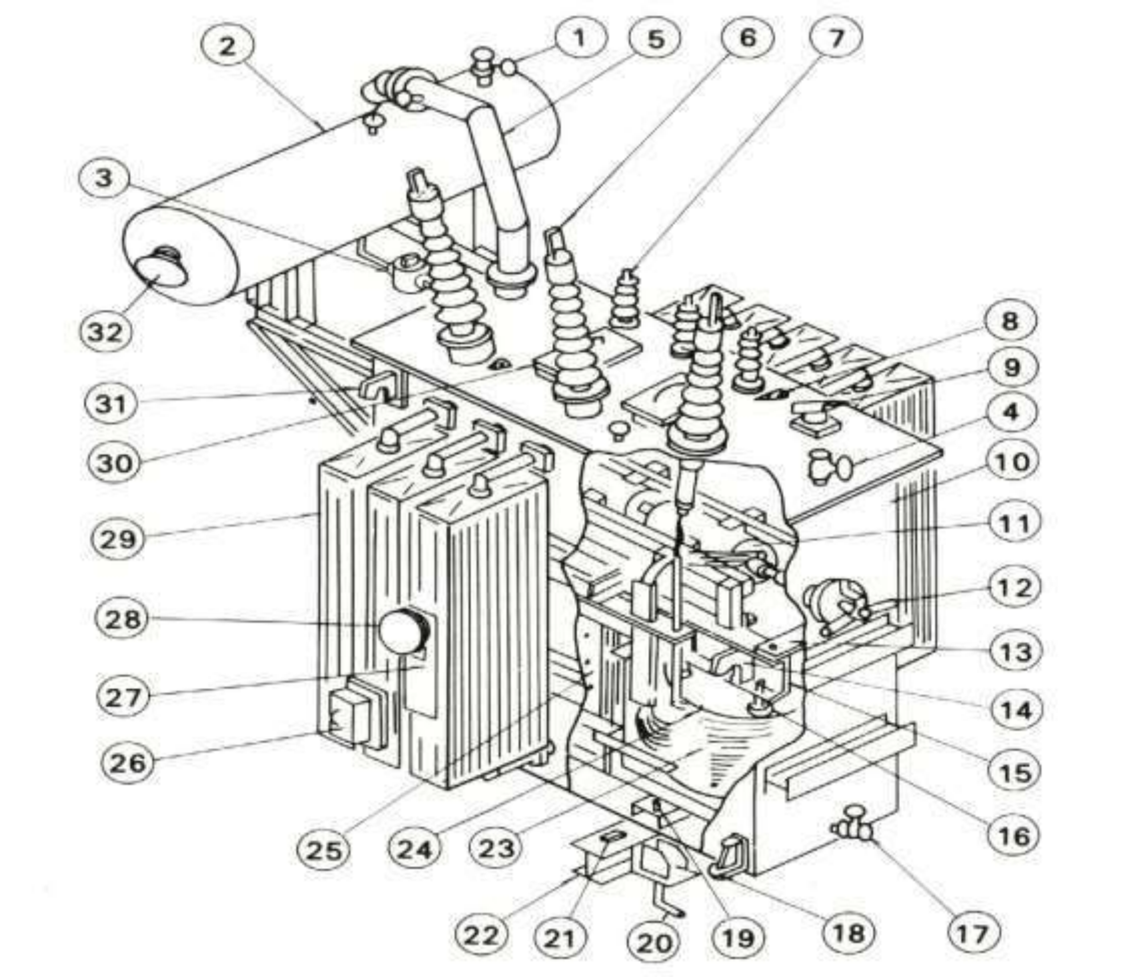
Bushings are meant to insulate the overhead lines from the earthed tank as these conductors have to pass through the top of the tank to get connected to the winding terminals inside. Bushings are made of porcelain or china clay.

BREATHER

Main function of the breather is to absorb moisture from the air during in breathing process of the transformer

SINGLE PHASE TRANSFORMER

1	Oil filter valve	17	Oil drain valve
2	Conservator	18	Jacking boss
3	Buchholz relay	19	Stopper
4	Oil filter valve	20	Foundation bolt
5	Pressure-relief vent	21	Grounding terminal
6	High-voltage bushing	22	Skid base
7	Low-voltage bushing	23	Coil
8	Suspension lug	24	Coil pressure plate
9	B C T Terminal	25	Core
10	Tank	26	Terminal box for protective devices
11	De-energized tap changer	27	Rating plate
12	Tap changer handle	28	Dial thermometer
13	Fastener for core and coil	29	Radiator
14	Lifting hook for core and coil	30	Manhole
15	End frame	31	Lifting hook
16	Coil pressure bolt	32	Dial type oil level gauge



SINGLE PHASE TRANSFORMER

TYPES OF TRANSFORMERS

There are different types of transformer based on their usage, design, construction as follow.

A. Types of Transformers based on its Phases

1. Single Phase Transformer
2. Three Phase Transformer

B. Types of Transformers based on its Core Design

1. Core Type Transformer
2. Shell Type Transformer
3. Berry Type Transformer

C. Types of Transformers based on its Core

1. Air core Transformer
2. Ferromagnetic/Iron Core Transformer

D. Types of Transformers based on Voltage level

1. Step Up Transformer
2. Step Down Transformer
3. Isolation Transformer

SINGLE PHASE TRANSFORMER

TYPES OF TRANSFORMERS

E. Types of Transformer based on its uses

1. Large Power Transformer
2. Distribution Transformer
3. Small Power Transformer
4. Sign Lighting Transformer
5. Control & Signaling Transformer
6. Gaseous Discharge Lamp Transformer
7. Bell Ringing Transformer
8. Instrument Transformer
9. Constant Current Transformer
10. Series Transformer for Street Lighting

F. Types of Instrument Transformer

1. Current Transformer
2. Potential Transformer
3. Constant Current Transformer
4. Rotating Core Transformer or Induction regulator
5. Autotransformer

G. Types of Transformer based on Insulation & Cooling

1. Self Air Cooled or Dry Type Transformer
2. Air Blast-Cooled Dry Type
3. Oil Immersed, Self Cooled (OISC) or ONAN (Oil natural, Air natural)
4. Oil Immersed, Combination of Self Cooled and Air blast (ONAN)
5. Oil Immersed, Water Cooled (OW)
6. Oil Immersed, Forced Oil Cooled
7. Oil Immersed, Combination of Self Cooled and Water Cooled (ONAN+OW)
8. Oil Forced, Air forced Cooled (OFAC)
9. Forced Oil, Water Cooled (FOWC)
10. Forced Oil, Self Cooled (OFAN)

MODULE:4

SINGLE PHASE TRANSFORMER

TOPIC:

- EMF EQUATION
- TRANSFORMATION RATIO
- RATING OF TRANSFORMER
- DIFFERENT TYPES OF COOLING METHODS
- APPLICATION OF TRANSFORMER
- PROBLEM SOLVING

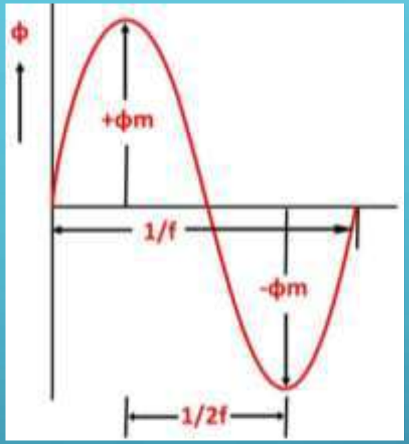
SINGLE PHASE TRANSFORMER

EMF EQUATION OF A TRANSFORMER

When a sinusoidal voltage is applied to the primary winding of a transformer, alternating flux ϕ_m sets up in the iron core of the transformer. This sinusoidal flux links with both primary and secondary winding. The function of flux is a sine function.

The rate of change of flux with respect to time is derived mathematically.

ϕ_m be the maximum value of flux in Weber
f be the supply frequency in Hz
N_1 is the number of turns in the primary winding
N_2 is the number of turns in the secondary winding



By Faraday's Law
Let E_1 be the emf induced in the primary winding

$$E_1 = -\frac{d\psi}{dt}$$

Where $\Psi = N_1\phi$

$$\text{Therefore, } E_1 = -N_1\frac{d\varphi}{dt}$$

Since ϕ is due to AC supply $\phi = \phi_m$ Sinwt

$$E_1 = -N_1\frac{d}{dt}(\varphi_m \,\mathrm{Sinwt})$$

$$E_1 = -N_1 w\varphi_m \,\mathrm{Coswt}$$

$$E_1 = N_1 w\varphi_m \,\mathrm{Sin}(wt - \pi/2)$$

So the induced emf lags flux by 90 degrees.
Maximum valve of emf

$$E_1 max = N_1 w\varphi_m$$

But $w = 2\pi f$

$$E_1 max = 2\pi f N_1 \varphi_m$$

Root mean square RMS value is

$$E_1 = \frac{E_{1max}}{\sqrt{2}}$$

$$E_1 = \sqrt{2}\pi f N_1 \varphi_m$$

$$E_1 = 4.44 f N_1 \varphi_m$$

$$E_2 = \sqrt{2}\pi f N_2 \varphi_m$$

Or

$$E_2 = 4.44 f N_2 \varphi_m$$

SINGLE PHASE TRANSFORMER

TRANSFORMER RATIO

As the transformer is basically a linear device, a ratio now exists between the number of turns of the primary coil divided by the number of turns of the secondary coil. This ratio, called the ratio of transformation, more commonly known as a transformers “turns ratio”, (TR). This turns ratio value dictates the operation of the transformer and the corresponding voltage available on the secondary winding.

It is necessary to know the ratio of the number of turns of wire on the primary winding compared to the secondary winding. The turns ratio, which has no units, compares the two windings in order and is written with a colon, such as 3:1 (3-to-1). This means in this example, that if there are 3 volts on the primary winding there will be 1 volt on the secondary winding, 3 volts-to-1 volt.

Transformers are all about “ratios”. The ratio of the primary to the secondary, the ratio of the input to the output, and the turns ratio of any given transformer will be the same as its voltage ratio. In other words for a transformer: “turns ratio = voltage ratio”.

$$\frac{E_1}{E_2} = \frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} = k$$

SINGLE PHASE TRANSFORMER

TRANSFORMER RATIO

Note that the current is inversely proportional to both the voltage and the number of turns. This means that with a transformer loading on the secondary winding, in order to maintain a balanced power level across the transformers windings, if the voltage is stepped up, the current must be stepped down and vice versa. In other words, “higher voltage — lower current” or “lower voltage — higher current”.

As a transformers ratio is the relationships between the number of turns in the primary and secondary, the voltage across each winding, and the current through the windings, we can rearrange the above transformer ratio equation to find the value of any unknown voltage, (V) current, (I) or number of turns, (N)

$$V_P = \frac{V_S N_P}{N_S} = \frac{V_S I_S}{I_P}, \qquad V_S = \frac{V_P N_S}{N_P} = \frac{V_P I_P}{I_S}$$

$$N_P = \frac{V_P N_S}{N_P} = \frac{N_S I_S}{I_P}, \qquad N_S = \frac{V_S N_P}{V_P} = \frac{N_P I_P}{I_S}$$

$$I_P = \frac{V_S I_S}{V_P} = \frac{N_S I_S}{N_P}, \qquad I_S = \frac{V_P I_P}{V_S} = \frac{N_P I_P}{N_S}$$

SINGLE PHASE TRANSFORMER

TRANSFORMER RATING

Transformer nameplates contain several standard items of information and other optional information. Transformer nameplate must specify the following parameters:

1. Volt-Ampere (VA) or kilovolt-amperes (kVA) rating

2. The voltage rating of both the primary and secondary circuits

3. The impedance rating of the transformer (normally restricted to 25 kVA or larger)

4. The required clearances for transformers with ventilated openings

5. The amount and kind of insulating liquid where used.

6. On dry-type transformers (no liquid coolant or insulation), the nameplate listing must also include the class temperature rating of the winding insulation.

Serial number	Number of phases
Frequency	Voltage rating
kVA Rating	Temperature Rise
Polarity	Percentage Impedance
Connection Diagram	Name of Manufacturer
Type of insulating liquid	Conductor Material for each Winding
Basic Insulation Level (BIL)	Total Weight (kg)

SINGLE PHASE TRANSFORMER

Basis for Comparison	Core Type Transformer	Shell Type Transformer
Definition	The winding surround the core.	The core surround the winding.
Lamination Shape	The lamination is cut in the form of the L strips.	Lamination are cut in the form of the long strips of E and L.
Cross Section	Cross-section may be square, cruciform and three stepped	The cross section is rectangular in shape.
Copper Require	More	Less
Other Name	Concentric Winding or Cylindrical Winding.	Sandwich or Disc Winding
Limb	Two	Three
Insulation	More	Less
Flux	The flux is equally distributed on the side limbs of the core.	Central limb carry the whole flux and side limbs carries the half of the flux.
Winding	The primary and secondary winding are placed on the side limbs.	Primary and secondary windings are placed on the central limb
Magnetic Circuit	Two	One
Losses	More	Less
Maintenance	Easy	Difficult
Mechanical Strength	Low	High
Output	Less	High
Natural Cooling	Does not Exist	Exist

SINGLE PHASE TRANSFORMER

DIFFERENT TYPES OF COOLING METHODS

No transformer is truly an ideal transformer and hence each will incur some losses, most of which get converted into heat. If this heat is not dissipated properly, the excess temperature in transformer may cause serious problems like insulation failure. It is obvious that transformer needs a cooling system. Transformers can be divided in two types as

(i) Dry type transformers

(ii) Oil immersed transformers.

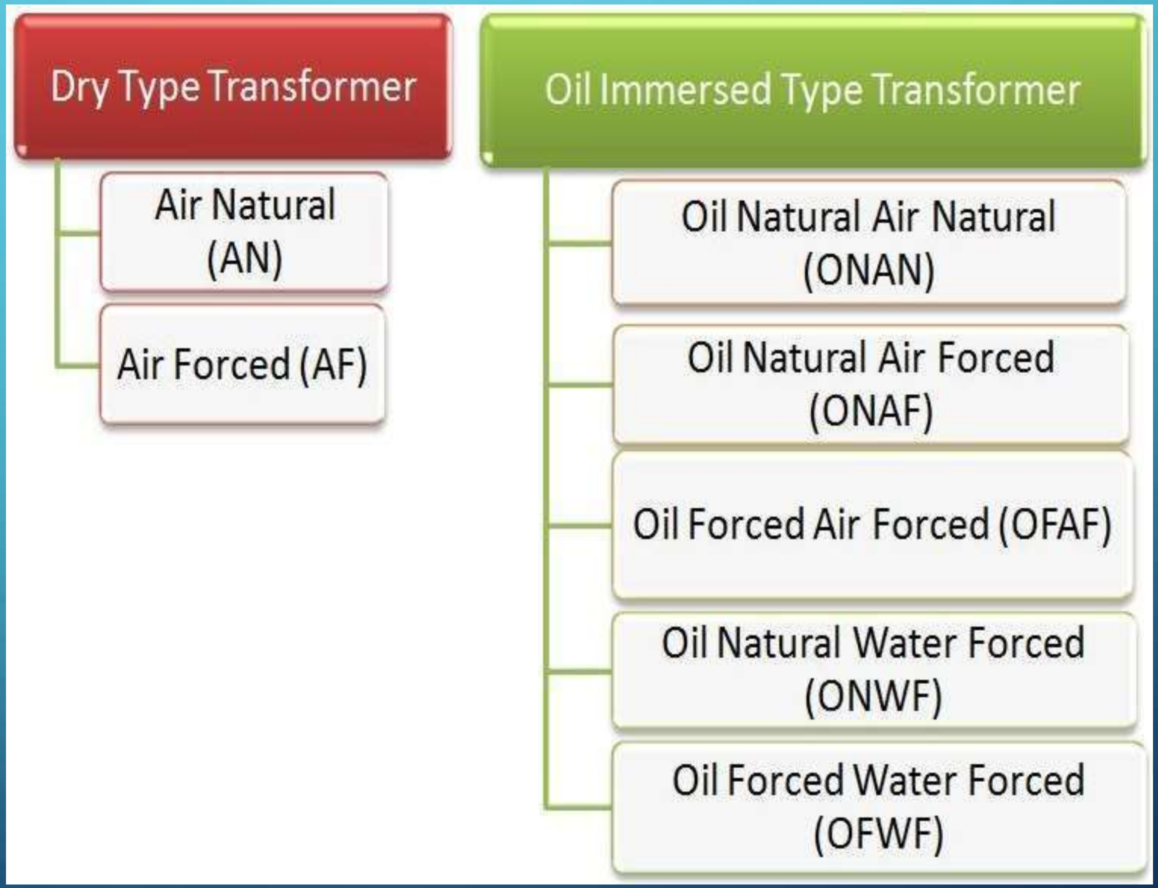
Cooling of Transformer is the process by which heat generated in the transformer is dissipated or treated to the safe value. This is achieved by various cooling methods of transformer available.

The major factor for the generation of heat in the transformer is the various losses like hysteresis, eddy current, iron, and copper loss. Among all the various losses the major contributor of the heat generation is the **copper loss** or I^2R loss.

SINGLE PHASE TRANSFORMER

DIFFERENT TYPES OF COOLING METHODS

Different cooling methods of transformers are -



SINGLE PHASE TRANSFORMER

APPLICATION OF TRANSFORMER

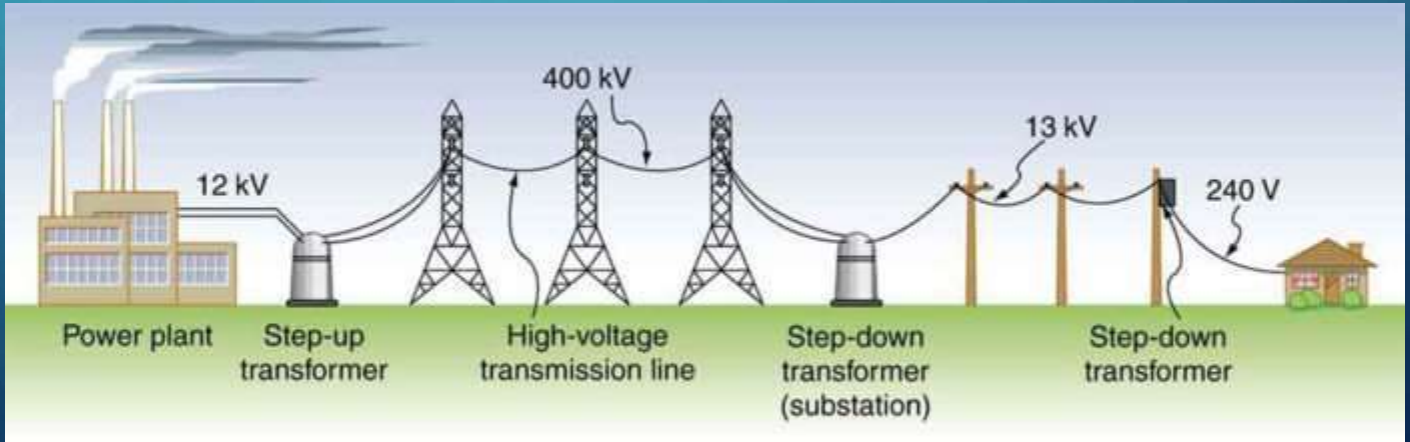
1. Transformer is used to get the required voltage level. Step-up transformer is used to increase the voltage and step down transformer is used to decrease the voltage level.

2. Transformer can increase or decrease the value of capacitor, an inductor or resistance in an AC circuit. Thus it acts as an impedance transferring device.

3. The transformer is also used for isolate two circuits electrically.

4. The transformer is used in impendence matching.

5. Transformer is used in the construction of electrical measuring device such as voltmeter, ammeter, relay etc.



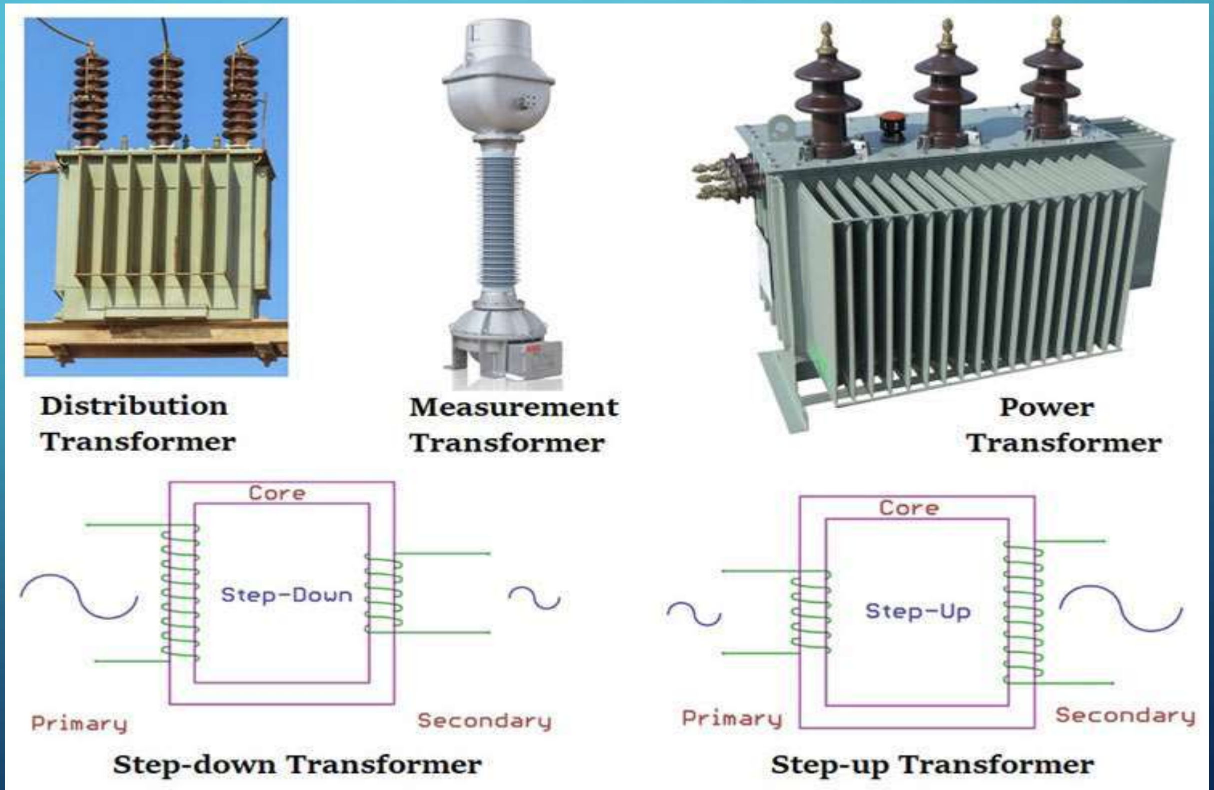
SINGLE PHASE TRANSFORMER

APPLICATION OF TRANSFORMER

6. It is used for rectification. Rectification is the process of converting A.C to D.C. Rectification is important for high voltage transmission. The best example of rectifier is a mobile charger.

7. It is used in the voltage regulator and voltage stabilizer.

8. it is widely used in power transmission and distribution process.



SINGLE PHASE TRANSFORMER

APPLICATION OF TRANSFORMER

Application of Isolation transformer

An isolation transformer is a transformer which is used to transfer electrical power from a source of alternating current (AC) power to some equipment or device while isolating the powered device from the power source, usually for safety reasons.

Application of instrument transformer

The main purpose of an instrument transformer is to provide voltage or current at a usable level which is used for measurement of electrical quantities. These instrument transformers are very high accuracy electrical device because it is going to be used in the measurement.

Application of Auto-transformer

Autotransformer is a transformer with single winding only. Generally, as we seen the transformer has two windings, primary and secondary winding. But here in autotransformer same single winding is act as a primary and secondary winding both. Autotransformer has many applications including starting of an induction motor, for variable output etc.

SINGLE PHASE TRANSFORMER

Problem 1. **A transformer has 500 primary turns and 3000 secondary turns. If the primary voltage is 240V, determine the secondary voltage, assuming an ideal transformer.**

Solution:

For an ideal transformer, voltage ratio = turns ratio, i.e.

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}, \text{ hence } \frac{240}{V_2} = \frac{500}{3000}$$

Thus secondary voltage $V_2 = \frac{(3000)(240)}{(500)}$

$= \mathbf{1440\ V\ or\ 1.44\ kV}$

SINGLE PHASE TRANSFORMER

Problem 2. A 5 kVA single-phase transformer has a turns ratio of 10:1 and is fed from a 2.5 kV supply. Neglecting losses, determine (a) the full load secondary current, (b) the minimum load resistance which can be connected across the secondary winding to give full load kVA, (c) the primary current at full load kVA.

Solution:

(a) $\frac{N_1}{N_2} = \frac{10}{1}$ and $V_1 = 2.5\,\text{kV} = 2500\,\text{V}$

Since $\frac{N_1}{N_2} = \frac{V_1}{V_2}$, secondary voltage

$$V_2 = V_1\left(\frac{N_2}{N_1}\right) = 2500\left(\frac{1}{10}\right) = 250\,\text{V}$$

The transformer rating in volt-amperes $= V_2 I_2$ (at full load), i.e. $5000 = 250 I_2$

Hence full load secondary current $I_2 = \frac{5000}{250} = \mathbf{20\,A}$

(b) Minimum value of load resistance, $R_L = \frac{V_2}{I_2}$

$$= \frac{250}{20}$$

$$= \mathbf{12.5\,\Omega}$$

(c) $\frac{N_1}{N_2} = \frac{I_2}{I_1}$, from which primary current $I_1 = I_2\left(\frac{N_2}{N_1}\right)$

$$= 20\left(\frac{1}{10}\right)$$

$$= \mathbf{2\,A}$$

Problem 3. A 100 kVA, 4000V/200V, 50 Hz single phase transformer has 100 secondary turns. Determine: (a) the primary and secondary current, (b) the number of primary turns, and (c) the maximum value of the flux.

Solution:

$V_1 = 4000\,\text{V}, V_2 = 200\,\text{V}, f = 50\,\text{Hz}, N_2 = 100$ turns

(a) Transformer rating $= V_1 I_1 = V_2 I_2 = 100\,000$ VA

Hence primary current, $I_1 = \frac{100\,000}{V_1} = \frac{100\,000}{4000}$

$= \mathbf{25\ A}$

and secondary current, $I_2 = \frac{100\,000}{V_2} = \frac{100\,000}{200}$

$= \mathbf{500\ A}$

(b) From equation (20.3), $\frac{V_1}{V_2} = \frac{N_1}{N_2}$

from which, primary turns, $N_1 = \left(\frac{V_1}{V_2}\right)(N_2)$

$= \left(\frac{4000}{200}\right)(100)$

i.e. $N_1 =$ **2000 turns**

(c) From equation (20.5), $E_2 = 4.44 f \Phi_m N_2$

from which, maximum flux Φ_m

$= \frac{E_2}{4.44 f N_2} = \frac{200}{4.44(50)(100)}$

(assuming $E_2 = V_2$)

$= \mathbf{9.01 \times 10^{-3}\ Wb}$ or **9.01 mWb**

[Alternatively, equation (20.4) could have been used, where $E_1 = 4.44 f \Phi_m N_1$

from which, $\Phi_m = \frac{E_1}{4.44 f N_1} = \frac{4000}{4.44(50)(2000)}$

(assuming $E_1 = V_1$)

$= 9.01$ mWb, as above]

MODULE:4

SINGLE PHASE TRANSFORMER

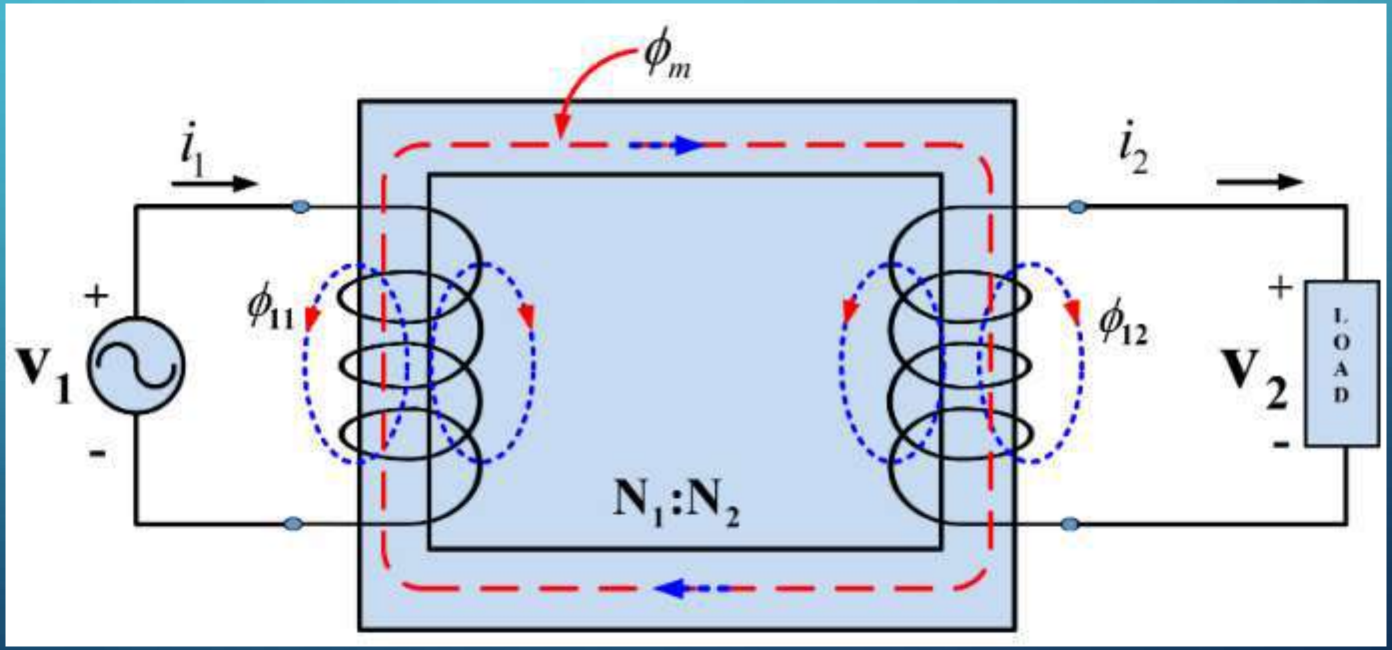
TOPIC:

- EQUIVALENT CIRCUIT DIAGRAM OF SINGLE PHASE TRANSFORMER
  - SECONDARY TRANSFERRED TO PRIMARY
  - PRIMARY TRANSFERRED TO SECONDARY
- OPEN CIRCUIT TEST AND SHORT CIRCUIT TEST OF A TRANSFORMER

EQUIVALENT CIRCUIT

The equivalent circuit diagram of any device can be quite helpful in the pre-determination of the behavior of the device under the various condition of operation. It is simply the circuit representation of the equation describing the performance of the device.

The simplified equivalent circuit of a transformer is drawn by representing all the parameters of the transformer either on the secondary side or on the primary side.



EQUIVALENT CIRCUIT

In a practical transformer -

(a) Some leakage flux is present at both primary and secondary sides. This leakage gives rise to leakage reactance's at both sides, which are denoted as X_1 and X_2 respectively.

(b) Both the primary and secondary winding possesses resistance, denoted as R_1 and R_2 respectively. These resistances causes voltage drop as, I_1R_1 and I_2R_2 and also copper loss $I_1^2R_1$ and $I_2^2R_2$.

(c) Permeability of the core can not be infinite, hence some magnetizing current is needed. Mutual flux also causes core loss in iron parts of the transformer.

Equivalent impedance of transformer is essential to be calculated because the electrical power transformer is an electrical power system equipment for estimating different parameters of the electrical power system which may be required to calculate the total internal impedance of an electrical power transformer, viewing from primary side or secondary side as per requirement.

This calculation requires equivalent circuit of transformer referred to the primary or equivalent circuit of transformer referred to secondary sides respectively.

EQUIVALENT CIRCUIT

Equivalent circuit diagram of a transformer is basically a diagram which can be resolved into an equivalent circuit in which the resistance and leakage reactance of the transformer are imagined to be external to the winding.

Where,

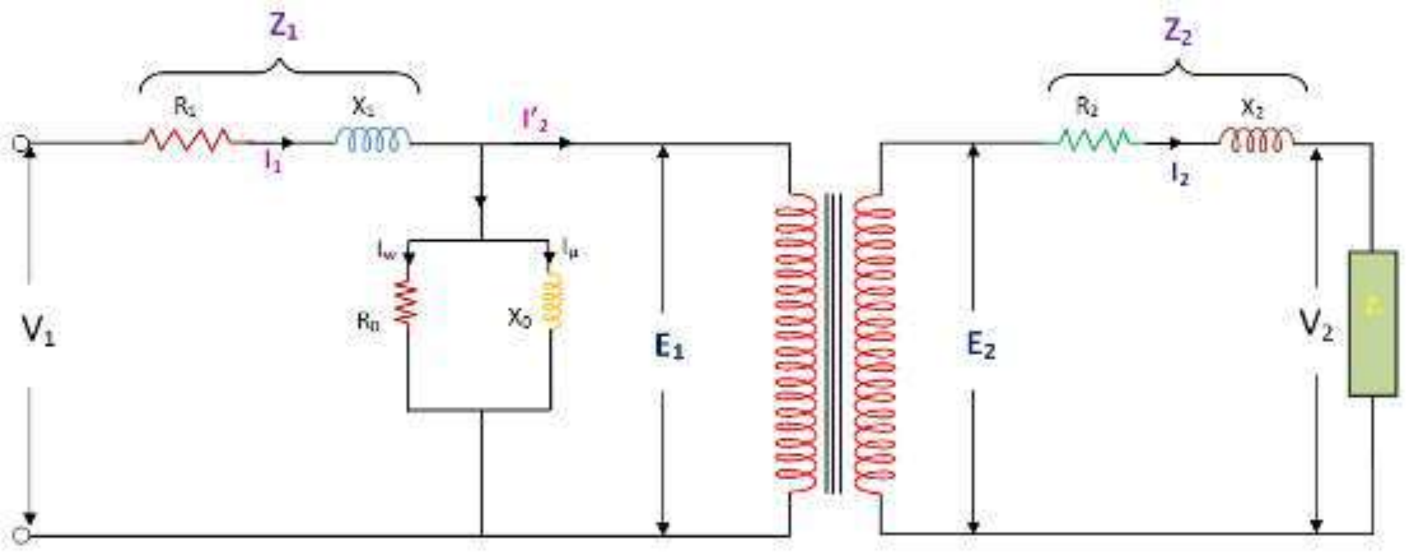
R_1 = Primary Winding Resistance.

R_2= Secondary winding Resistance.

I_0= No-load current.

I_μ = Magnetizing Component,

I_w = Working Component,

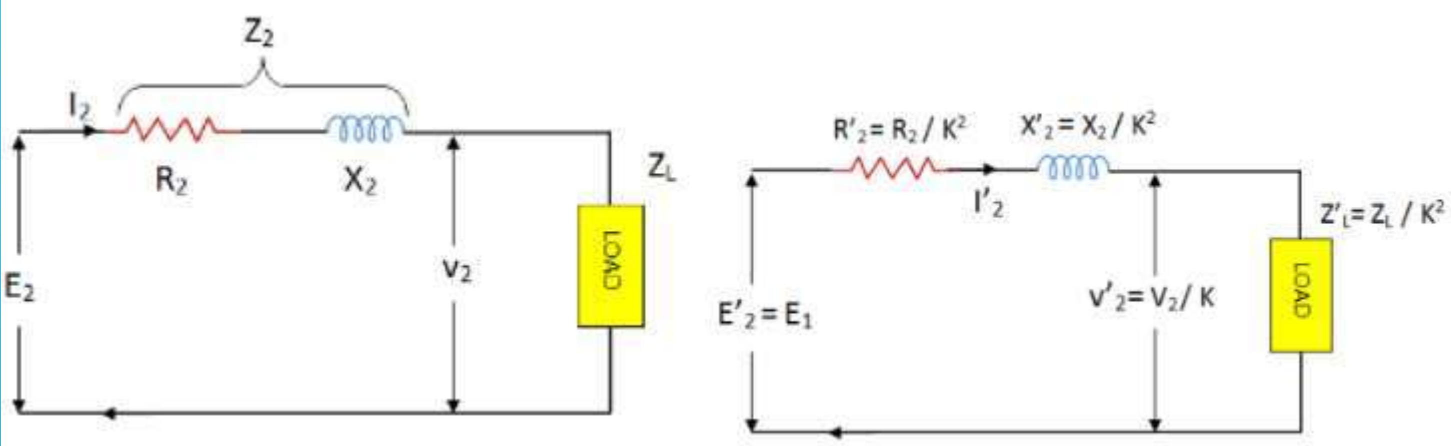


This I_μ & I_w are connected in parallel across the primary circuit. The value of E_1 (Primary e.m.f) is obtained by subtracting vector ally I_1 Z_1 from V_1 .

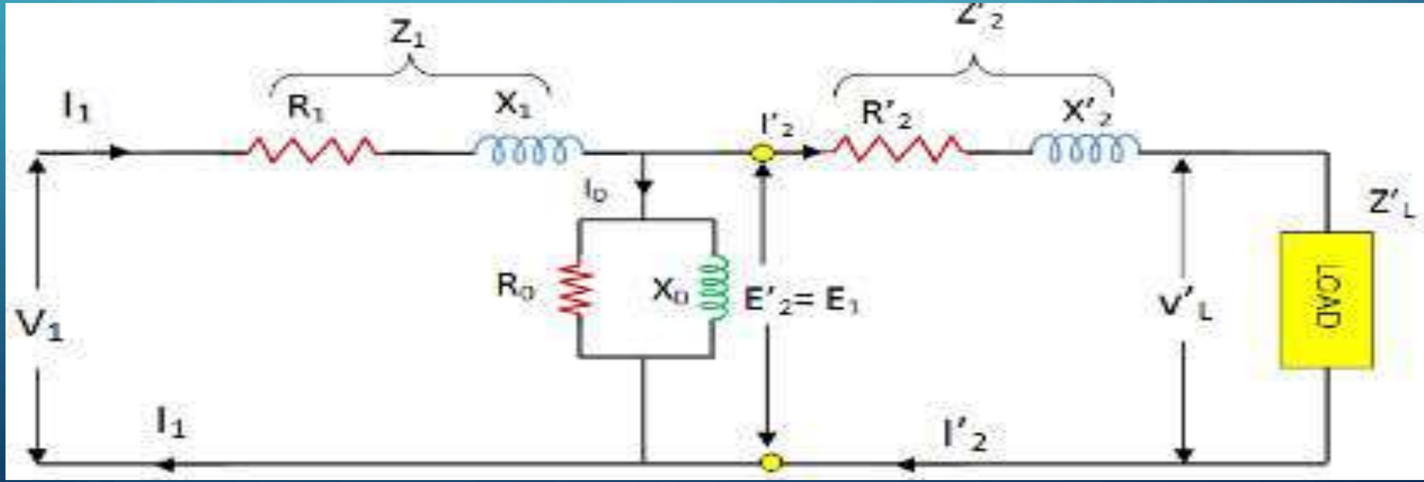
The value of $X_0 = E_1 / I_0$ and $R_0 = E_1 / I_w$. We know that the relation of E_1 and E_2 is $E_2 / E_1 = N_2 / N_1 = K$, (transformation Ratio) From the equivalent circuit , we can easily calculate the total impedance of to transfer voltage, current, and impedance either to the primary or the secondary.

EQUIVALENT CIRCUIT

The secondary circuit is shown in fig-1. and its equivalent primary value is shown in fig- 2,



The total equivalent circuit of the transformer is obtained by adding in the primary impedance as shown in – Fig-3 .



EQUIVALENT CIRCUIT

EQUIVALENT CIRCUIT WHEN ALL THE QUANTITIES ARE REFERRED TO PRIMARY SIDE

1. Secondary resistance referred to the primary side is given as:

$$R'_2 = \frac{R_2}{K^2}$$

The equivalent resistance referred to the primary side is given as:

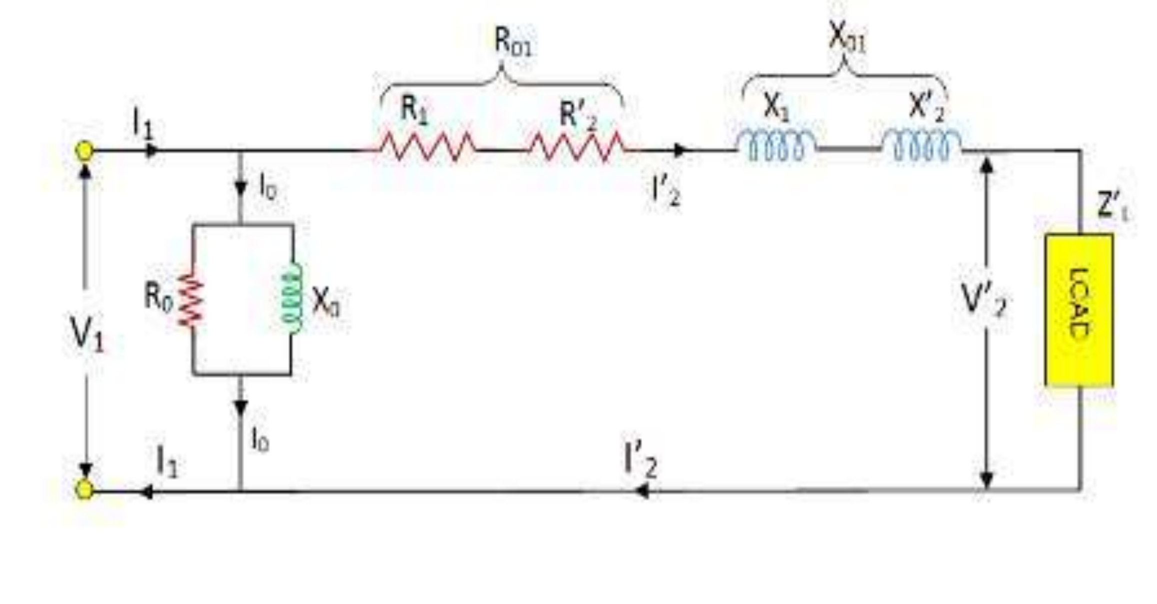
$$R_{ep} = R_1 + R'_2$$

2. Secondary reactance referred to the primary side is given as:

$$X'_2 = \frac{X_2}{K^2}$$

The equivalent reactance referred to the primary side is given as:

$$X_{ep} = X_1 + X'_2$$



EQUIVALENT CIRCUIT

EQUIVALENT CIRCUIT WHEN ALL THE QUANTITIES ARE REFERRED TO SECONDARY SIDE

1. Primary resistance referred to the secondary side is given as

$$R_1' = K^2 R_1$$

The equivalent resistance referred to the secondary side is given as

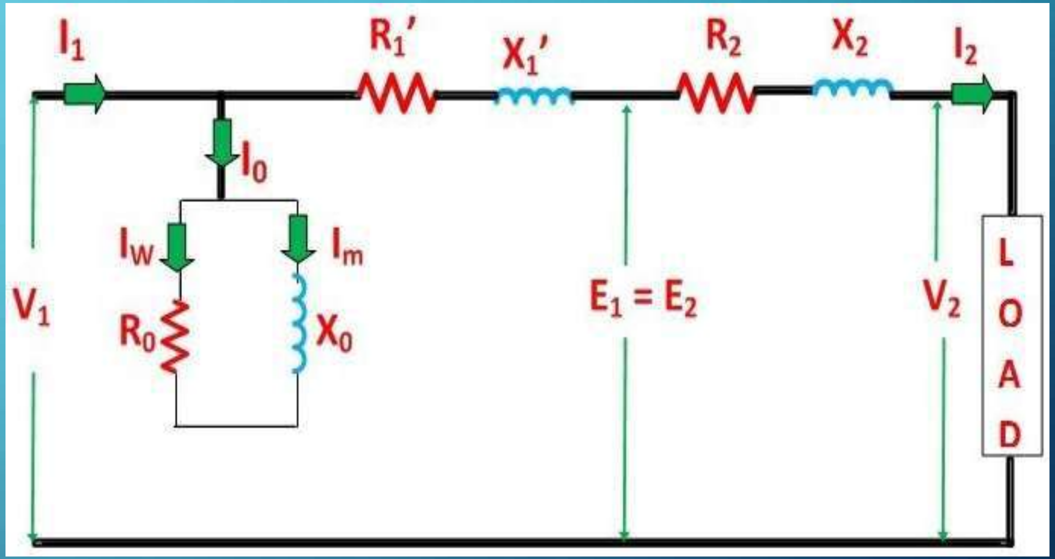
$$R_{es} = R_2 + R_1'$$

2. Primary reactance referred to the secondary side is given as

$$X_1' = K^2 X_1$$

The equivalent reactance referred to the secondary side is given as

$$X_{eq} = X_2 + X_1'$$



No-load current I_0 is hardly **3 to 5%** of full load rated current, the parallel branch consisting of resistance R_0 and reactance X_0 can be omitted without introducing any appreciable error in the behavior of the transformer under the loaded condition.

OPEN CIRCUIT TEST AND SHORT CIRCUIT TEST OF A TRANSFORMER

Open and short circuit tests are performed on a transformer to determine the:

1. Equivalent circuit of transformer

2. Voltage regulation of transformer

3. Efficiency of transformer

The power required for open circuit tests and short circuit tests on a transformer is equal to the power loss occurring in the transformer.

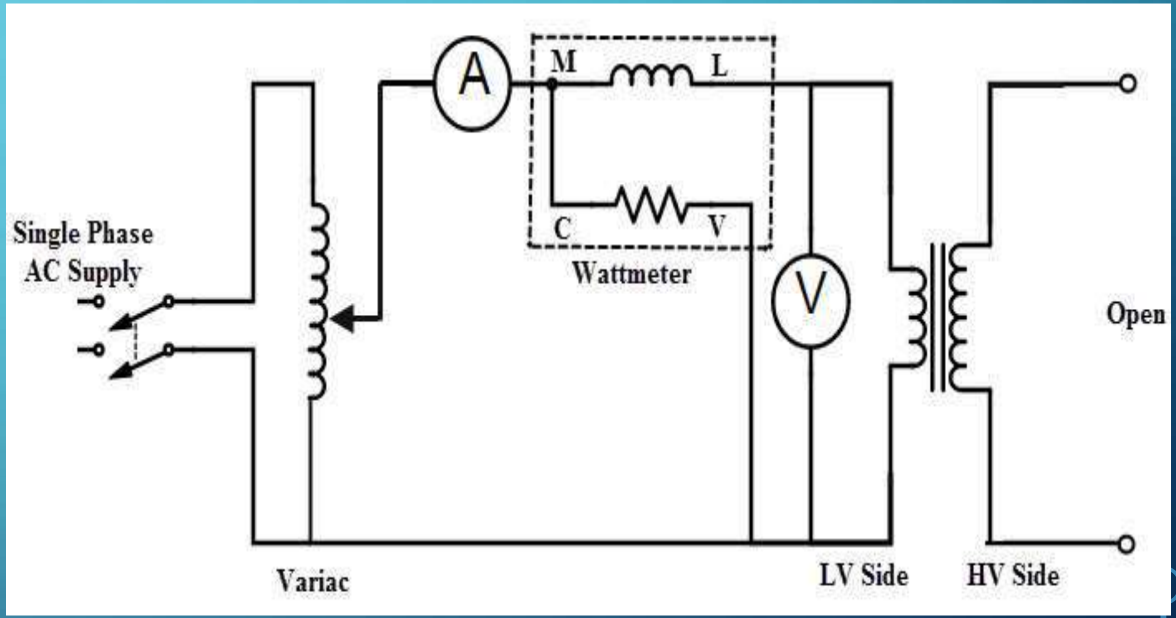
The open circuit and short circuit test are performed for determining the parameter of the transformer like their efficiency, voltage regulation, circuit constant etc. These tests are performed without the actual loading and because of this reason the very less power is required for the test. The open circuit and the short circuit test gives a very **accurate result** as compared to the full load test.

OPEN CIRCUIT TEST OF A TRANSFORMER

The purpose of the open-circuit test is to determine the no-load current and losses of the transformer because of which their no-load parameters are determined. This test is performed on the primary winding of the transformer. The wattmeter, ammeter and the voltage are connected to their primary winding. The nominal rated voltage is supplied to their primary winding with the help of the ac source.

The secondary winding of the transformer is kept open, and the voltmeter is connected to their terminal. This voltmeter measures the **secondary induced voltage**. As the secondary of the transformer is open, thus no-load current flows through the primary winding.

The value of no-load current is very small as compared to the full rated current. The copper loss occurs only on the primary winding of the transformer because the secondary winding is open. The reading of the wattmeter only represents the core and iron losses. The core loss of the transformer is the same for all types of loads.



OPEN CIRCUIT TEST OF A TRANSFORMER

CALCULATION OF OPEN-CIRCUIT TEST

Let,
W_0 – wattmeter reading
V_1 – voltmeter reading
I_0 – ammeter reading

1. Then the iron loss of the transformer $P_i = W_0$ and

$$W_0 = V_1 I_0 \cos\varphi_0$$

2. The no-load power factor is

$$\cos\varphi_0 = \frac{W_0}{V_1 I_0}$$

3. Working component I_w is

$$I_w = \frac{W_0}{V_1}$$

$$I_w = I_0 \cos\varphi_0$$

4. Magnetizing component is

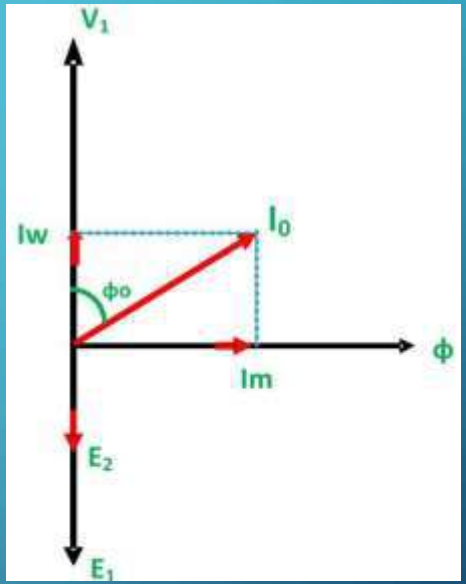
$$I_m = \sqrt{I_0^2 - I_w^2}$$

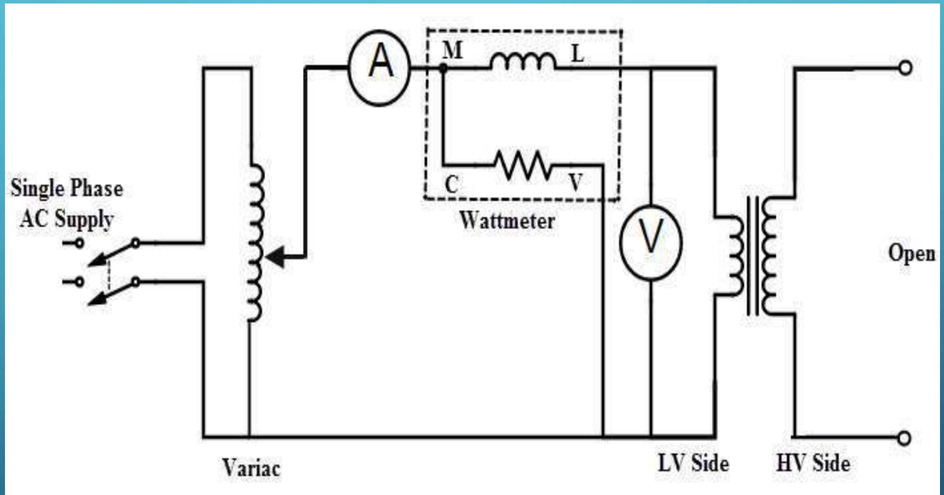
5. Equivalent exciting resistance is

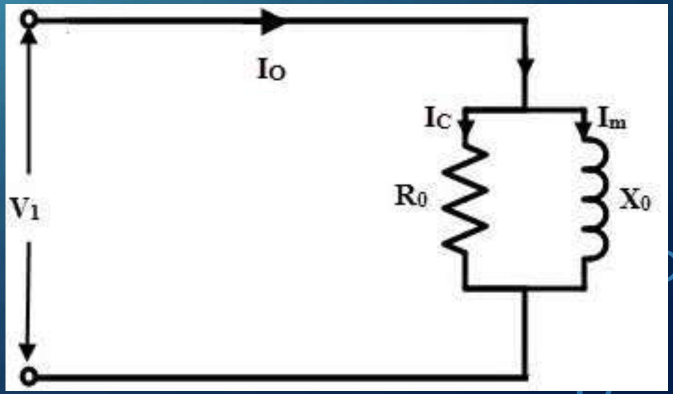
$$R_0 = \frac{V_1}{I_w}$$

6. Equivalent exciting reactance is

$$X_0 = \frac{V_1}{I_m}$$







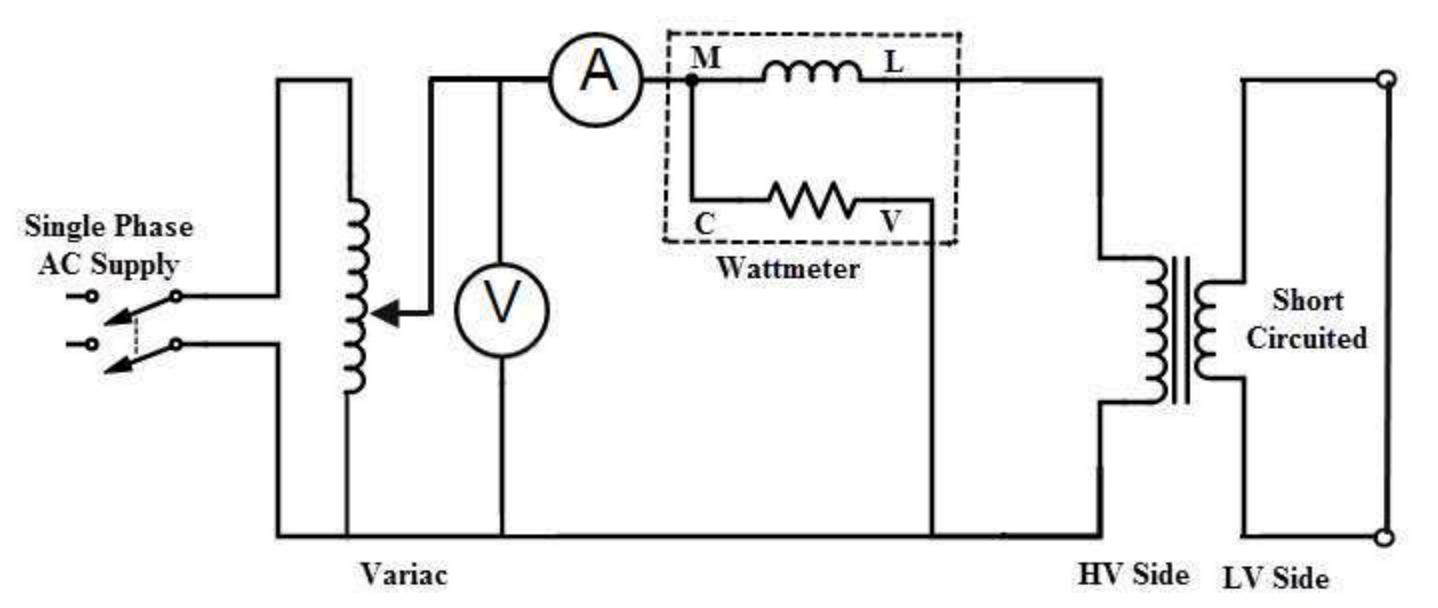
SHORT CIRCUIT TEST OF A TRANSFORMER

The short circuit test is performed for determining the below mention parameter of the transformer.

It determines the copper loss occur on the full load. The copper loss is used for finding the efficiency of the transformer. The equivalent resistance, impedance, and leakage reactance are known by the short circuit test.

The short circuit test is performed on the secondary or high voltage winding of the transformer. The measuring instrument like wattmeter, voltmeter and ammeter are connected to the high voltage winding of the transformer. Their primary winding is short-circuited by the help of thick strip or ammeter which is connected to its terminal.

The low voltage source is connected across the secondary winding because of which the full load current flows from both the secondary and the primary winding of the transformer. The full load current is measured by the ammeter connected across their secondary winding.



SHORT CIRCUIT TEST OF A TRANSFORMER

CALCULATION OF SHORT-CIRCUIT TEST

Let,
W_c – Wattmeter reading
V_{2sc} – voltmeter reading
I_{2sc} – ammeter reading

Then the full load copper loss of the transformer is given by

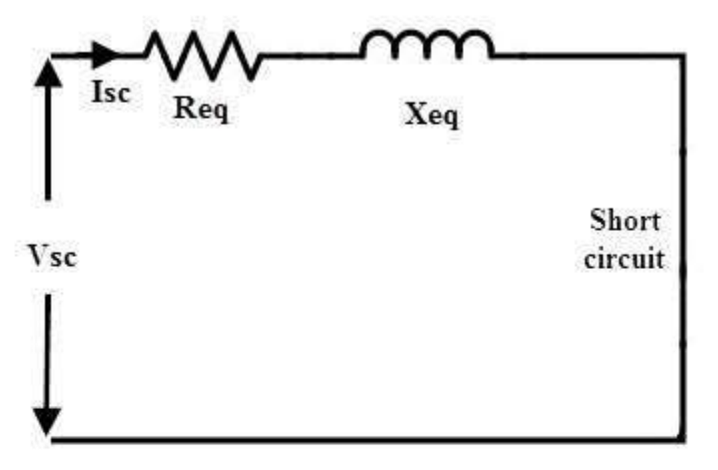
$$I_{2sc}^2 R_{es} = W_c$$

Equivalent resistance referred to the secondary side is $$R_{es} = \frac{W_c}{I_{2sc}^2}$$

Equivalent impedance referred to the secondary side is given by $$Z_{es} = \frac{V_{2sc}}{I_{2sc}}$$

The equivalent reactance referred to the secondary side is given by

$$X_{es} = \sqrt{(Z_{es})^2 - (R_{es})^2}$$



The voltage regulation of the transformer can be determined at any load and power factor after knowing the values of $\mathbf{Z_{es}}$ and $\mathbf{R_{es}}$.

In the short circuit test the wattmeter record, the total losses, including core loss but the value of core loss are very small as compared to copper loss so the core loss can be neglected.

MODULE:4

SINGLE PHASE TRANSFORMER

TOPIC:

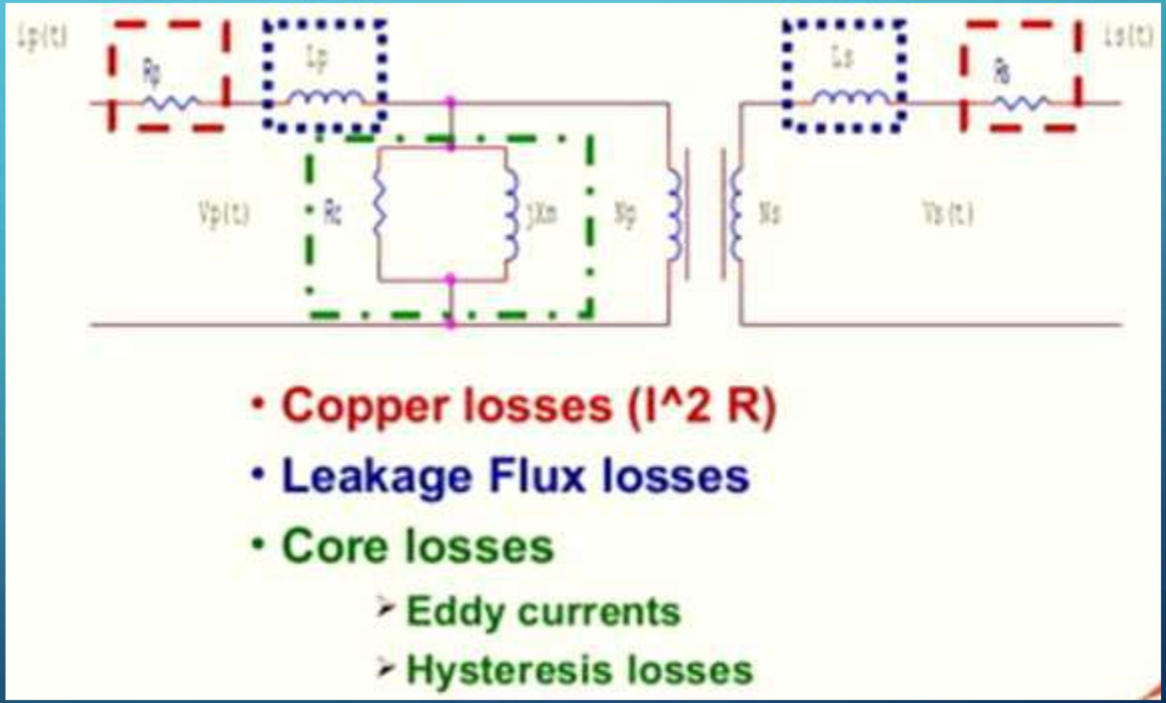
- LOSSES IN A TRANSFORMER
- PERFORM OPEN CIRCUIT AND SHORT CIRCUIT TEST OF A SINGLE PHASE TRANSFORMER IN VIRTUAL LABS

LOSSES IN A TRANSFORMER

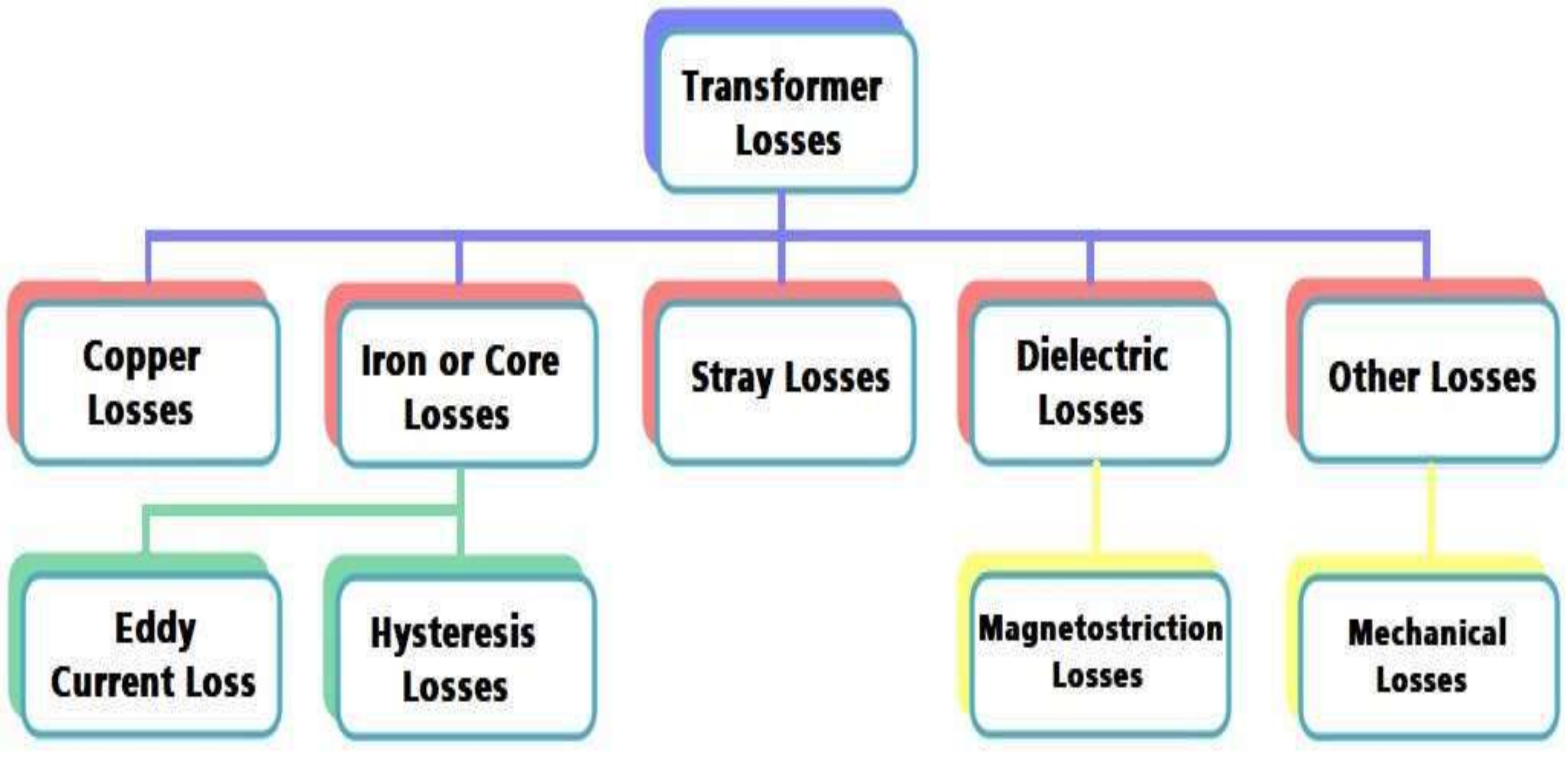
There are various types of losses in the transformer such as iron loss, copper loss, hysteresis loss, eddy current loss, stray loss, and dielectric loss. The hysteresis losses occur because of the variation of the magnetization in the core of the transformer and the copper loss occurs because of the transformer winding resistance.

Losses of transformer are divided mainly into two types:

1. Iron Loss
2. Copper Losses



TYPES OF LOSSES IN A TRANSFORMER



LOSSES IN A TRANSFORMER

1. Copper Losses (Winding Resistance)

Current flowing through the windings causes resistive heating of the conductors. At higher frequencies, skin effect and proximity effect create additional winding resistance and losses.

$$\textbf{Total copper losses.} = I_1^2 . R_1 + I_2^2 R_2 = I_1^2 . R_{01} + I_2^2 R_{02}$$

2. Core or Iron Losses

a) Hysteresis Losses

Each time the magnetic field is reversed, a small amount of energy is lost due to hysteresis within the core. For a given core material, the transformer losses are proportional to the frequency, and is a function of the peak flux density to which it is subjected.

$$W_h = \eta B^{1.6}_{max} f.v \ \text{watt}$$

b) Eddy Current Losses

Ferromagnetic materials are also good conductors, and a core made from such a material also constitutes a single short-circuited turn throughout its entire length. Eddy currents therefore circulate within the core in a plane normal to the flux, and are responsible for resistive heating of the core material.

$$W_e = PB^2_{max}.f^2 t^2 \ \text{Watt}$$

3. Stray losses (leakage Flux)

However, any leakage flux that intercepts nearby conductive materials such as the transformer’s support structure will give rise to eddy currents and be converted to heat. There are also radioactive losses due to the oscillating magnetic field, but these are usually small and negligible.

LOSSES IN A TRANSFORMER

4. Dielectric Loss

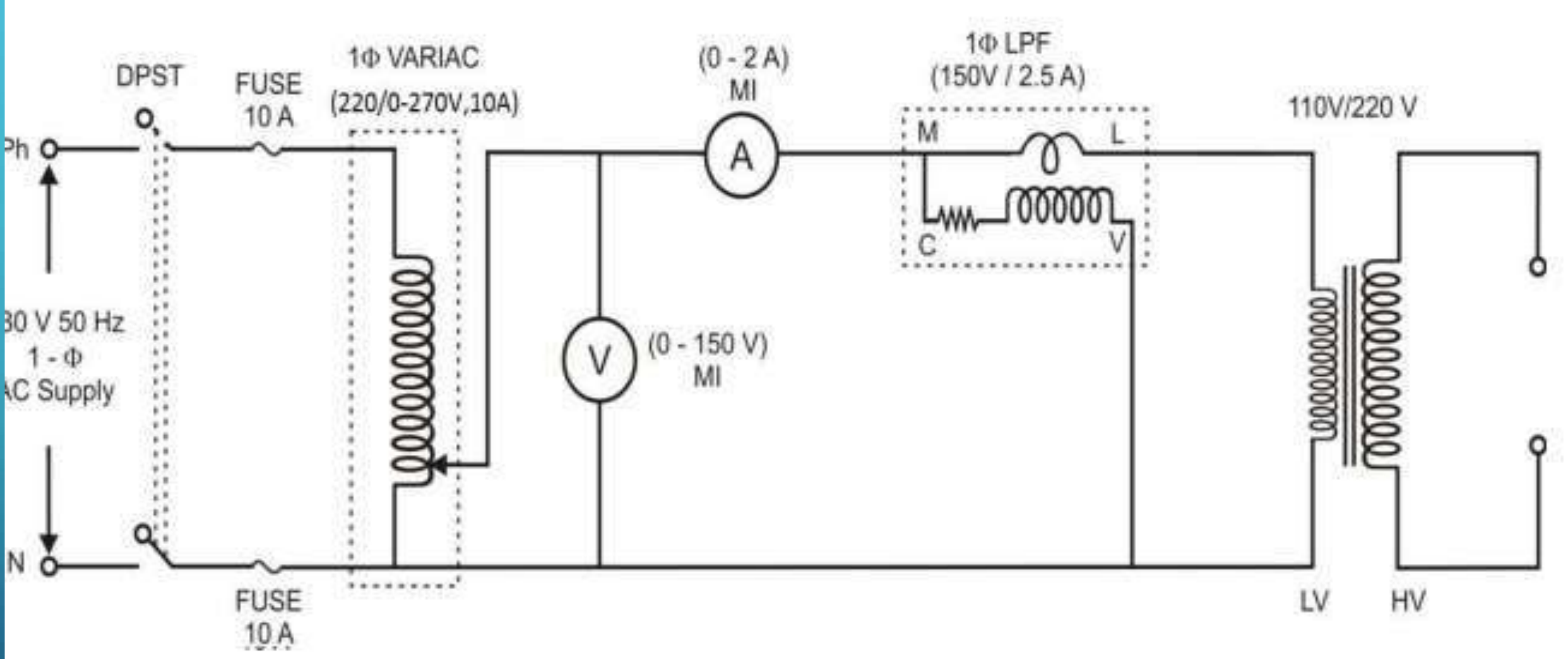
In the solid insulation or transformer oil i.e. insulation material of the transformer, dielectric loss occurs when the solid insulation get damaged or the oil gets deteriorated or its quality decreases over the time. Hence, the overall efficiency of transformer may be affected due to this loss.

5. Magnetostriction Losses

Magnetic flux in a ferromagnetic material, such as the core, causes it to physically expand and contract slightly with each cycle of the magnetic field, an effect known as magnetostriction. This produces the buzzing sound commonly associated with transformers, and can cause losses due to frictional heating.

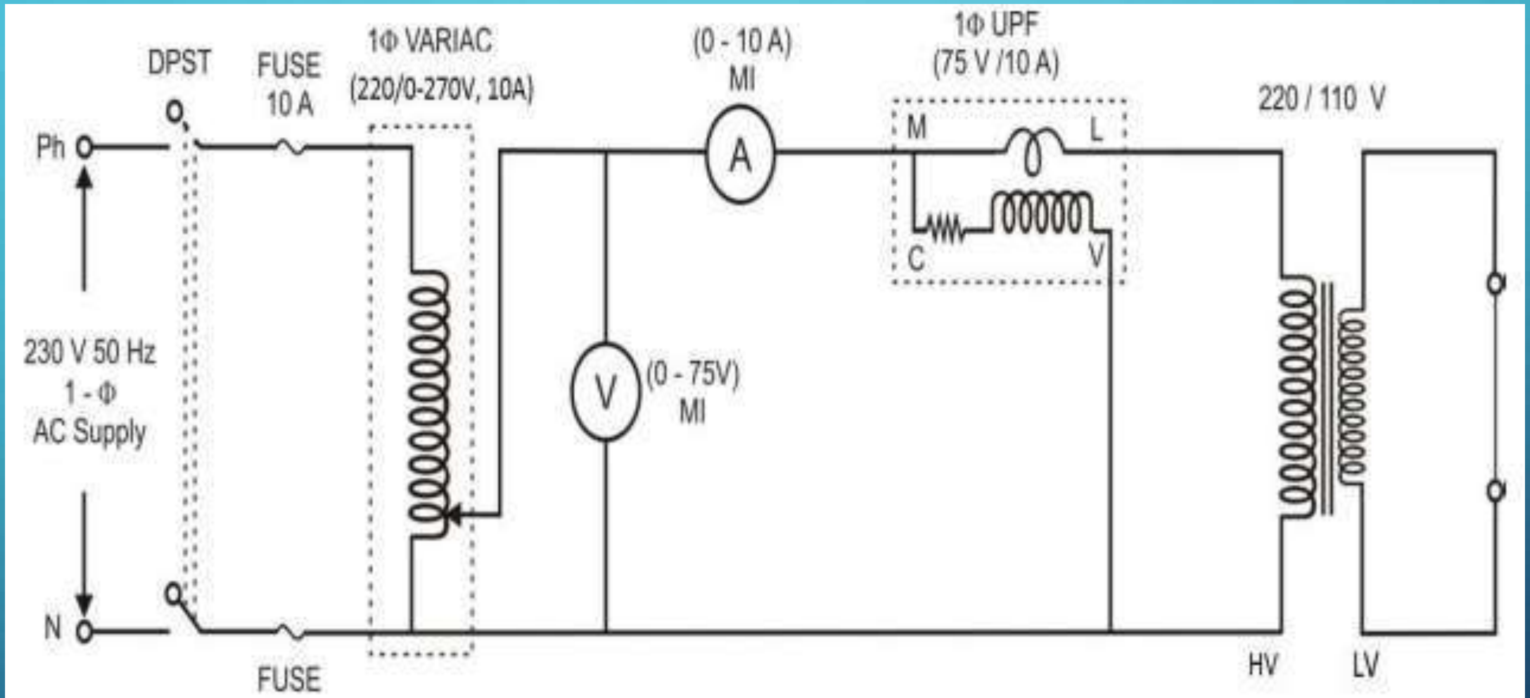
OPEN CIRCUIT TEST OF A SINGLE PHASE TRANSFORMER

CONNECTION DIAGRAM



SHORT CIRCUIT TEST OF A SINGLE PHASE TRANSFORMER

CONNECTION DIAGRAM



LABORATORY SET UP FOR OPEN AND SHORT CIRCUIT TEST OF A TRANSFORMER

http://www.vlab.co.in/

MODULE:4

SINGLE PHASE TRANSFORMER

TOPIC:

- **EFFICIENCY OF TRANSFORMER**
- **ALL DAY EFFICIENCY**
- **VOLTAGE REGULATION**
- **PROBLEM SOLVING**

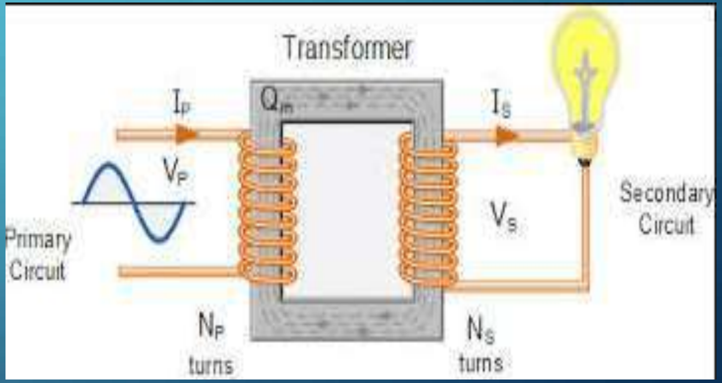
EFFICIENCY OF TRANSFORMER

Transformers form the most important link between supply systems and load. Transformer's efficiency directly affects its performance and aging. The transformer's efficiency, in general, is in the range of 95 – 99 %. For large power transformers with very low losses, the efficiency can be as high as 99.7%. The input and output measurements of a transformer are not done under loaded conditions as the wattmeter readings inevitably suffer errors of 1 – 2%. So for the purpose of efficiency calculations, OC and SC tests are used to calculate rated core and winding losses in the transformer. The core losses depend on the transformer rated voltage, and the copper losses depend on the currents through the transformer primary and secondary windings. Hence transformer efficiency is of prime importance to operate it under constant voltage and frequency conditions. The rise in the temperature of the transformer due to heat generated affects the life of transformer oil properties and decides the type of cooling method adopted. The temperature rise limits the rating of the equipment. The **efficiency of transformer** is simply given as:

$$\text{efficiency, } \eta = \frac{\text{Output Power}}{\text{Input Power}} \times 100\%$$

$$= \frac{\text{Input Power - Losses}}{\text{Input Power}} \times 100\%$$

$$= 1 - \frac{\text{Losses}}{\text{Input Power}} \times 100\%$$



Where: Input, Output and Losses are all expressed in units of power. Generally when dealing with transformers, the primary watts are called "volt-amps", **VA** to differentiate them from the secondary watts. Then the efficiency equation above can be modified to:

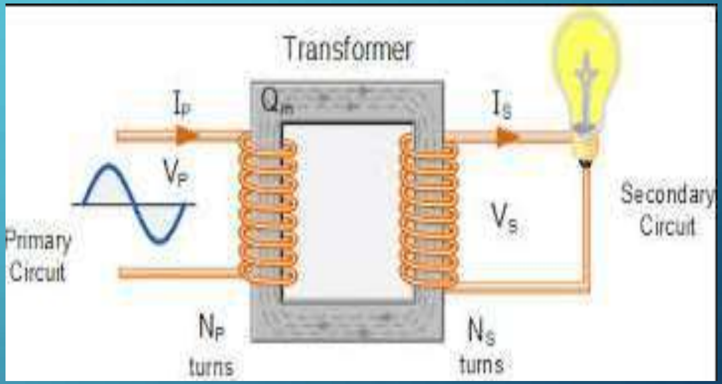
$$\text{Efficiency, } \eta = \frac{\text{Secondary Watts (Output)}}{\text{Primary VA (Input)}}$$

EFFICIENCY OF TRANSFORMER

The output power is the product of the fraction of the rated loading (volt-ampere), and power factor of the load.

The losses are the sum of copper losses in the windings + the iron loss + dielectric loss + stray load loss.

The iron losses include the hysteresis and eddy current losses in the transformer. These losses depend on the flux density inside the core. Mathematically,



Hysteresis Loss :

$$P_h = k_h f B_{max}^n$$

Eddy Current Loss

$$P_e = k_e f^2 B_{max}^n t^2$$

Where k_h and k_e are constants, B_{max} is the peak magnetic field density, f is the source frequency, and t is the thickness of the core. The power 'n' in the hysteresis loss is known as Steinmetz constant whose value can be nearly 2

$$Total\ iron\ or\ core\ losses(P_i) = Hysteresis\ loss + eddy\ current\ loss$$

The dielectric losses take place inside the transformer oil. For low voltage transformers, it can be neglected.
The leakage flux links to the metal frame, tank,etc. to produce eddy currents and are present all around the transformer hence called stray loss, and it depends on the load current and so named as 'stray load loss.' It can be represented by resistance in series to the leakage reactance.

EFFICIENCY OF TRANSFORMER

The **Efficiency** of the transformer is defined as the ratio of useful output power to the input power. The input and output power are measured in the same unit. Its unit is either in Watts (W) or KW. **Transformer efficiency** is denoted by **η**.

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

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

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

Where,

V_2 – Secondary terminal voltage

I_2 – Full load secondary current

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

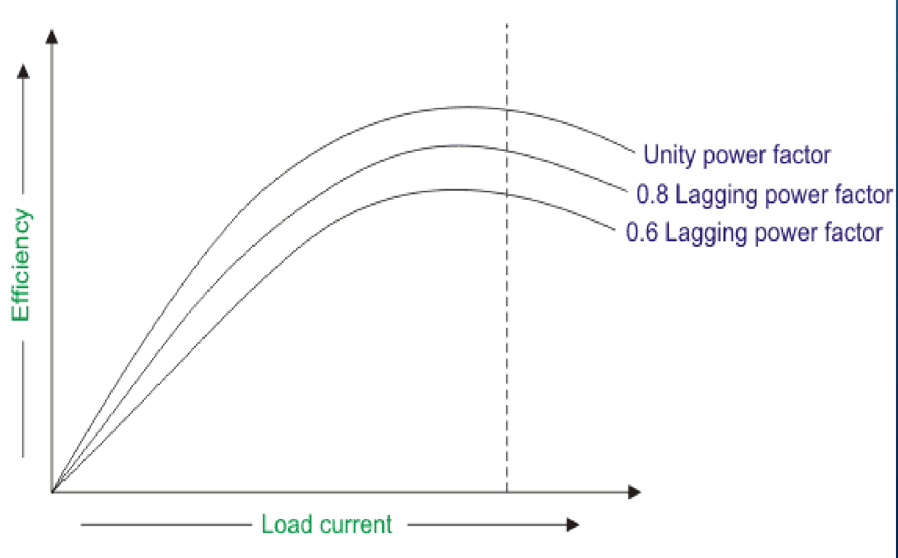
P_i – Iron losses = hysteresis losses + eddy current losses

P_c – Full load copper losses = $I_2^2 R_{es}$

Consider, the x is the fraction of the full load. The efficiency of the transformer regarding x is expressed as

$$\eta_x = \frac{x \text{ X output}}{x \text{ X output} + P_i + x^2 P_c}$$

$$\frac{x V_2 I_2 \cos\varphi_2}{x V_2 I_2 \cos\varphi_2 + P_i + x^2 I_2^2 R_{es}}$$



EFFICIENCY OF TRANSFORMER

CONDITION FOR MAXIMUM EFFICIENCY

$$\text{efficiency} = 1 - \frac{\text{losses}}{\text{input}} = 1 - \frac{I_1^2R_1 + W_i}{V_1I_1\cos\Phi_1}$$

$$\eta = 1 - \frac{I_1R_1}{V_1\cos\Phi_1} - \frac{W_i}{V_1I_1\cos\Phi_1}$$

differentiating above equation with respect to I_1

$$\frac{d\eta}{dI_1} = 0 - \frac{R_1}{V_1\cos\Phi_1} + \frac{W_i}{V_1I_1^2\cos\Phi_1}$$

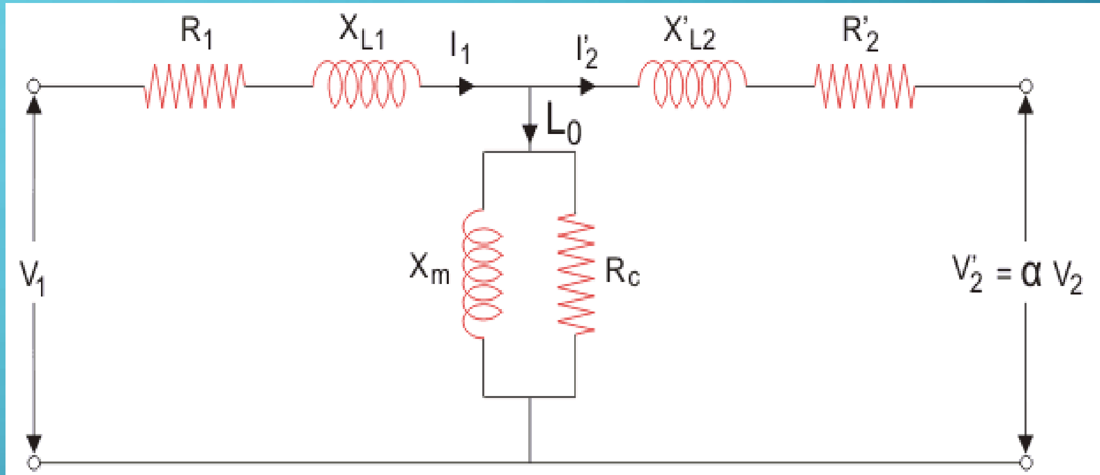
η will be maximum at $\frac{d\eta}{dI_1} = 0$

Hence efficiency η will be maximum at

$$\frac{R_1}{V_1\cos\Phi_1} = \frac{W_i}{V_1I_1^2\cos\Phi_1}$$

$$\frac{I_1^2R_1}{V_1I_1^2\cos\Phi_1} = \frac{W_i}{V_1I_1^2\cos\Phi_1}$$

Copper loss = $I_1^2R_1$ Iron loss = Wi



Equivalent Circuit of Transformer

$$I_1^2R_1 = W_i$$

Hence, efficiency of a transformer will be maximum when copper loss and iron losses are equal.
That is **Copper loss = Iron loss**.

EFFICIENCY OF TRANSFORMER

ALL DAY EFFICIENCY OF TRANSFORMER

As we have seen above, ordinary or commercial efficiency of a transformer can be given as

$$\text{ordinary efficiency} = \frac{\text{output (in watts)}}{\text{input (in watts)}}$$

But in some types of transformers, their performance can not be judged by this efficiency. For example, distribution transformers have their primaries energized all the time. But, their secondary's supply little load all no-load most of the time during day (as residential use of electricity is observed mostly during evening till midnight).

That is, when secondary's of transformer are not supplying any load (or supplying only little load), then only core losses of transformer are considerable and copper losses are absent (or very little). Copper losses are considerable only when transformers are loaded. Thus, for such transformers copper losses are relatively less important. The performance of such transformers is compared on the basis of energy consumed in one day.

$$\text{All day efficiency} = \frac{\text{output (in kWh)}}{\text{input (in kWh)}} \quad \text{(for 24 hours)}$$

All day efficiency of a transformer is always less than ordinary efficiency of it.

EFFICIENCY OF TRANSFORMER

WHAT IS THE NEED FOR ALL DAY EFFICIENCY

Some transformer efficiency cannot be judged by simple commercial efficiency as the load on certain transformer fluctuate throughout the day.

For example, the distribution transformers are energized for 24 hours, but they deliver very light loads for the major portion of the day, and they do not supply rated or full load, and most of the time the distribution transformer has **50 to 75%** load on it.

As we know, there are various losses in the transformer such as iron and copper loss. The iron loss takes place at the core of the transformer. Thus, the iron or core loss occurs for the whole day in the distribution transformer.
The second type of loss known as a copper loss and it takes place in the windings of the transformer and is also known as the **variable loss**. It occurs only when the transformers are in the loaded condition.

Hence, the performance of such transformers cannot be judged by the commercial or ordinary efficiency, but the efficiency is calculated or judged by All Day Efficiency also known as **operational efficiency** or **energy efficiency** which is computed by the energy consumed for 24 hours.

VOLTAGE REGULATION

The term voltage regulation identifies the characteristic of the voltage change in the transformer with loading.

The voltage regulation of a transformer is defined as the change in the secondary terminal voltage between no load and full load at a specified power factor expressed as a percentage of the full load terminal voltage.

$$\%Voltage\ Regulation = \frac{(no\ load\ Sec.Voltage) - (full\ load\ Sec.Voltage)}{full\ load\ Sec.Voltage} \times 100$$

Voltage regulation is a measure of the change in the terminal voltage of a transformer between No load and Full load. A good transformer has least value of the regulation of the order of ±5%

The voltage regulation of the transformer is defined as the arithmetical difference in the secondary terminal voltage between no-load (I_2=0) and full rated load (I_2 = I_{2fl}) at a given power factor with the same value of primary voltage for both rated load and no-load.

The numerical difference between no-load and full-load voltage is called **inherent voltage regulation**.

VOLTAGE REGULATION

voltage regulation $\triangleq |V_{2nl}| - |V_{2fl}|$

Where V_{2fl} = rated secondary terminal voltage at rated load.

V_{2nl} = no load secondary terminal voltage with the same value of primary voltage for both rated load and no load.

Per unit voltage regulation at full load is

$$\triangleq \left. \frac{|V_{2nl}| - |V_{2fl}|}{|V_{2fl}|} \right|_{|V_1| = \text{constant}}$$

Percent voltage regulation at full load

$$\triangleq \left. \frac{|V_{2nl}| - |V_{2fl}|}{|V_{2fl}|} \right|_{|V_1| = \text{constant}} \times 100$$

We can say that voltage regulation is an important measure for the performance of the transformer. We can specify the limits of the transformer in terms of voltage regulation.

VOLTAGE REGULATION

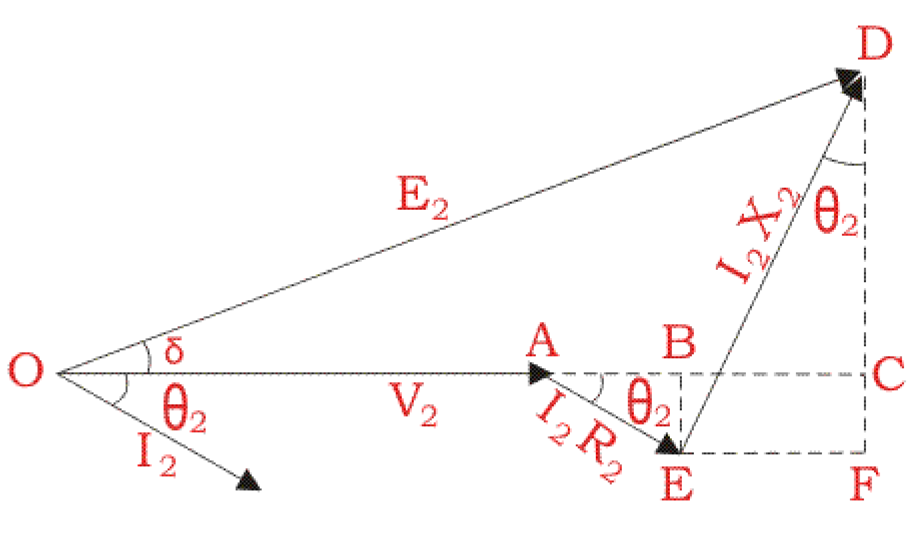
VOLTAGE REGULATION OF TRANSFORMER FOR LAGGING POWER FACTOR

$$OC = OA + AB + BC$$

$$Here,\ OA = V_2$$

$$Here,\ AB = AE\cos\theta_2 = I_2R_2\cos\theta_2$$

$$and,\ BC = DE\sin\theta_2 = I_2X_2\sin\theta_2$$



Angle between OC and OD may be very small, so it can be neglected and OD is considered nearly equal to OC i.e.

$$E_2 = OC = OA + AB + BC$$

$$E_2 = OC = V_2 + I_2R_2\cos\theta_2 + I_2X_2\sin\theta_2$$

Voltage regulation of transformer at lagging power factor,

$$Voltage\ regulation\ (\%) = \frac{E_2 - V_2}{V_2} \times 100(\%)$$

$$= \frac{I_2R_2\cos\theta_2 + I_2X_2\sin\theta_2}{V_2} \times 100(\%)$$

VOLTAGE REGULATION

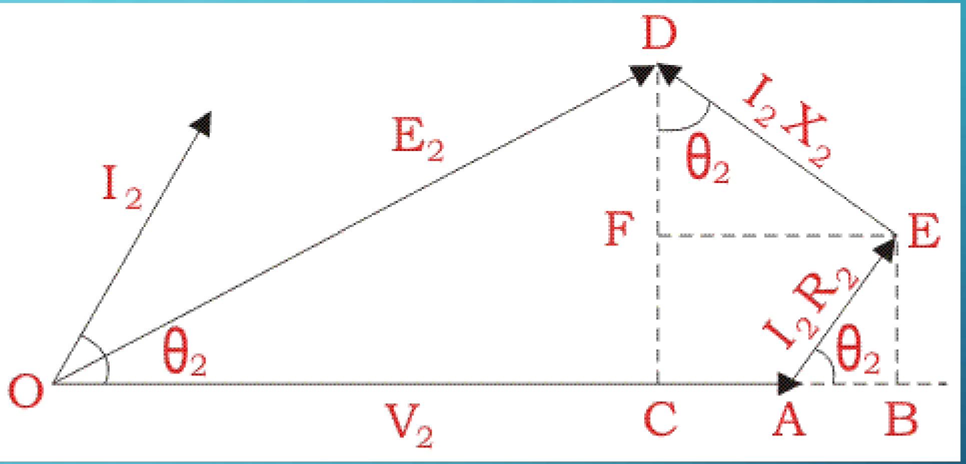
VOLTAGE REGULATION OF TRANSFORMER FOR LEADING POWER FACTOR

$$OC = OA + AB - BC$$

$$Here,\ OA = V_2$$

$$Here,\ AB = AE\cos\theta_2 = I_2R_2\cos\theta_2$$

$$and,\ BC = DE\sin\theta_2 = I_2X_2\sin\theta_2$$



Angle between OC and OD may be very small, so it can be neglected and OD is considered nearly equal to OC i.e.

$$E_2 = OC = OA + AB - BC$$

$$E_2 = OC = V_2 + I_2R_2\cos\theta_2 - I_2X_2\sin\theta_2$$

Voltage regulation of transformer at leading power factor

$$Voltage\ regulation\ (\%) = \frac{E_2 - V_2}{V_2} \times 100(\%)$$

$$= \frac{I_2R_2\cos\theta_2 - I_2X_2\sin\theta_2}{V_2} \times 100(\%)$$

PROBLEM SOLVING

Problem-01: Calculate the values of equivalent circuit parameters referred to the LV side of a single-phase 3kVA, 220/440V, 50 Hz transformer with the following test results:

Open circuit test (HV open): 220 V, 1 A, 100 W
Short circuit test (LV short): 20 V, 9 A, 75 W

Solution:

Open circuit test

Voltmeter reading = V_1 = Rated LV voltage = 220 V
Ammeter reading = I_0 = No-load current = 1 A
Wattmeter reading = P_0 = No-load power loss = 100 W

$$P_0 = \frac{V_1^2}{R_{h+e}}$$

or,

$$R_{h+e} = \frac{V_1^2}{P_0} = \frac{220^2}{100} = 484 \text{ W}$$

$$I_{h+e} = \frac{V_1}{R_{h+e}} = \frac{220}{484} = 0.455 \text{ A}$$

∴

$$I_m = \sqrt{I_0^2 - I_{h+e}^2} = \sqrt{1^2 - 0.455^2} = 0.891 \text{ A}$$

∴

$$X_m = \frac{V_1}{I_m} = \frac{220}{0.891} = 247\ \Omega$$

Short circuit test

Voltmeter reading = V_{SC} = 20 V
Ammeter reading = I_{SC} = 9 A
Wattmeter reading = P_{SC} = 75 W

$$P_{SC} = I_{SC}^2 \times R_e$$

$$R_e = \frac{P_{SC}}{I_{SC}^2} = \frac{75}{9^2} = 0.93\ \Omega,\quad Z_e = \frac{V_{SC}}{I_{SC}} = \frac{20}{9} = 2.22\ \Omega$$

∴

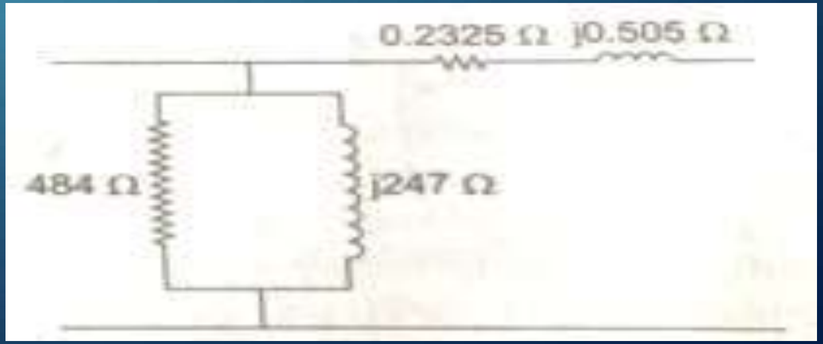
$$X_e = \sqrt{Z_e^2 - R_e^2} = \sqrt{2.22^2 - 0.93^2} = 2.02\ \Omega$$

Turns ratio, $a = \frac{V_1}{V_2} = \frac{220}{440} = \frac{1}{2} = 0.5$

∴ Values of R_e and X_e with respect to the LV side can now be calculated as:

$$R'_e = a^2 R_e = 0.5^2 \times 0.93 = 0.2325\ \Omega$$

$$X'_e = a^2 X_e = 0.5^2 \times 2.02 = 0.505\ \Omega$$



PROBLEM SOLVING

Problem-02: A single-phase 10 kVA 2000/200 V, 50 Hz transformer has the following test results:

Open circuit test: 200 V, 0.8 A, 60 W
Short circuit test: 40 V, 4 A, 70 W

i) Find efficiency of the transformer at full load and 0.8 power factor lagging
ii) Find efficiency of the transformer at half load and 0.8 power factor lagging

Solution:

Full load current on HV side $= \frac{10 \times 10^3}{2000} = 5\text{ A}.$

Full load copper loss $P_{cu} = 70 \times \frac{5^2}{4^2} = 109.375\text{ W}$

(i) Efficiency of the transformer at full load and 0.8 power factor lagging

$$\eta_P = \frac{10 \times 10^3 \times 0.8}{10 \times 10^3 \times 0.8 + 60 + 109.375} \times 100\%$$

$$= \frac{8000}{8169.375} \times 100\% = 97.93\%$$

(ii) At half load, output kVA $= \frac{10}{2} = 5$

$$\text{Copper loss} = \left(\frac{1}{2}\right)^2 \times \text{Full load copper loss}$$

$$= \frac{109.375}{4} = 27.34\text{ W}$$

Core loss remains same = 60 W

∴ Efficiency at half load and 0.8 power factor is

$$\eta_P = \frac{5 \times 10^3 \times 0.8}{5 \times 10^3 \times 0.8 + 60 + 27.34} \times 100\%$$

$$= \frac{4000}{4087.34} \times 100\% = 97.86\%$$

MODULE:4

SINGLE PHASE TRANSFORMER

TOPIC:

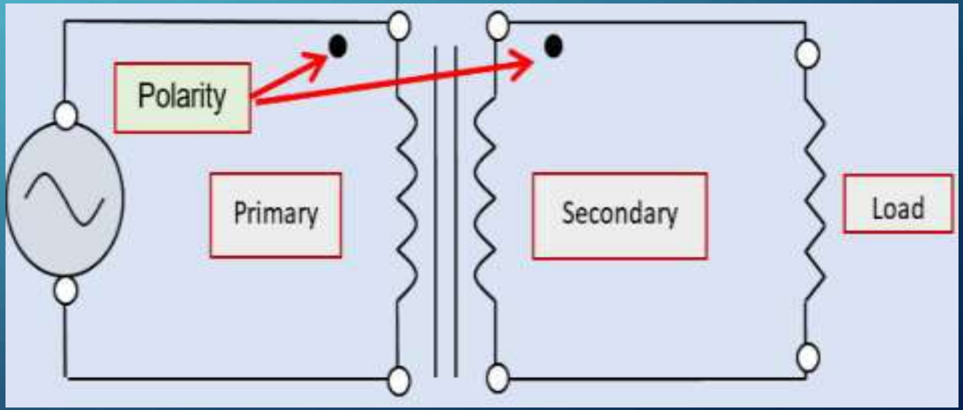
- POLATITY TEST OF TRANSFORMER
- PARALLEL OPERATIONON OF SINGLE PHASE TRANSFORMER
- AUTO TRANSFORMER

POLATITY TEST OF TRANSFORMER

The term **polarity** refers to the conductors in a DC circuit like positive or else negative conductors. In an electrical circuit, the flow of current direction is called as **electrical polarity**. The flow of current will be from positive terminal to negative terminal, whereas electrons flow from the negative terminal to the positive terminal. In a DC circuit, the flow of current will be in one direction only where the one terminal is positive and other terminal is negative always. In an AC circuit, the two terminals change among positive and negative and the direction of electron flow sometimes turns around. A **Polarity Test** is used in the situation of electricity fixing to verify the exact line connection as well as neutral conductors. For instance, for an Edison screw light holder, it is significant that the connection of line conductor should be to the center terminal as well as the neutral conductor is allied to the external conductor. Likewise, it is significant to verify that switches are situated within the line conductor, not the neutral conductor.

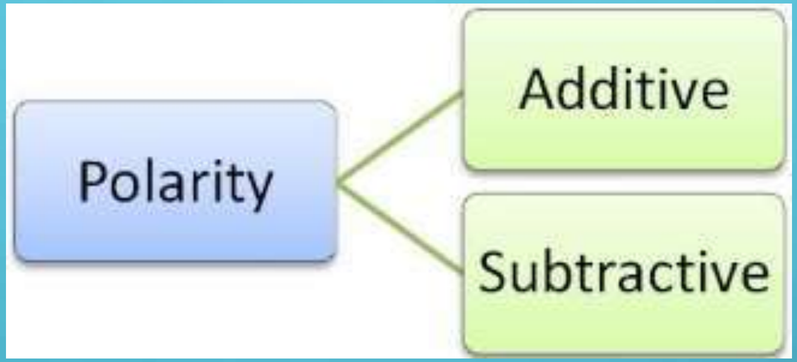
What is Polarity Test

The polarity can be defined as the induced voltage direction in the two windings of the transformer namely primary as well as secondary. If the connection of two transformers can be done in parallel, then the polarity must be identified for the good connection of the transformer.



POLATITY TEST OF TRANSFORMER

Polarity means the direction of the induced voltages in the primary and the secondary winding of the transformer. If the two transformers are connected in parallel, then the polarity should be known for the proper connection of the transformer. There are two types of polarity one is Additive, and another is Subtractive.



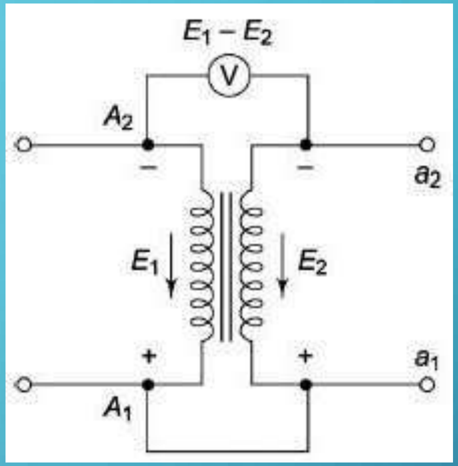
Additive Polarity: In additive polarity, the same terminals of the primary and the secondary windings of the transformer are connected

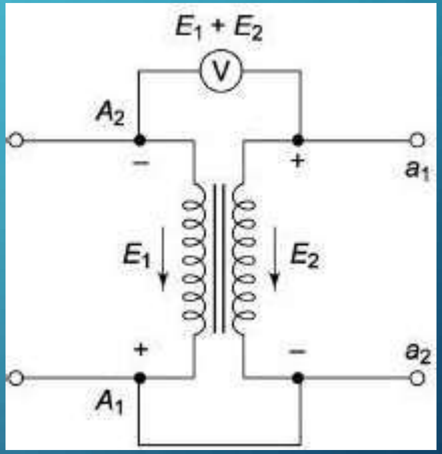
Subtractive Polarity: In subtractive polarity, different terminals of the primary and secondary side of the transformer is connected.

POLATITY TEST OF TRANSFORMER

CONNECTION DIAGRAM

Each of the terminals of the primary, as well as the secondary winding of a transformer, is alternatively positive and negative with respect to each other as shown in the figure below. Let A_1 and A_2 be the positive and negative terminal, respectively of the primary side of the transformer and a_1, a_2 are the positive and negative terminal of the secondary side of the transformer.





If A_1 is connected to a_1 and A_2 is connected to a_2 that means similar terminals of the transformer are connected, then the polarity is said to be **additive**. If A_1 is connected to a_2 and A_2 to a_1, that means the opposite terminals are connected to each other, and thus the voltmeter will read the **subtractive** polarity.

It is essential to know the relative polarities at any instant of the primary and the secondary terminals for making the correct connections if the transformers are to be connected in parallel or they are used in a three-phase circuit.

In the primary side, the terminals are marked as A_1 and A_2 and from the secondary side, the terminals are named as a_1 and a_2. The terminal A_1 is connected to one end of the secondary winding, and a voltmeter is connected between A_2 and the other end of the secondary winding.

When the voltmeter reads the difference that is $(V_1 – V_2)$, the transformer is said to be connected with opposite polarity know as **subtractive polarity** and when the voltmeter reads $(V_1 + V_2)$, the transformer is said to have **additive polarity**.

POLATITY TEST OF TRANSFORMER

PROCEDURE OF POLARITY TEST OF TRANSFORMER

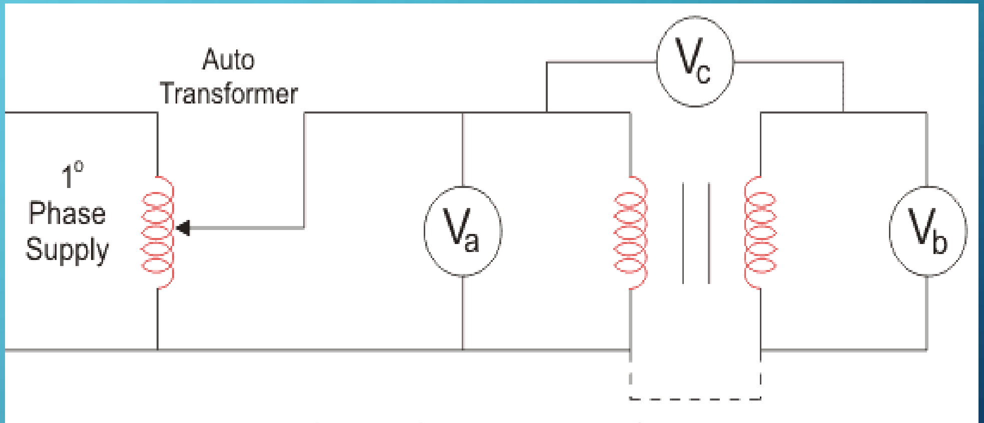
1. Connect the circuit as shown above with a voltmeter (V_a) across primary winding and another voltmeter (V_b) across the secondary winding.

2. If available, take down the ratings of the transformer and the turn ratio.

3. We connect a voltmeter (V_c) between primary and secondary windings.

4. We apply some voltage to the primary side.

5. By checking the value in the voltmeter (V_c), we can find whether it is additive or subtractive polarity.



Transformer Circuit Diagram for Test

If additive polarity – V_c should be showing the sum of V_a and V_b.

If subtractive polarity – V_c should be showing the difference between V_a and V_b.

Caution: Be careful that the max. measuring the voltage of voltmeter V_c should be greater than the sum of V_a (Primary winding) and V_b (Secondary winding) otherwise during the additive polarity, the sum of V_a and V_b comes across it.

PARALLEL OPERATION OF TRANSFORMERS

For supplying a load in excess of the rating of an existing transformer, two or more transformers may be connected in parallel with the existing transformer. The transformers are connected in parallel when load on one of the transformers is more than its capacity. The reliability is increased with parallel operation than to have single larger unit. The cost associated with maintaining the spares is less when two transformers are connected in parallel.

It is usually economical to install another transformer in parallel instead of replacing the existing transformer by a single larger unit. The cost of a spare unit in the case of two parallel transformers (of equal rating) is also lower than that of a single large transformer. In addition, it is preferable to have a parallel transformer for the reason of reliability. With this at least half the load can be supplied with one transformer out of service.

Parallel operation of two or more Transformers means that all the Transformers Primary is connected with the common supply and their Secondary are feeding to a common bus through which load is connected. Parallel operation of Transformers requires that their Primaries as well as Secondary's are connected in parallel.

PARALLEL OPERATION OF TRANSFORMERS

WHY PARALLEL OPERATION OF TRANSFORMERS IS REQUIRED

It is economical to installed numbers of smaller rated **transformers in parallel** than installing a bigger rated electrical power transformers. This has mainly the following advantages

1. To maximize electrical power system efficiency:

Generally electrical power transformer gives the maximum efficiency at full load. If we run numbers of **transformers in parallel**, we can switch on only those transformers which will give the total demand by running nearer to its full load rating for that time. When load increases, we can switch none by one other transformer connected in parallel to fulfill the total demand. In this way we can run the system with maximum efficiency.

2. To maximize electrical power system availability:

If numbers of transformers run in parallel, we can shutdown any one of them for maintenance purpose. Other **parallel transformers** in system will serve the load without total interruption of power.

3. To maximize power system reliability:

If any one of the transformers run in parallel, is tripped due to fault of other **parallel transformers** is the system will share the load, hence power supply may not be interrupted if the shared loads do not make other transformers over loaded.

PARALLEL OPERATION OF TRANSFORMERS

WHY PARALLEL OPERATION OF TRANSFORMERS IS REQUIRED

4. To maximize electrical power system flexibility:

There is always a chance of increasing or decreasing future demand of power system. If it is predicted that power demand will be increased in future, there must be a provision of connecting transformers in system in parallel to fulfill the extra demand because, it is not economical from business point of view to install a bigger rated single transformer by forecasting the increased future demand as it is unnecessary investment of money. Again if future demand is decreased, transformers running in parallel can be removed from system to balance the capital investment and its return.

5. When the load power is greater than the power handled by single transformer.

6. When expansion of the plant or additional load necessary, it is better to connect second transformer of suitable rating is in parallel with first transformer rather than using single transformer of higher capacity in the future.

7. Although the parallel operation is expansive but single transformer supply load when other transformer is in fault condition or take out of maintenance.

CONDITIONS FOR PARALLEL OPERATION OF SINGLE-PHASE TRANSFORMERS

NECESSARY CONDITIONS:

1. The transformers must have the same polarities.
2. The transformers should have equal turn ratios.

DESIRABLE CONDITIONS:

1. The voltages at full load across transformers internal impedance should be equal.

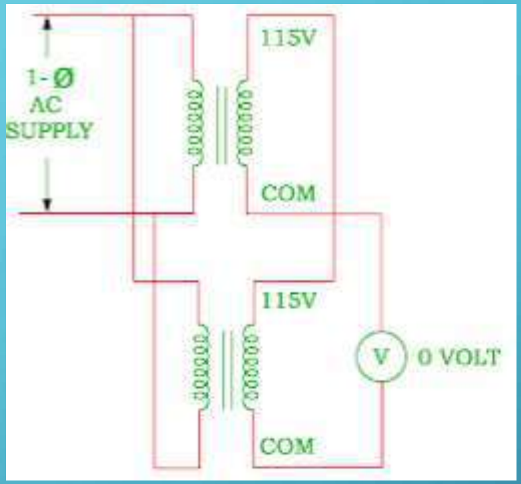
2. The ratios of their winding resistances to reactance's should be equal for both transformers. This condition ensures that both transformers operate at the same power factor, thus sharing active power and reactive volt-amperes according to their ratings.

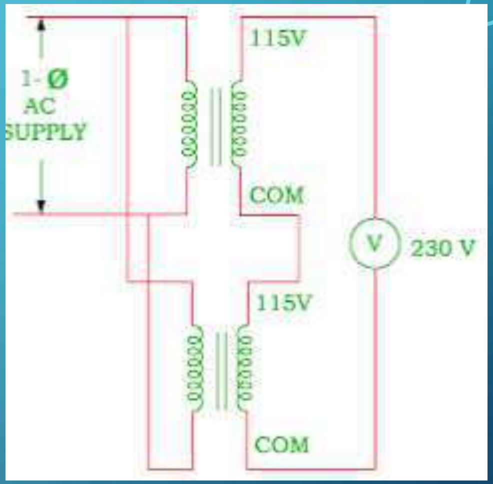
CONDITIONS FOR PARALLEL OPERATION OF SINGLE-PHASE TRANSFORMERS

1. THE POLARITY OF BOTH TRANSFORMERS MUST BE SAME

If the voltmeter indicates zero, it is **"Correct''** polarity.

If the voltmeter indicates double voltage that of secondary rated voltage of a transformer, it is **"Incorrect''** polarity.





2. THE TURNS - RATIO OF BOTH TRANSFORMERS ARE THE SAME

If the voltage ratio of the both transformer is not identical the secondary emf will induce resulting circulating current flow in the secondary circuit.
Therefore the primaries of the transformer will draw reflected secondary circulating current, in addition to the magnetizing current.
This additional current cause copper losses on both winding of the transformers.

CONDITIONS FOR PARALLEL OPERATION OF SINGLE-PHASE TRANSFORMERS

DISADVANTAGES OF TRANSFORMER PARALLEL OPERATION

1. Increasing short-circuit currents that increase necessary breaker capacity.

2. The risk of circulating currents running from one transformer to another transformer. Circulating currents that diminish load capability and increased losses.

3. The bus ratings could be too high.

4. Paralleling transformers reduce the transformer impedance significantly, i.e. the parallel transformers may have very low impedance, which creates the high short circuit currents. Therefore, some current limiters are needed, e.g. reactors, fuses, high impedance buses, etc

5. The control and protection of three units in parallel is more complex.

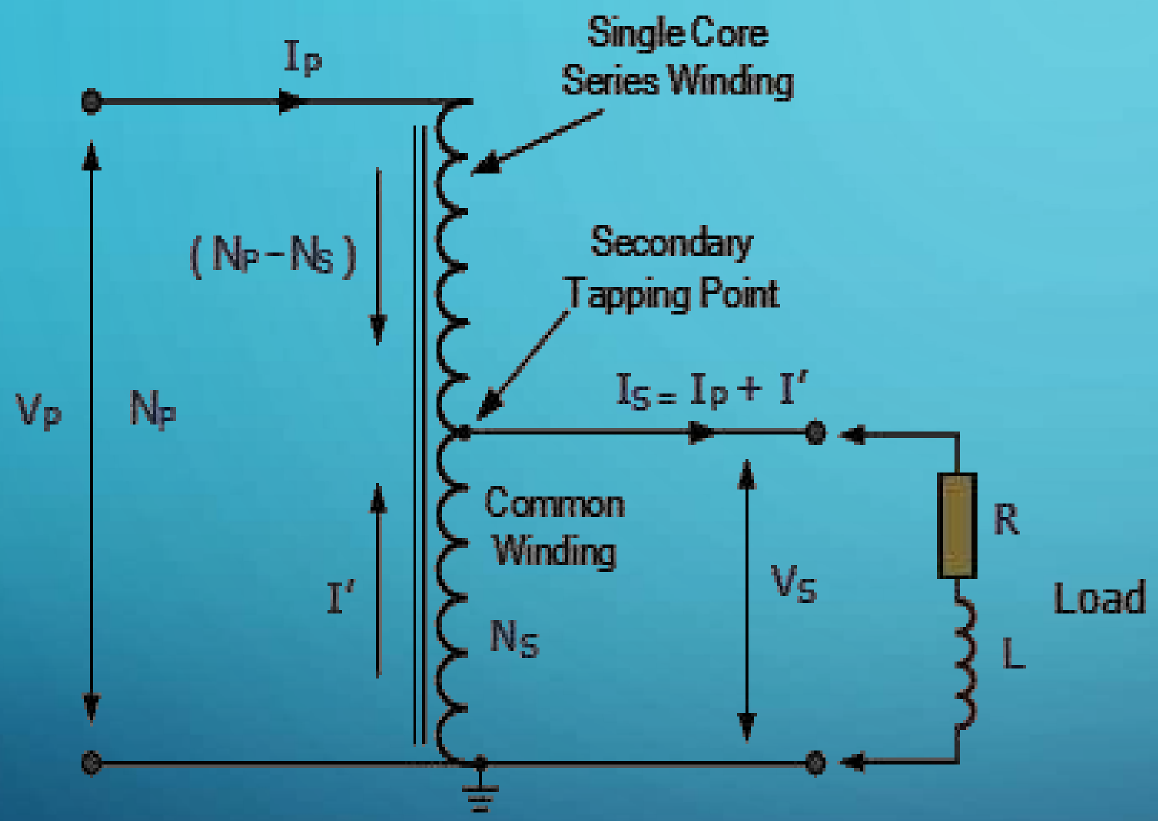
6. It is not a common practice in this industry.

AUTO TRANSFORMER

A transformer that has a single winding is known as an Auto Transformer. The term ‘auto’ is taken from a Greek word and the meaning of this is single coil works alone. The working principle of the autotransformer is similar to a 2-winding transformer but the only difference is, the portions of the single winding in this transformer will work at both sides of the windings like primary & secondary. In a normal transformer, it includes two separate windings that are not allied with each other.

Autotransformers are lighter, smaller, cheaper comparing with other transformers, but they will not provide electrical isolation between two windings.

AUTOTRANSFORMER DESIGN



When the primary current I_P is flowing through the single winding in the direction of the arrow as shown, the secondary current, I_S, flows in the opposite direction. Therefore, in the portion of the winding that generates the secondary voltage, V_S the current flowing out of the winding is the difference of I_P and I_S.

The **Autotransformer** can also be constructed with more than one single tapping point. Auto-transformers can be used to provide different voltage points along its winding or increase its supply voltage with respect to its supply voltage V_P

AUTO TRANSFORMER

Advantages of Auto Transformer

1. It uses single winding, so these are smaller & cost-effective.

2. These transformers are more efficient

3. It needs lesser excitation currents to compare with the conventional type transformers.

4. In these transformers, the voltage can be changed easily and smoothly

5. Enhanced regulation

6. Fewer losses

7. It needs less copper

8. Efficiency is high due to low losses in ohmic and core. These losses will be occurred because of the reduction in transformer material.

Disadvantages of Auto Transformer

1. In this transformer, the secondary winding cannot be insulated from the primary.

2. It is applicable in restricted areas where a small difference in the o/p voltage from i/p voltage is necessary.

3. This transformer is not used for interconnecting systems like high voltage & low voltage.

4. The leakage flux is small among the two windings so the impedance will below.

5. If the winding in the transformer breaks, the transformer will not work then the full primary voltage comes into view across the o/p.

6. It can be dangerous to the load while we are utilizing an autotransformer like a step-down transformer. So this transformer is used only to make small changes within the o/p voltage.

AUTO TRANSFORMER

APPLICATIONS OF AUTO TRANSFORMER

1. It increases the voltage drop for the distribution cable
2. It is used as a voltage regulator
3. It is used in audio, distribution, power transmission and railways
4. Autotransformer with several tapping's is used to start the motors like induction as well as synchronous.
5. It is used in laboratories to obtain a varying voltage continuously.
6. It is used like regulating transformers in voltage stabilizers.
7. It increases the voltage in AC feeders
8. It is applicable in electronics testing centers wherever frequently changing voltages are required.
9. It is used where high voltages are necessary like boosters or amplifiers
10. It is used in audio devices like speakers to match the impedance as well as to adjust the device for nonstop voltage supply.
11. It is used in power stations where the voltage needs to step down and step up to equal the voltage at the receiving end which is necessary for the device.

MODULE:4

SINGLE PHASE TRANSFORMER

TOPIC:

- COPPER USED IN A AUTOTRANSFORMER AND A TWO-WINDING TRANSFORMER

- TRANSFORMER TAP CHANGING
  - TWO WINDING TRANSFORMER
  - AUTOTRANSFORMER

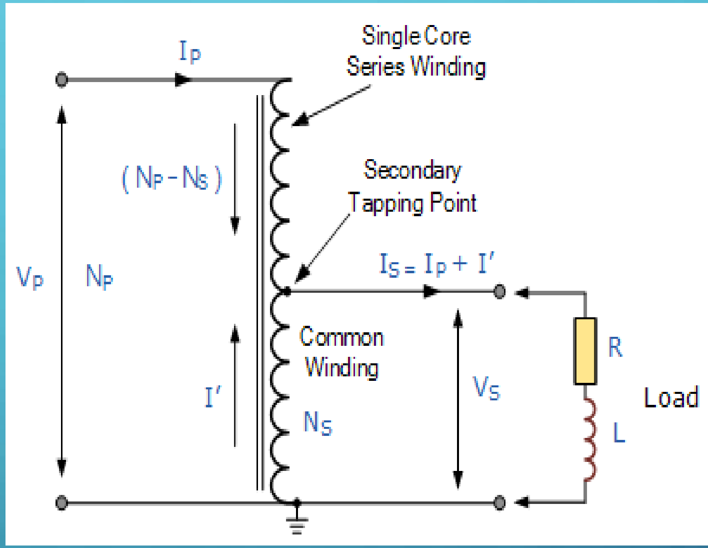
- PROBLEM SOLVING

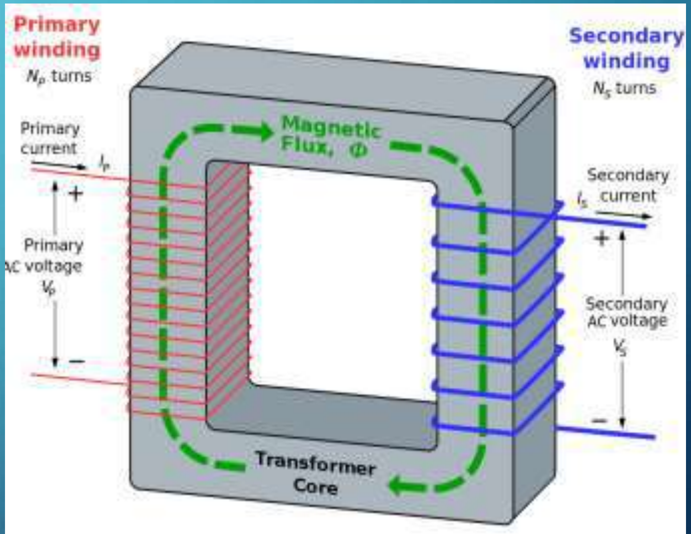
AUTO TRANSFORMER

COMPARISON BETWEEN COPPER USED IN AN AUTOTRANSFORMER AND A TWO-WINDING TRANSFORMER OF THE SAME RATING

In **two winding transformer**, whole power is transferred from primary to secondary side by means of induction ONLY While, in the case of **Auto transformer**, part of the whole power is transferred by induction and rest of the power is transferred through conduction.

In **two-winding transformers**, primary and secondary windings are wounded on separate limbs or interleaved means one winding over the other one concentrically and insulation is retained in between). So, fundamentally both the windings are isolated from each other electrically and connected ONLY magnetically by means of flux. So whatever power is transferred to secondary side is through induction ONLY (induced emf in secondary winding).





In the case of **Autotransformer**, there exists ONLY one winding, part of which is common between primary and secondary. That means by this mutual winding both primary and secondary windings are linked electrically and hence the power transferred because of this common winding, is essentially by conduction. The power transferred, because of winding which is not mutual (common) between primary and secondary, is by induction.

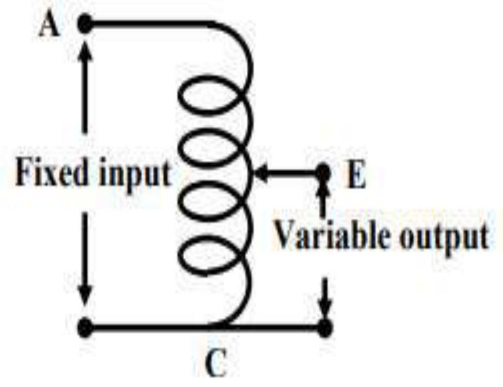
AUTO TRANSFORMER

COMPARISON BETWEEN COPPER USED IN AN AUTOTRANSFORMER AND A TWO-WINDING TRANSFORMER OF THE SAME RATING

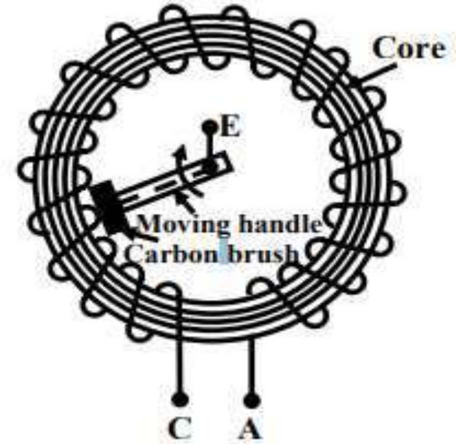
In autotransformer, the copper savings compared to conventional two winding transformers can be discussed. In the above winding, the weight of copper mainly depends on its length as well as the cross-sectional area.

Again conductor's length within the winding can be proportional to the no. of turns as well as cross-sectional area changes with the rated current. So copper weight within the winding can be directly proportional to the product of no. of turns & rated current of the winding.

In this aspect let us compare the two types of transformers in equal terms. Let,



Input voltage = V1
Output voltage required across the load = V2
Rated current to be supplied to the load = I2
Current drawn from the supply at rated condition = I1
KVA to be handled by both types of transformers = V1I1 = V2I2



Primary number of turns = N1
Secondary number of turns = N2

For the autotransformer:

Number of turns between A & C = N1
Number of turns between E & C = N2
Therefore, number of turns between A & E = N1 – N2

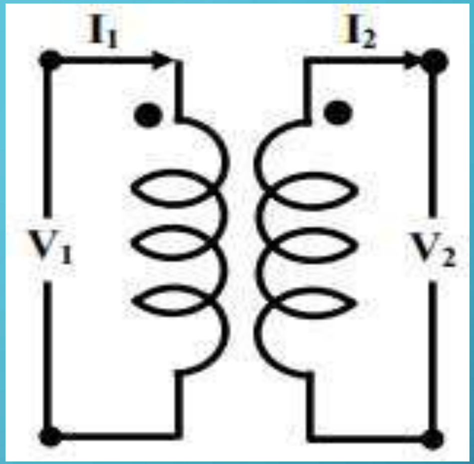
AUTO TRANSFORMER

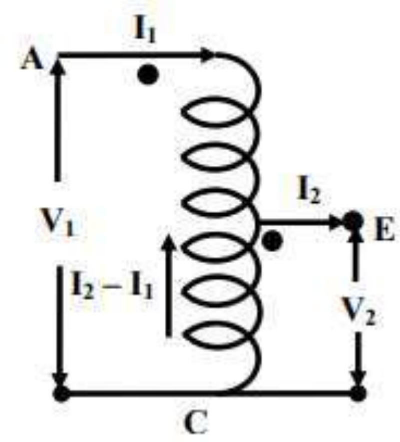
COMPARISON BETWEEN COPPER USED IN AN AUTOTRANSFORMER AND A TWO-WINDING TRANSFORMER OF THE SAME RATING

Let us now right down the mmf balance equation of the transformers.

For the two winding transformer:
MMF balance equation is N1I1 = N2I2

For the autotransformer: MMF balance equation is (N1 – N2)I1 = N2(I2 – I1)
or, N1I1 = N2I2





Volume of copper ∝ length of the wire × cross sectional area of copper wire ∝ N × I

$$\frac{\text{Amount of copper required in an autotransformer}}{\text{Amount of copper required in a two winding transformer}} = \frac{(N_1 - N_2)I_1 + N_2(I_2 - I_1)}{N_1 I_1 + N_2 I_2}$$

$$\text{Noting that } N_1 I_1 = N_2 I_2 = \frac{2N_1 I_1 - 2N_2 I_1}{2N_1 I_1}$$

$$= \frac{N_1 - N_2}{N_1}$$

$$= 1 - \frac{1}{a} \text{ where, } a \text{ is the turns ratio.}$$

AUTO TRANSFORMER

COMPARISON BETWEEN COPPER USED IN AN AUTOTRANSFORMER AND A TWO-WINDING TRANSFORMER OF THE SAME RATING

$$\frac{\text{Amount of copper required in an autotransformer}}{\text{Amount of copper required in a two winding transformer}} = 1 - \frac{1}{a}$$ where, a is the turns ratio.

Here we have assumed that N1 is greater than N2 i.e., a is greater than 1. The savings will of course be appreciable if the value of a is close to unity. For example if a = 1.2, copper required for autotransformer will be only 17% compared to a two winding transformer, i.e, saving will be about 83%. On the other hand, if a = 2, savings will be only 50%. Therefore, it is always economical to employ autotransformer where the voltage ratio change is close to unity. In fact autotransformers could be used with advantage, to connect two power systems of voltages say 11 kV and 15 kV.

If, for example, the ratio of the primary to secondary voltage of an autotransformer is 100: 50, then the above ratio would be (2-1)/2=1/2. Thus the saving in copper by using an autotransformer would be 50%

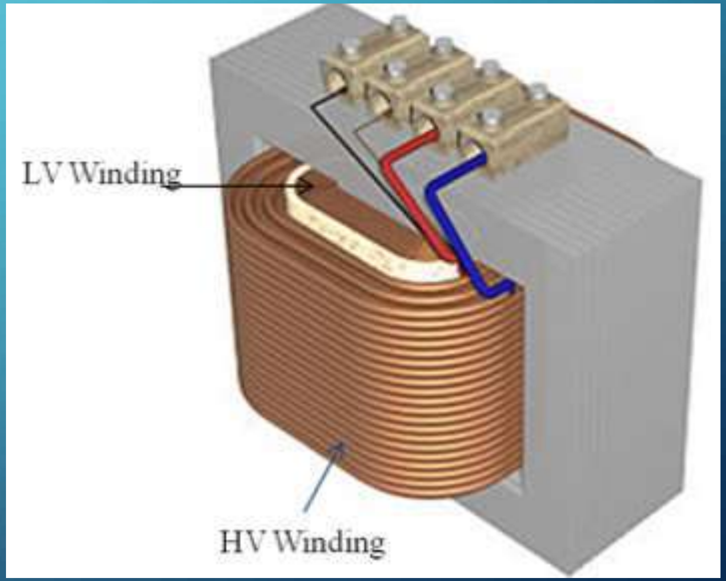
TAP-CHANGING TRANSFORMERS

The change of voltage is affected by changing the numbers of turns of the transformer provided with taps. For sufficiently close control of voltage, taps are usually provided on the high voltage windings of the transformer. There are two types of tap-changing transformers

The transformer voltage at the load side desired to be constant or as close to the design value. But the load voltage may vary according to current drawn by the load or supply voltage.

Secondary voltage = (supply voltage or primary voltage) / Turns ratio.

Based on the above equation to maintain constant secondary voltage/load voltage or as close to the desired value it is needed to change the turn's ratio. The tap changer of the transformer performs this task to change the turn's ratio. The tap changer basic function is that it removes or connects some portion of the winding to the load side or source side. Tap changer can be located on primary side or secondary side. However it will be placed on high voltage winding side.



TAP-CHANGING TRANSFORMERS

Need for system voltage control

System voltage control is essential for:

1. Adjusting the terminal voltage of consumer within the prescribed limits.

2. Adjustment of voltage based on change in load.

3. In order to control the real and reactive power.

4. For varying the secondary voltage based on the requirement.

Types of taps

Taps may be principal, positive or negative. Principal tap is one at which rated secondary voltage can be obtained for the rated primary voltage. As the name states positive and negative taps are those at which secondary voltage is more or less than the principle tap.

Taps are provided at the HV windings of the transformer because of the following reasons.
Taps are provided at the HV windings of the transformer because of the following reasons.

1. The number of turns in the High voltage winging is large and hence a fine voltage variation can be obtained.

2. The current on the low voltage winding of large transformers are high. Therefore interruption of high currents is a difficult task.

3. LV winding is placed nearer to the core and HV winding is placed outside. Therefore providing taps on the HV winding is comparatively easier than that of the LV winding.

TAP-CHANGING TRANSFORMERS

Location of Taps

The taps can be provided at the phase ends, at the neutral point, or in the middle of the winding. The number of bushing insulators can be reduced by providing taps at the phase ends. When the taps are provided at the neutral point the insulation between various parts will be reduced. This arrangement is economical particularly important for the large transformer.

Tap changing methods

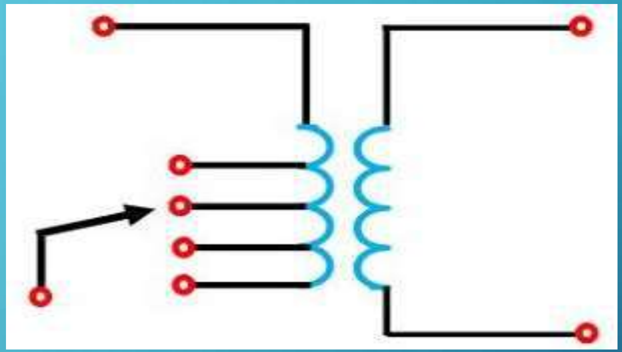
Tap changing causes change in leakage reactance, core loss, copper loss and perhaps some problems in the parallel operation of dissimilar transformer. There are two methods of tap changing.

1. Off load tap changing
2. On load tap changing

TAP-CHANGING TRANSFORMERS

1. OFF LOAD (NO LOAD OR OFF CIRCUIT) TAP CHANGING

As the name indicates, in this method tap changing is done after disconnecting the load from the transformer. Off load tap changing is normally provided in low power, low voltage transformers. It is the cheapest method of tap changing. The tap changing is done manually though hand wheel provided in the cover. In some transformers arrangements to change the taps by simply operating the mechanical switches are also provided.



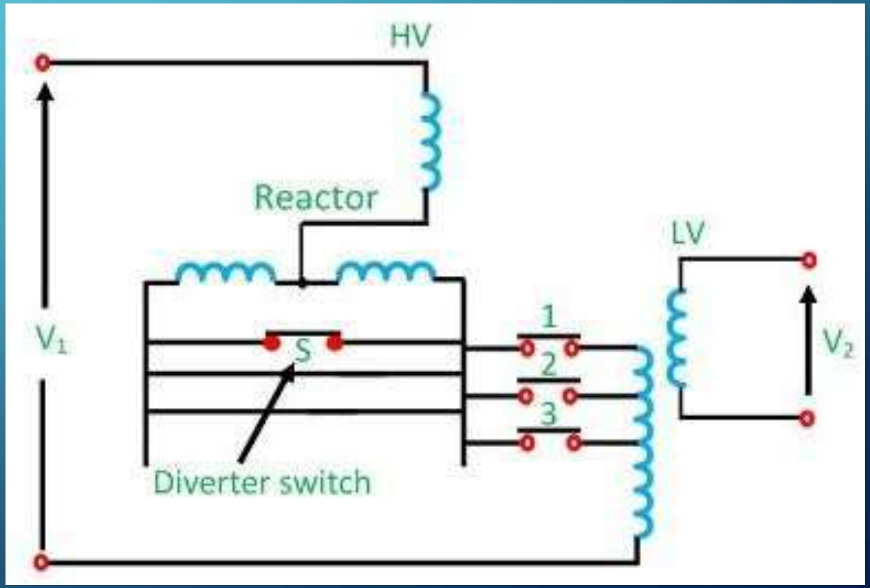
The winding is tapped at various points. Since the taps are provided at various points in the winding single tap must be connected at a time otherwise it will lead to short circuit. Hence the selector switch is operated after disconnecting the load. To prevent unauthorized operation of an off load tap changer, mechanical lock is provided. To prevent inadvertent operation, electromechanical latching devices are provided to operate the circuit breakers and de-energize the transformer as soon as the tap changer handle is moved.

TAP-CHANGING TRANSFORMERS

2. ON LOAD TAP CHANGING

On load tap changers are used to change the turns ratio without disconnecting the load from it. Tap changing can be done even when the transformer is delivering load. On load tap changers considerable increases the efficiency of the system. Nowadays almost all the large power transformers are provided with on load tap changers. The reason for providing On load tap changer in power transformers are1. During the operation of on load tap changers the main circuit remains unaffected.2. Dangerous sparking is prevented. The taps on the windings are brought to a separate oil filled compartment in which the on load tap changer switch is housed. The tap changer is a form of mechanical selector switch which is operated by a motor by local or remote control.

A handle fitted for manual operation in case of emergency. The selector switch is a form of make before break switch and during the transition of the tap changers from one tap to another, momentary connection must be made between the adjacent taps. This results in short circuit between the adjacent taps. The short circuit current must be limited by including resistor or reactor. Hence all forms of on load tap changer are provided with an impedance to limit short circuit current during tap changing operation. The impedance may be resistance or a center tapped reactance. In modern designs it is invariably carried out by a pair of resistors.



TAP-CHANGING TRANSFORMERS

Consider a high speed resistor type on load tap changers provided at neutral end of each phase as shown. The load is now supplied from the tap 1. The selector switches 1 and 2 are in contact with the taps 1 and 2. Now to switch over to the tap 2, the selector switch follows the following steps:

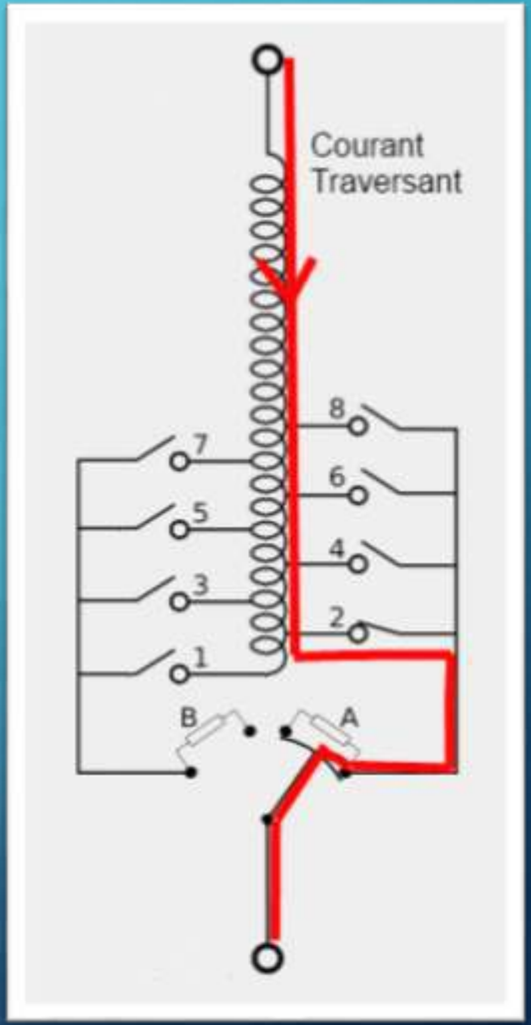
1. Contacts a and b are closed. The load current flows from tap 1 through contact b.

2. The external mechanism moves the diverter switch S3 from b, now load is supplied from contact a through resistor R_1.

3. When diverter switch moves further it closes the contact d and both R1 and R2 are connected across taps 1 and 2 and the load current flows through these resistances to its mid point.

4. When S_3 moves further to the left, contact a is opened and the load current flows from tap 2 through resistor R_2 and d.

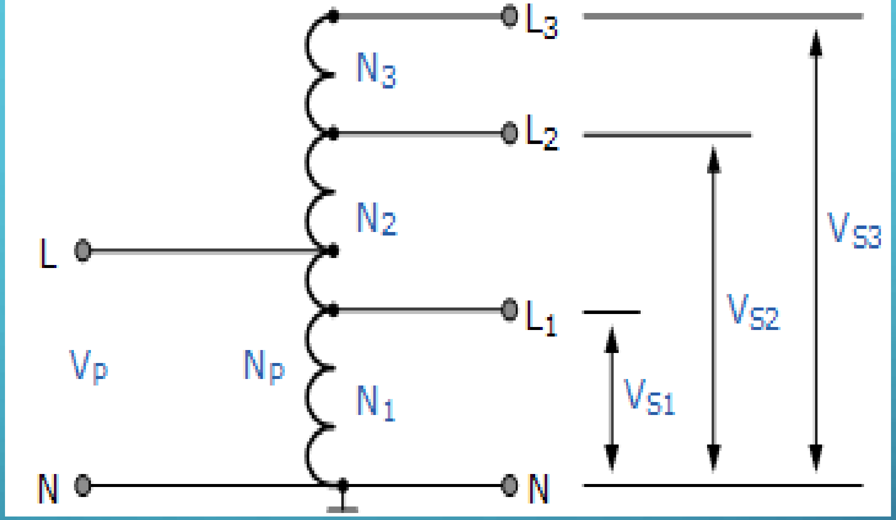
5. Finally the contact reaches the contact c and resistor R_2 is short circuited. The load current flows from tap $_2$ through contact c.



TAP-CHANGING TRANSFORMERS

AUTOTRANSFORMER WITH MULTIPLE TAPPING POINTS

The **Autotransformer** can also be constructed with more than one single tapping point. Auto-transformers can be used to provide different voltage points along its winding or increase its supply voltage with respect to its supply voltage V_P as shown.



The standard method for marking an auto-transformer windings is to label it with capital (upper case) letters. So for example, A, B, Z etc to identify the supply end. Generally the common neutral connection is marked as N or n. For the secondary tapping's, suffix numbers are used for all tapping points along the auto-transformers primary winding. These numbers generally start at number "1" and continue in ascending order for all tapping points

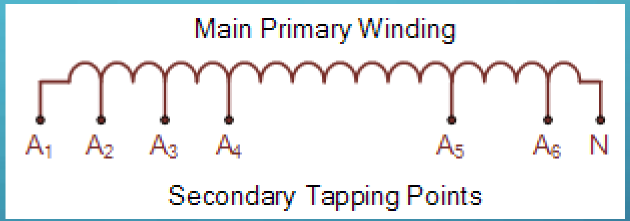
TAP-CHANGING TRANSFORMERS

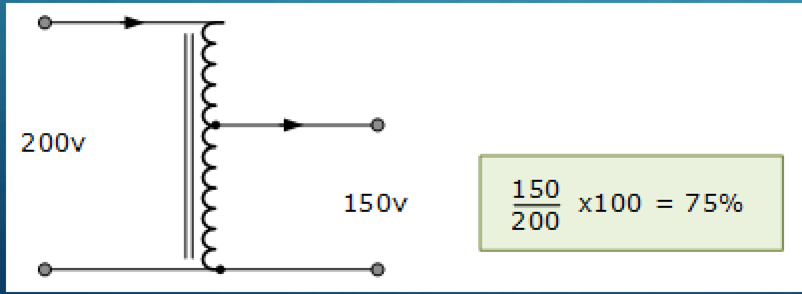
AUTOTRANSFORMER TERMINAL MARKINGS

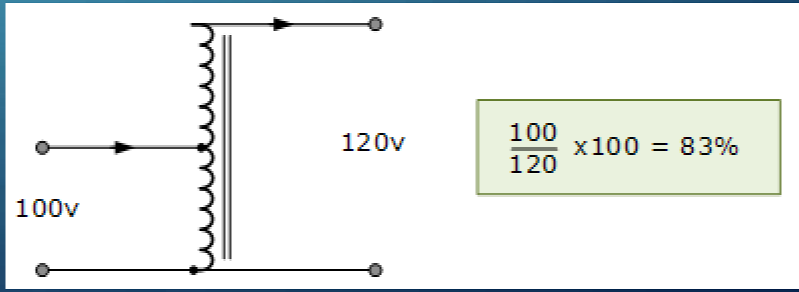
An autotransformer is used mainly for the adjustments of line voltages to either change its value or to keep it constant. If the voltage adjustment is by a small amount, either up or down, then the transformer ratio is small as V_P and V_S are nearly equal. Currents I_P and I_S are also nearly equal.

Therefore, the portion of the winding which carries the difference between the two currents can be made from a much smaller conductor size, since the currents are much smaller saving on the cost of an equivalent double wound transformer.

However, the regulation, leakage inductance and physical size (since there is no second winding) of an autotransformer for a given VA or KVA rating are less than for a double wound transformer.







PROBLEM SOLVING

PROBLEM:01 A 100 kVA distribution transformer supplying light and fan loads has full-load copper-loss and core-loss of 1.5 and 2 kW respectively. During 24 h in a day the transformer is loaded as follows:

6 AM to 10 AM (4h) Half-load
10 AM to 06 PM (8h) One-fourth load
6 PM to 10 PM (4h) Full-load
10 PM to 6 AM (8h) Negligible load
Calculate the all-day efficiency of the transformer.

SOLUTION:

Full-load core-loss = 2.0 kW

This core-loss is constant for any load.

Total core-loss for 24 h = 2.0 × 24 = 48 kWh

Full-load copper-loss = 1.5 kW

Copper-loss is proportional to the square of the load, i.e. if copper-loss at full-load is x, copper-loss at half-load will be 1/4 x. Thus,

$$\text{Copper-loss from 6 AM to 10 AM} = \frac{1.5}{4} \times 4 = 1.5 \text{ kWh}$$

$$\text{Copper-loss from 10 AM to 6 PM} = \frac{1.5}{16} \times 8 = 0.75 \text{ kWh}$$

$$\text{Copper-loss from 6 PM to 10 PM} = 1.5 \times 4 = 6.0 \text{ kWh}$$

Copper-loss from 10 PM to 6 AM = Negligible

$$\text{Total copper-loss for 24 h} = 1.5 + 0.75 + 6.0 = 8.25 \text{ kWh}$$

$$\text{Output for 24 h} = 50 \times 4 + 25 \times 8 + 100 \times 4 + 0 = 800 \text{ kWh}$$

(load is considered of unity power-factor)

Thus,

$$\text{All-day efficiency} = \frac{\text{Output in kWh for 24 h}}{\text{Input in kWh for 24 h}} \times 100$$

$$= \frac{\text{Output in kWh for 24 h} \times 100}{\text{Output in kWh for 24 h} + \text{losses in 24 h}}$$

$$= \frac{800}{800 + 48 + 8.25} \times 100 = 93.4\%$$

PROBLEM SOLVING

PROBLEM:02 The primary and secondary voltages of an autotransformer are 230V and 75V respectively. Calculate the currents in different parts of the winding when the load current is 200 A. Also calculate the saving In the use of copper.

SOLUTION:

$$I_2 N_s = I_1 N_p$$

$$I_1 = I_2 \frac{N_s}{N_p} = I_2 \frac{V_s}{V_p} = 200 \times \left[\frac{75}{230}\right]$$

Primary current, $I_1 = 65.2$ A

Load current, $I_2 = 200$ A

Current flowing through the common portion of the winding $= I_2 - I_1 = 200 - 65.2$

$= 134.8$ A

Let weight of copper required in a two-winding transformer $= W_{TW}$ and weight of copper required in an auto transformer $= W_a$

Economy in saving in copper in percentage $= \frac{W_{TW} - W_a}{W_{TW}}$

$$= \left[1 - \frac{W_{TW}}{W_a}\right] \times 100$$

$$= \left[1 - \left(1 - \frac{N_s}{N_p}\right)\right] \times 100$$

$$= \frac{N_s}{N_p} \times 100$$

$$= \frac{V_s}{V_p} \times 100 = \frac{75 \times 100}{230}$$

$= 32.6\%$

MODULE:4

SINGLE PHASE TRANSFORMER

TOPIC:

- COMPARISON BETWEEN AUTO-TRANSFORMER & TWO WINDING TRANSFORMER
- TRANSFORMER TESTING
- TRANSFORMER NAME PLATE DETAILS

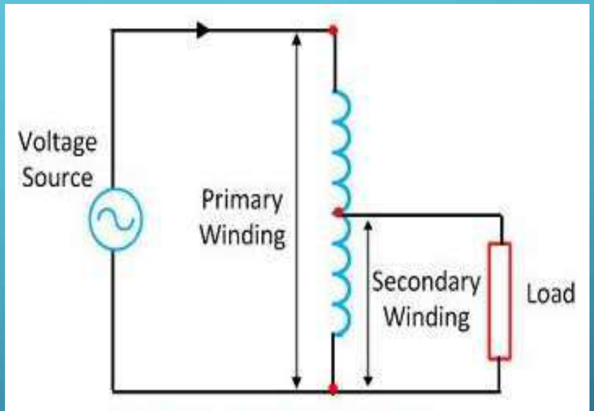
COMPARE AUTO TRANSFORMER WITH TWO WINDING TRANSFORMER

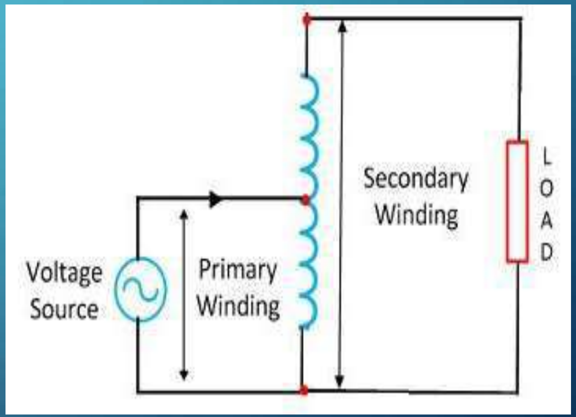
There are several differences between the autotransformer and the conventional transformer. One of the major difference between them is that the autotransformer has only one winding whereas the conventional transformer has two separate windings. The other differences between them are explained below

A transformer, having only one winding a part of which acts as a primary winding and the other as secondary is called an autotransformer. The windings of the autotransformer are connected magnetically and electrically.

When the primary voltage is greater than the secondary voltage, then the transformer is called step down autotransformer, and when the primary voltage is smaller than secondary, then it is called step-up auto-transformer.

The autotransformer has a low cost, better regulation and low losses. The disadvantage of the autotransformer is that the primary winding of the auto-transformer is not insulated from the secondary. Thus, if the low voltage is supplied from the high voltage, then the full voltage came across the secondary terminal which is dangerous for the load and operator.

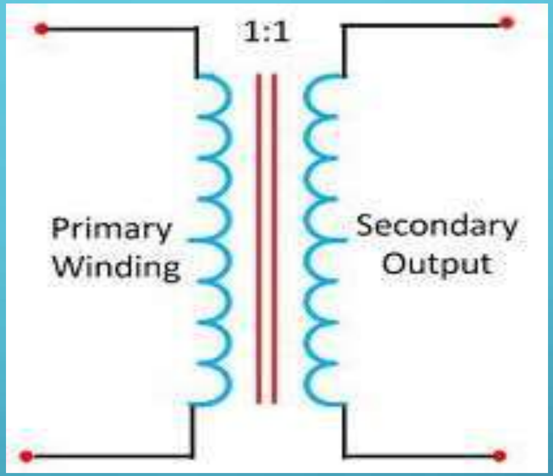




The auto-transformer is not used for interconnecting the high voltage and low voltage system. It is used in the places where slight variation is required

COMPARE AUTO TRANSFORMER WITH TWO WINDING TRANSFORMER

A conventional transformer is a static device which transfers electrical energy from one circuit to another at the same frequency but different voltage. It works on the principle of electromagnetic induction, i.e., the electromotive force is induced in the closed circuit due to the variable magnetic field around it. The windings of the conventional transformer are electrically insulated, but magnetically connected.



The conventional transformer has two windings. i.e., the primary winding and the secondary winding. The primary winding takes the input from the supply, and the secondary winding is connected to a load and supply energy to the load.

When the output voltage of the transformer is greater than the input voltage, then such type of transformers is called step up transformer, and when the output voltage is less than the input voltage, then it is called a step-down transformer. A transformer in which receiving voltage and the sending voltage is same, then such type of transformer is called one to one transformer.

BASIS FOR DIFFERENCES	AUTOTRANSFORMER	CONVENTIONAL TRANSFORMER
Definition	A transformer, having only one winding a part of which acts as a primary and the other as a secondary.	It is a static machine which transfers electrical energy from one end to another without changing frequency.
Number of Windings	Auto-transformer has only one winding wound on a laminated core	It has two separate winding, i.e., primary and secondary winding.
Insulation	The primary and secondary winding are not electrically insulated.	The primary and secondary winding are electrically insulated from each other.
Induction	Self Induction	Mutual Induction
Size	Small	Large
Power Transfer	Partly by transformation and partly by direct electrical connection.	Through transformation
Voltage Regulation	Better	Good
Winding Material	Less requires	More requires
Circuit	The primary and secondary winding circuits are connected magnetically.	The primary and secondary winding circuits are connected both electrically and magnetically.
Connection	Depends upon the tapping	Connect directly to the load.
Starting current	Decreases	Decreases by 1/3 times.
Excitation current	Small	Large
Economical	More	Less
Cost	Less costly	More costly
Efficient	More	Less
Leakage flux and resistance	Low	High
Impedance	Less	High
Cost	Cheap	Very costly
Losses	Low	High
Output voltage	Variable	Constant.
Applications	Use as a starter in an induction motor, as a voltage regulator, in railways, in a laboratory.	Use in power system for step up and step down the voltage.

TRANSFORMER TESTING

For confirming the specifications and performances of an electrical power transformer it has to go through a number of testing procedures. Some tests are done at a transformer manufacturer premises before delivering the transformer.

Transformer manufacturers perform two main types of **transformer testing** – **type test of transformer** and **routine test of transformer**.

Type of Transformer Testing

1. Tests done at factory

   a. Type tests
   b. Routine tests
   c. Special tests

2. Tests done at site

   a. Pre-commissioning tests
   b. Periodic/condition monitoring tests
   c. Emergency tests

TRANSFORMER TESTING

Type Test of Transformer

To prove that the transformer meets customer's specifications and design expectations, the transformer has to go through different testing procedures in manufacturer premises. Some transformer tests are carried out for confirming the basic design expectation of that transformer. These tests are done mainly in a prototype unit not in all manufactured units in a lot. **Type test of transformer** confirms main and basic design criteria of a production lot.

1. Routine Tests of Transformer

Routine tests of transformer is mainly for confirming the operational performance of the individual unit in a production lot. Routine tests are carried out on every unit manufactured.

2. Special Tests of Transformer

Special tests of transformer is done as per customer requirement to obtain information useful to the user during operation or maintenance of the transformer.

3. Pre Commissioning Test of Transformer

In addition to these, the transformer also goes through some other tests, performed on it, before actual commissioning of the transformer at the site. The transformer testing performed before commissioning the transformer at the site is called the pre-commissioning test of transformer. These tests are done to assess the condition of transformer after installation and compare the test results of all the low voltage tests with the factory test reports.

TRANSFORMER TESTING

Type tests of transformer include:

1. Winding resistance test of transformer
2. Transformer ratio test
3. Transformer vector group test
4. Measurement of impedance voltage/short circuit impedance (principal tap) and load loss (Short circuit test)
5. Measurement of no-load loss and current (Open circuit test)
6. Measurement of insulation resistance
7. Dielectric tests of transformer
8. Temperature rise test of transformer
9. Tests on on-load tap-changer
10. Vacuum tests on tank and radiators

TRANSFORMER TESTING

Routine tests of transformer include

1. Winding resistance test of transformer
2. Transformer ratio test
3. Transformer vector group test
4. Measurement of impedance voltage/short circuit impedance (principal tap) and load loss (Short circuit test)
5. Measurement of no load loss and current (Open circuit test)
6. Measurement of insulation resistance
7. Dielectric tests of transformer.
8. Tests on on-load tap-changer.
9. Oil pressure test on transformer to check against leakages past joints and gaskets

That means Routine tests of transformer include all the type tests except temperature rise and vacuum tests. The oil pressure test on transformer to check against leakages past joints and gaskets is included.

TRANSFORMER TESTING

Special Tests of transformer include

1. Dielectric tests.
2. Measurement of zero-sequence impedance of three-phase transformers
3. Short-circuit test
4. Measurement of acoustic noise level
5. Measurement of the harmonics of the no-load current.
6. Measurement of the power taken by the fans and oil pumps.
7. Tests on bought out components / accessories such as buchholz relay, temperature indicators, pressure relief devices, oil preservation system etc.

TRANSFORMER TESTING

Transformer Winding Resistance Measurement

Transformer winding resistance measurement is carried out to calculate the I^2R losses and to calculate winding temperature at the end of a temperature rise test. It is carried out as a type test as well as routine test. It is also done at site to ensure healthiness of a transformer that is to check loose connections, broken strands of conductor, high contact resistance in tap changers, high voltage leads and bushings etc.

There are different methods for measuring of the transformer winding, likewise:

1. Current-voltage method of measurement of winding resistance.

2. Bridge method of measurement of winding resistance.

3. Kelvin bridge method of Measuring Winding Resistance.

4. Measuring winding resistance by Automatic Winding Resistance Measurement Kit.

TRANSFORMER TESTING

Transformer Ratio Test

The performance of a transformer largely depends upon perfection of specific turns or voltage ratio of transformer. So transformer ratio test is an essential **type test of transformer**. This test also performed as a routine test of transformer. So for ensuring proper performance of electrical power transformer, voltage and turn ratio test of transformer one of the important tests.

The procedure of the transformer ratio test is simple. We just apply three phase 415 V supply to HV winding, with keeping LV winding open. We measure the induced voltages at HV and LV terminals of the transformer to find out actual voltage ratio of the transformer. We repeat the test for all tap position separately.

Magnetizing Current Test of Transformer

Magnetizing current test of transformer is performed to locate defects in the magnetic core structure, shifting of windings, failure in between turn insulation or problem in tap changers. These conditions change the effective reluctance of the magnetic circuit, thus affecting the current required to establish flux in the core.

TRANSFORMER TESTING

Insulation Resistance Test or Megger Test of Transformer

Insulation resistance test of transformer is essential type test. This test is carried out to ensure the healthiness of the overall insulation system of an electrical power transformer.

1. Disconnect all the line and neutral terminals of the transformer
2. Megger leads to be connected to LV and HV bushing studs to measure insulation resistance IR value in between the LV and HV windings
3. Megger leads to be connected to HV bushing studs and transformer tank earth point to measure insulation resistance IR value in between the HV windings and earth
4. Megger leads to be connected to LV bushing studs and transformer tank earth point to measure insulation resistance IR value in between the LV windings and earth

Dielectric Tests of Transformer

Dielectric test of a transformer is one kind of insulation test. This test is performed to ensure the expected overall insulation strength of the transformer. There are several tests performed to ensure the required quality of transformer insulation; the dielectric test is one of them. Dielectric test of the transformer is performed in two different steps.

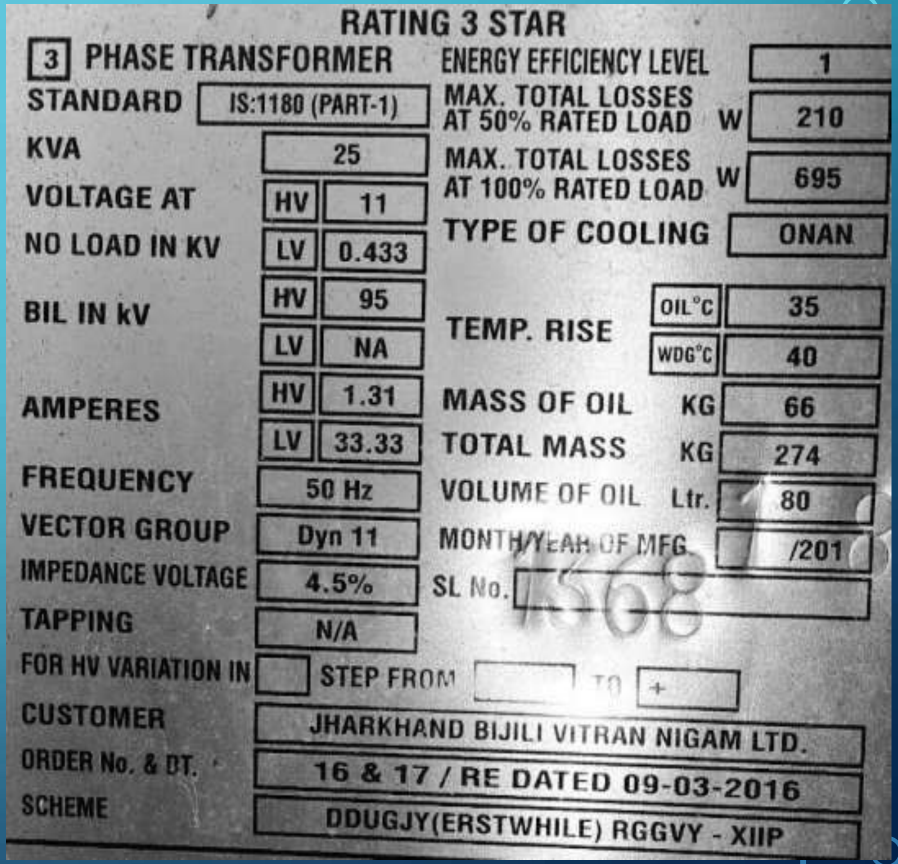
First one is called Separate Source Voltage Withstand Test of transformer, where a single phase power frequency voltage of prescribed level, is applied on transformer winding under test for 60 seconds while the other windings and tank are connected to the earth, and it is observed that whether any failure of insulation occurs or not during the test.

The second one is the induced voltage test of Transformer where, three-phase voltage, twice of rated secondary voltage is applied to the secondary winding for 60 seconds by keeping the primary of the transformer open circuited.

TRANSFORMER NAMEPLATE

Transformer nameplates contain several standard items of information and other optional information. Transformer nameplate must specify the following parameters:

1. Name of manufacturer
2. Serial number
3. year of manufacture
4. Number of phases
5. kVA or MVA rating
6. Frequency
7. Voltage ratings.
8. Tap voltages.
9. Connection diagram.
10. Cooling class
11. Rated temperature in °C
12. Polarity (for Single Phase Transformers)
13. % impedance.
14. Approximate mass or weight of the transformer
15. Type of insulating liquid.
16. Conductor material of each winding.
17. Oil volume (of each transformer Container/Compartment)
18. Instruction for Installation and Operation



TRANSFORMER NAMEPLATE

==

S.No. Description of Data to be given Ra-marks for example

==

[1] [2]

[3]==

1.	Manufacturer's Name:	ABB/206788
2.	Manufacture's Serial Number	224106
3.	Kind of Transformer	Power Transformer
4.	236839Relevent Standard Year	I.S/P.S/B.S/ IEC /DIS/JIS NEMA
5.	Year of Manufacture	2013
6.	Number of Phase	3
7.	Rated Power	1000kVA = 1MVA
8.	Rated Frequency:	50Hz
9.	Rated Voltages:	HV 33 kV, LV 11 kV,
10.	Rated Currents	HV_______,LV________.
11.	Vector Group Symbol	______________________
12	% Impedance Voltage (At Raed Current)	______________________
13.	% Reactance Voltage in % :	______________________
14.	Types of Cooling	ONAM
15	.Total Weight	____________Kg
	..Mass or insulating Oil	____________Kg
	..Transportation Weight	____________Kg
	..Untanking Weight	____________Kg
16.	Insulating liquid (if Not Oil) Types:	_________________
17.	Quantity of Oil (Liters):	____________
18.	Details about Tap-Changer	____________
19.	Rated insulation Level:	____________
	..Power-Frequency withstand Voltage	kV(rms)
20.	Other	....

PROBLEM SOLVING

PROBLEM:01 A 100 kVA distribution transformer supplying light and fan loads has full-load copper-loss and core-loss of 1.5 and 2 kW respectively. During 24 h in a day the transformer is loaded as follows:

6 AM to 10 AM (4h) Half-load

10 AM to 06 PM (8h) One-fourth load

6 PM to 10 PM (4h) Full-load

10 PM to 6 AM (8h) Negligible load

Calculate the all-day efficiency of the transformer.

SOLUTION:

$$\text{Full-load core-loss} = 2.0 \text{ kW}$$

This core-loss is constant for any load.

$$\text{Total core-loss for 24 h} = 2.0 \times 24 = 48 \text{ kWh}$$

$$\text{Full-load copper-loss} = 1.5 \text{ kW}$$

Copper-loss is proportional to the square of the load, i.e. if copper-loss at full-load is x, copper-loss at half-load will be $1/4\ x$. Thus,

$$\text{Copper-loss from 6 AM to 10 AM} = \frac{1.5}{4} \times 4 = 1.5 \text{ kWh}$$

$$\text{Copper-loss from 10 AM to 6 PM} = \frac{1.5}{16} \times 8 = 0.75 \text{ kWh}$$

$$\text{Copper-loss from 6 PM to 10 PM} = 1.5 \times 4 = 6.0 \text{ kWh}$$

$$\text{Copper-loss from 10 PM to 6 AM} = \text{Negligible}$$

$$\text{Total copper-loss for 24 h} = 1.5 + 0.75 + 6.0 = 8.25 \text{ kWh}$$

$$\text{Output for 24 h} = 50 \times 4 + 25 \times 8 + 100 \times 4 + 0 = 800 \text{ kWh}$$

(load is considered of unity power-factor)

Thus,

$$\text{All-day efficiency} = \frac{\text{Output in kWh for 24 h}}{\text{Input in kWh for 24 h}} \times 100$$

$$= \frac{\text{Output in kWh for 24 h} \times 100}{\text{Output in kWh for 24 h} + \text{losses in 24 h}}$$

$$= \frac{800}{800 + 48 + 8.25} \times 100 = 93.4\%$$

MODULE:4

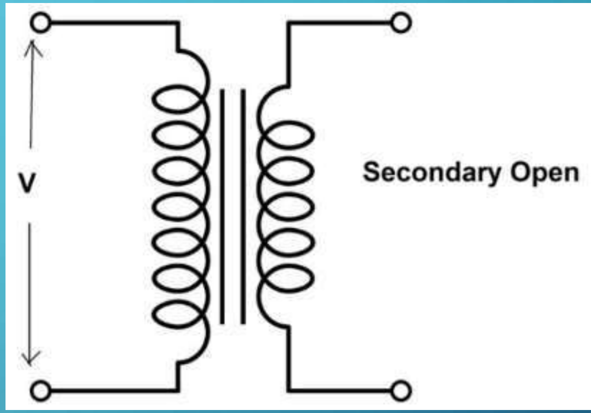
SINGLE PHASE TRANSFORMER

TOPIC:

- **PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER**
    - **NO-LOAD CONDITION**
    - **ON-LOAD CONDITION**
        - **INDUCTIVE LOAD**
        - **CAPACITIVE LOAD**
        - **RESISTIVE LOAD**

PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

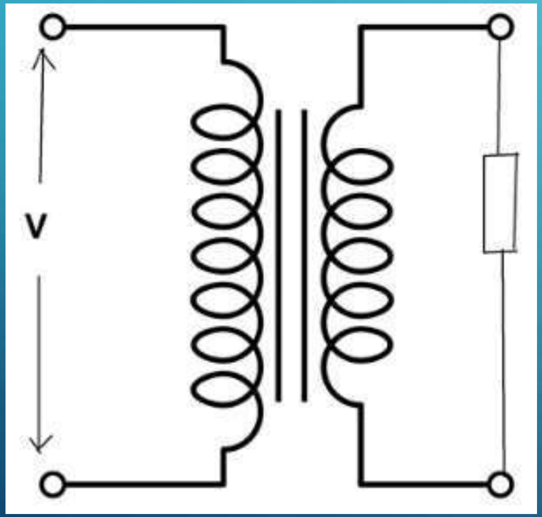
we have assumed that the transformer is ideal, that is one in which there are no core losses or copper losses in the transformers windings. However, in real world transformers there will always be losses associated with the transformers loading as the transformer is put "on-load"



According to the transformer loading, single phase transformer associated with:

1. Single phase transformer NO-LOAD Condition.

1. Single phase transformer ON-LOAD Condition.



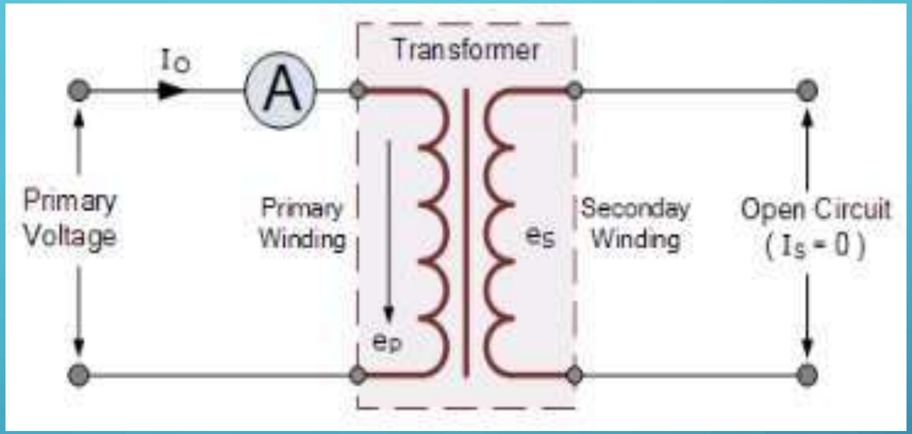
A transformer when it is in this "no-load" condition, that is with no electrical load connected to its secondary winding and therefore no secondary current flowing. A transformer is said to be on "no-load" when its secondary side winding is open circuited, in other words, nothing is attached and the transformer loading is zero.

When the transformer is on the loaded condition, the secondary of the transformer is connected to load. The load can be resistive, inductive or capacitive. The current I_2 flows through the secondary winding of the transformer. The magnitude of the secondary current depends on the terminal voltage V_2 and the load impedance. The phase angle between the secondary current and voltage depends on the nature of the load.

PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

TRANSFORMER “NO-LOAD” CONDITION

When the transformer is operating at no load, the secondary winding is open-circuited, which means there is no load on the secondary side of the transformer and, therefore, current in the secondary will be zero. While primary winding carries a small current I_0 called no-load current which is **2 to 10% of the rated current**.



With the secondary circuit open, nothing connected, a back EMF along with the primary winding resistance acts to limit the flow of this primary current. Obviously, this no-load primary current (Io) must be sufficient to maintain enough magnetic field to produce the required back emf.

This current is responsible for supplying the iron losses (hysteresis and eddy current losses) in the core and a very small amount of copper losses in the primary winding. The angle of lag depends upon the losses in the transformer. The power factor is very low and varies from **0.1 to 0.15**.

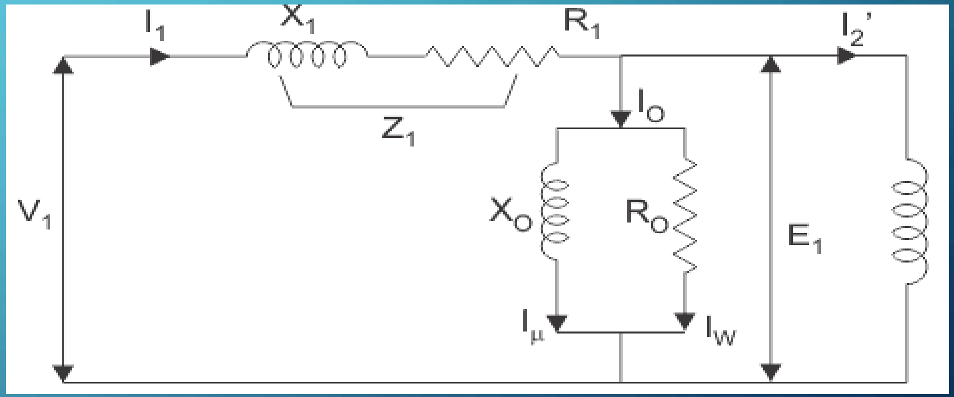
PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

TRANSFORMER "NO-LOAD" CONDITION

No load Transformer means a transformer which has no load connection at secondary winding only normal voltage is applied at the primary winding. Let V_1 is applied at the primary winding. After applying A.C voltage V_1, it is seen that small amount of current I_0 flows through the primary winding. In case of Ideal Transformer, no load primary current (I_0) will be equal to magnetizing current (I_μ) of the transformer. We assumed there is no core losses and copper loss, So $I_0 = I_\mu$. But, in case of actual transformer, there is two losses, i.e i) Iron Losses in the core i.e hysteresis loss and eddy current loss , ii) and a very small amount copper loss in the primary winding.

So, the primary current I_0 has two components:

1. I_w = Iron loss component which is same ph of applied voltage V_1.
2. I_μ = magnetizing component which is 90^o behind V_1.



MAGNETIZING COMPONENT (I_M) :

This component is known as magnetizing component, because it is actually use to magnetize the core of the transformer. We can also say that, $\mathbf{I_\mu}$ is used to set up flux(ϕ_M) in the core. Now, as the flux ϕ_M is developed by the $\mathbf{I_\mu}$, so they both will be in phase to each other as shown in the phasor diagram below.

This current $\mathbf{I_\mu}$ is also called **reactive** or **wattles** component of no-load current, because this component does not consume active power. **It is not responsible for any losses in the circuit**.

PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

TRANSFORMER "NO-LOAD" CONDITION

WORKING COMPONENT (I_W) :

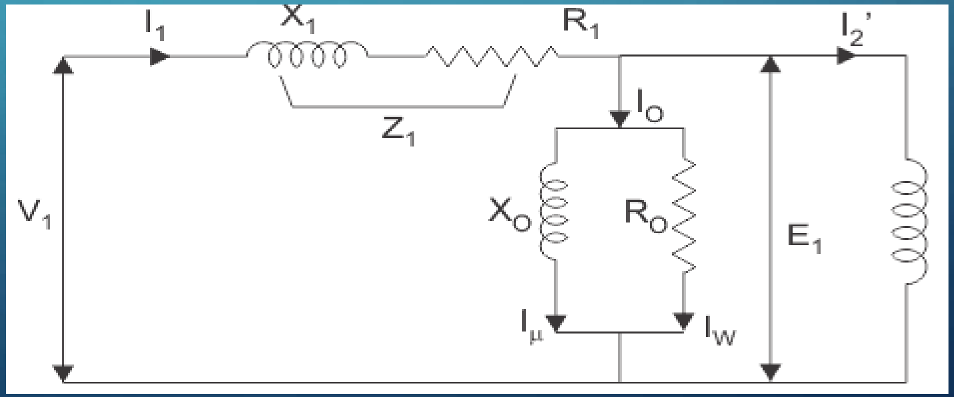
This current I_W is basically responsible for the losses in the transformer. Mainly, it is responsible for the hysteresis and eddy current losses but it is also responsible for the negligible I^2R losses.

Note:- I^2R losses are take place due to winding resistances, hence, they are negligible in No-load condition.

As we know that this component is responsible for the losses in the transformer, and it actually does some work in the transformer, hence it is called **working** component or **active** component or **wattful** component of no-load current.

I_W is in phase with the applied voltage V_1.

Note:-The no-load current I_o is small of the order of 3 to 5 percent of rated current of the Primary.



PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

TRANSFORMER "NO-LOAD" CONDITION

The following steps are given below to draw the phasor diagram:

1. The function of the magnetizing component is to produce the magnetizing flux, and thus, it will be in phase with the flux.

2. Induced emf in the primary and the secondary winding lags the flux ϕ by 90 degrees.

3. The primary copper loss is neglected, and secondary current losses are zero as $I_2 = 0$.

4. Therefore, the current I_0 lags behind the voltage vector V_1 by an angle ϕ_0 called the no-load power factor angle .

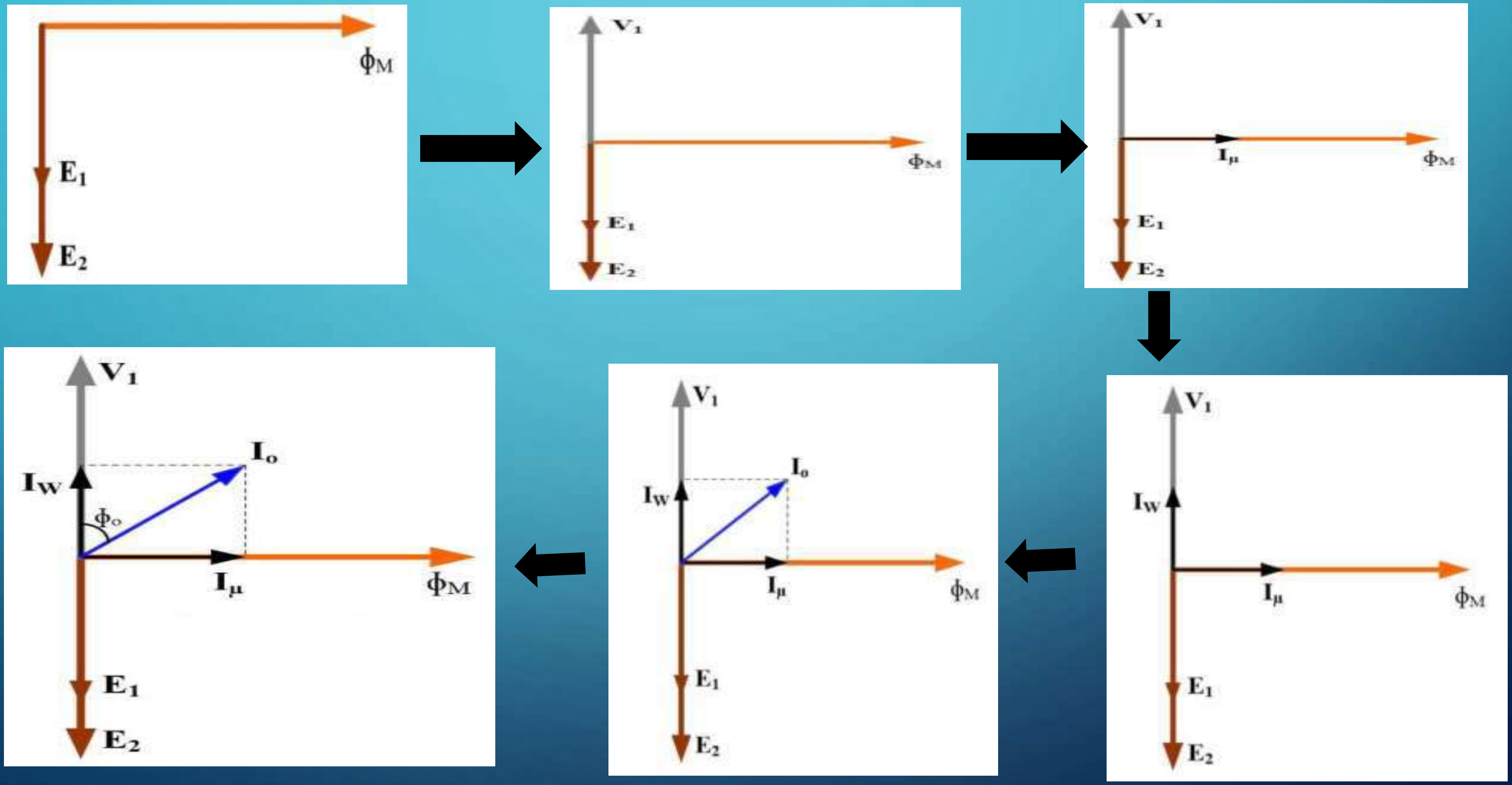
5. The applied voltage V_1 is drawn equal and opposite to the induced emf E_1 because the difference between the two, at no load, is negligible.

6. Active component I_w is drawn in phase with the applied voltage V_1.

The phasor sum of magnetizing current I_m and the working current I_w gives the no-load current I_0.

PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

TRANSFORMER "NO-LOAD" CONDITION



PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

TRANSFORMER "NO-LOAD" CONDITION

From the phasor diagram drawn above, the following conclusions are made

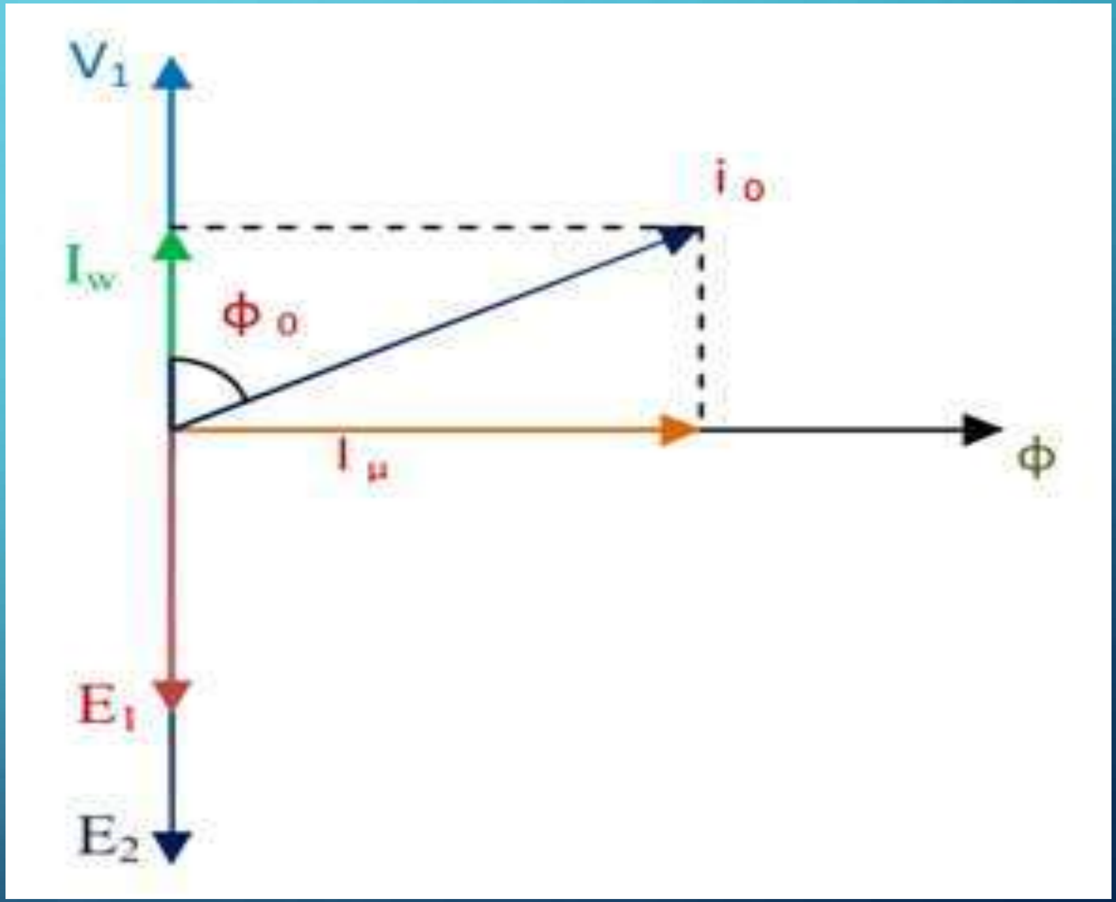
Working component $I_w = I_0 Cos\varphi_0$

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

Magnetizing component $I_m = I_0 Sin\varphi_0$

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

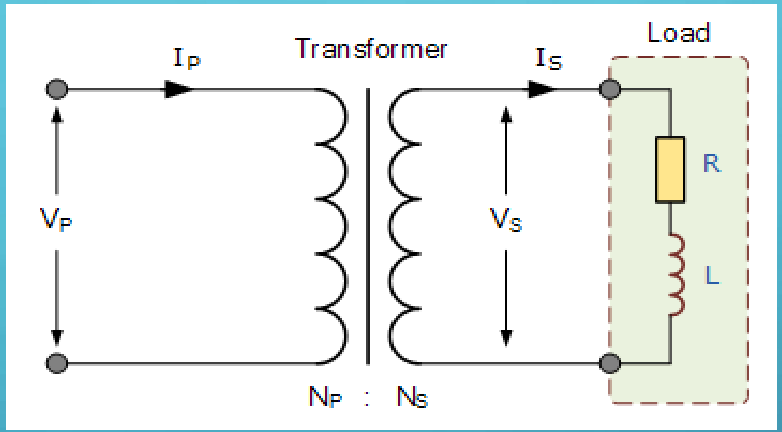
No load power input $P_0 = V_1 I_0 Cos\varphi_0$



PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

TRANSFORMER "ON-LOAD" CONDITION

When an electrical load is connected to the secondary winding of a transformer and the transformer loading is therefore greater than zero, a current flows in the secondary winding and out to the load. This secondary current is due to the induced secondary voltage, set up by the magnetic flux created in the core from the primary current.



The load can be resistive, inductive or capacitive.

The secondary current, I_S which is determined by the characteristics of the load, creates a self-induced secondary magnetic field, Φ_S in the transformer core which flows in the exact opposite direction to the main primary field, Φ_P. These two magnetic fields oppose each other resulting in a combined magnetic field of less magnetic strength than the single field produced by the primary winding alone when the secondary circuit was open circuited.

This combined magnetic field reduces the back EMF of the primary winding causing the primary current, I_P to increase slightly. The primary current continues to increase until the cores magnetic field is back at its original strength, and for a transformer to operate correctly, a balanced condition must always exist between the primary and secondary magnetic fields. This results in the power to be balanced and the same on both the primary and secondary sides.

PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

TRANSFORMER "ON-LOAD" CONDITION

OPERATION OF THE TRANSFORMER ON LOAD CONDITION

The Operation of the Transformer on Load Condition is explained below:

When the load is connected to the secondary of the transformer, I_2 current flows through their secondary winding. The secondary current induces the magneto motive force N_2I_2 on the secondary winding of the transformer. This force set up the flux φ_2 in the transformer core. The flux φ_2 opposes the flux φ, according to **Lenz's law**.

As the flux φ_2 opposes the flux φ, the resultant flux of the transformer decreases and this flux reduces the induced EMF E_1. Thus, the strength of the V_1 is more than E_1 and an additional primary current I'_1 drawn from the main supply. The additional current is used for restoring the original value of the flux in the core of the transformer so that $V_1 = E_1$. The primary current I'_1 is in phase opposition with the secondary current I_2. Thus, it is called the **primary counter-balancing current**.

The additional current I'_1 induces the magneto motive force $N_1I'_1$. And this force set up the flux φ'_1. The direction of the flux is the same as that of the φ and it cancels the flux φ_2 which induces because of the MMF N_2I_2

$$I'_1 = \left(\frac{N_2}{N_1}\right) I_2 = KI_2$$

PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

TRANSFORMER "ON-LOAD" CONDITION

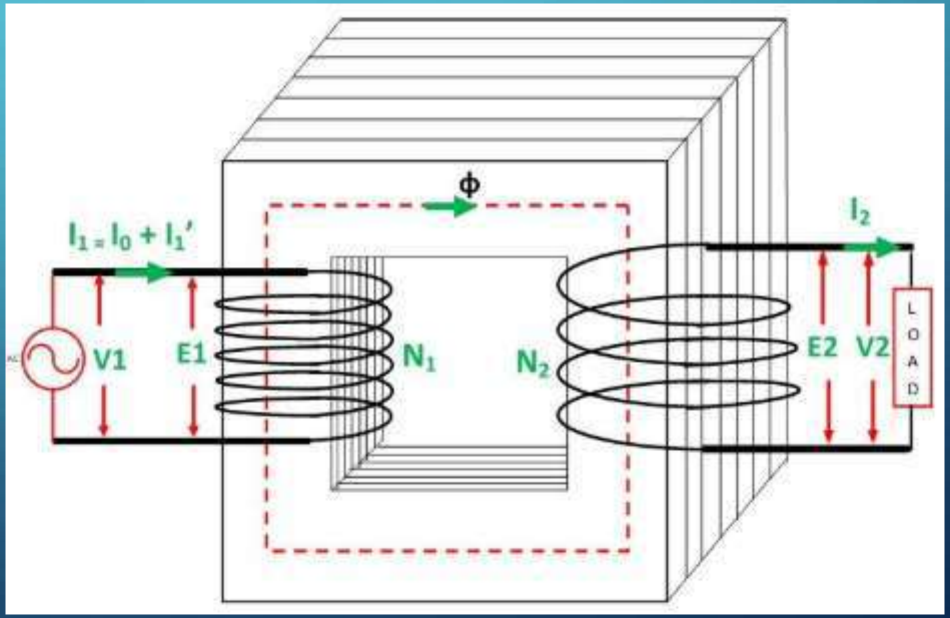
OPERATION OF THE TRANSFORMER ON LOAD CONDITION

The phase difference between V_1 and I_1 gives the power factor angle ϕ_1 of the primary side of the transformer.

The power factor of the secondary side depends upon the type of load connected to the transformer.

If the load is inductive as shown in the above phasor diagram, the power factor will be lagging, and if the load is capacitive, the power factor will be leading. The total primary current I_1 is the vector sum of the currents I_0 and I_1'. i.e

$$\overline{I_1} = \overline{I_0} + \overline{I_1'}$$



PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

TRANSFORMER "ON-INDUCTIVE LOAD" CONDITION

1. Take flux ϕ, a reference
2. Induces emf E_1 and E_2 lags the flux by 90 degrees.
3. The component of the applied voltage to the primary equal and opposite to induced emf in the primary winding. E_1 is represented by V_1'.
4. Current I_0 lags the voltage V_1' by 90 degrees.
5. The power factor of the load is lagging. Therefore current I_2 is drawn lagging E_2 by an angle ϕ_2.
6. The resistance and the leakage reactance of the windings result in a voltage drop, and hence secondary terminal voltage V_2 is the phase difference of E_2 and voltage drop. $V_2 = E_2$ – voltage drops

$I_2 R_2$ is in phase with I_2 and I_2X_2 is in Quadrature with I_2

7. The total current flowing in the primary winding is the phasor sum of I_1' and I_0.
8. Primary applied voltage V_1 is the phasor sum of V_1' and the voltage drop in the primary winding.
9. Current I_1' is drawn equal and opposite to the current I_2

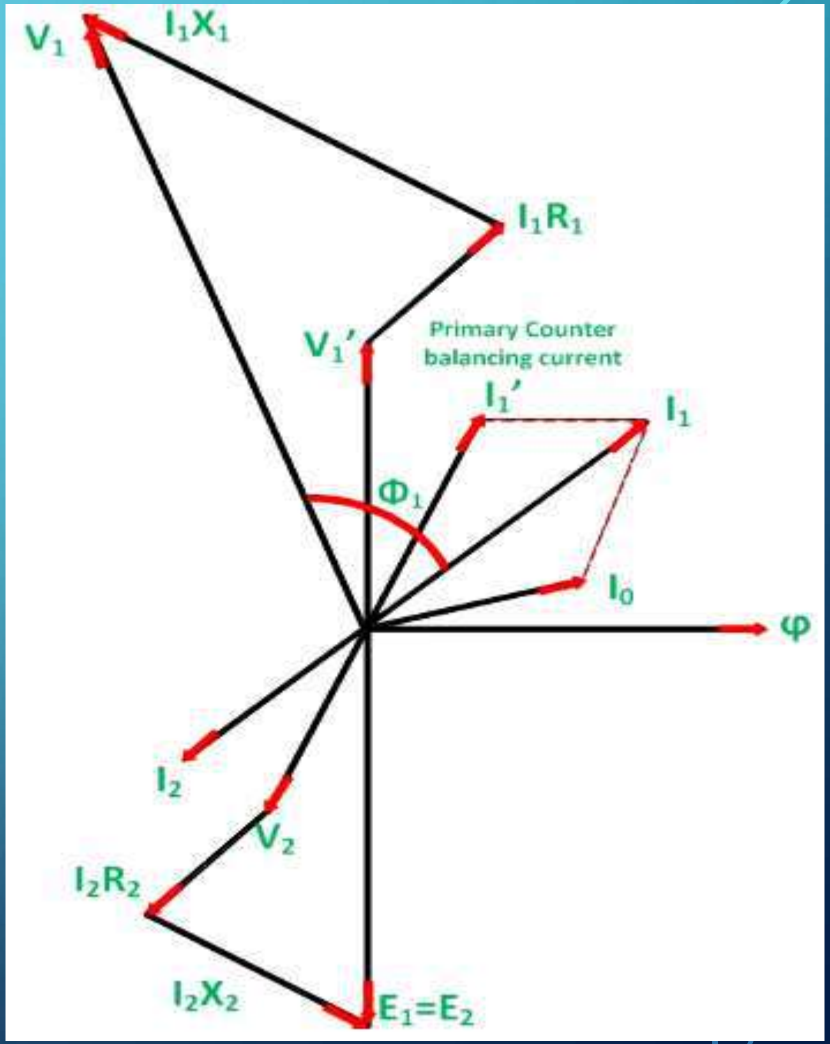
$V_1 = V_1' +$ voltage drop

I_1R_1 is in phase with I_1 and I_1X_I is in Quadrature with I_1.

10. The phasor difference between V_1 and I_1 gives the power factor angle ϕ_1 of the primary side of the transformer.
11. The power factor of the secondary side depends upon the type of load connected to the transformer.
12. If the load is inductive as shown in the above phasor diagram, the power factor will be lagging, and if the load is capacitive, the power factor will be leading. Where

I_1R_1 is the resistive drop in the primary windings

I_2X_2 is the reactive drop in the secondary winding

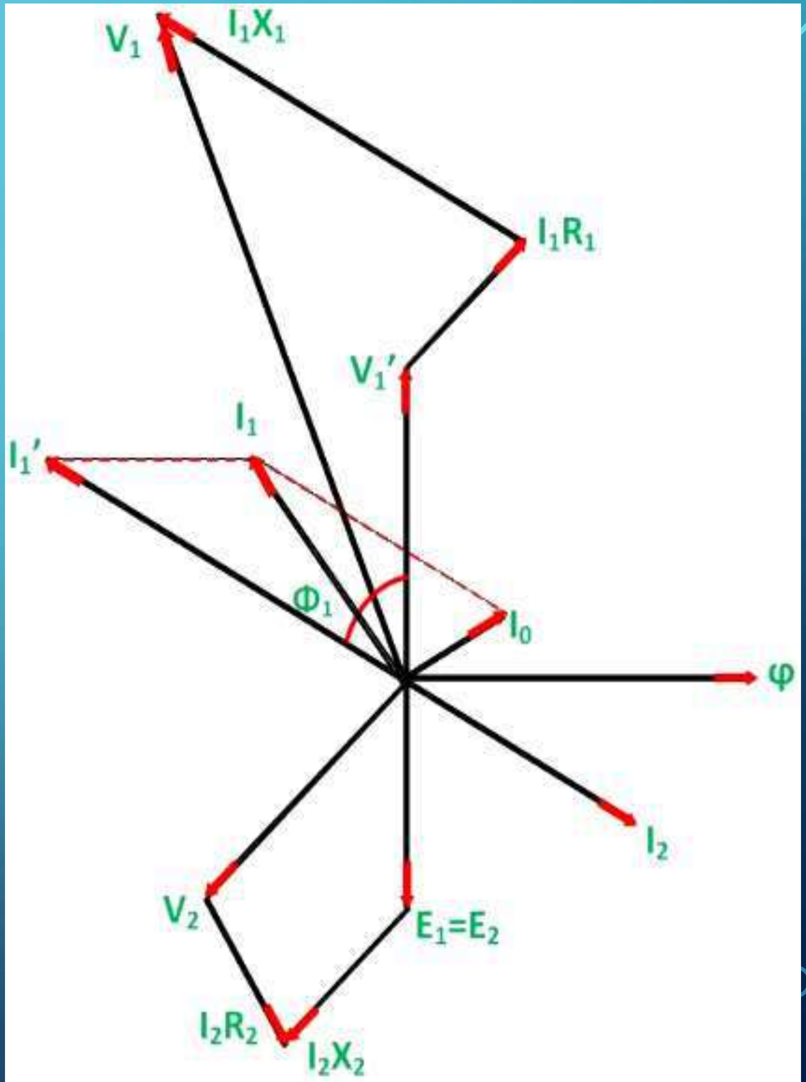


PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

TRANSFORMER "ON-CAPACITIVE LOAD" CONDITION

1. Take flux ϕ a reference
2. Induces emf E_1 and E_2 lags the flux by 90 degrees.
3. The component of the applied voltage to the primary equal and opposite to induced emf in the primary winding. E_1 is represented by V_1'.
4. Current I_0 lags the voltage V_1' by 90 degrees.
5. The power factor of the load is leading. Therefore current I_2 is drawn leading E_2
6. The resistance and the leakage reactance of the windings result in a voltage drop, and hence secondary terminal voltage V_2 is the phasor difference of E_2 and voltage drop. $V_2 = E_2$ – voltage drops
$I_2 R_2$ is in phase with I_2 and I_2X_2 is in Quadrature with I_2.

7. Current I_1' is drawn equal and opposite to the current I_2
8. The total current I_1 flowing in the primary winding is the phasor sum of I_1' and I_0.
9. Primary applied voltage V_1 is the phasor sum of V_1' and the voltage drop in the primary winding.
$V_1 = V_1$' + voltage drop
10. I_1R_1 is in phase with I_1 and I_1X_I is in Quadrature with I_1.
11. The phasor difference between V_1 and I_1 gives the power factor angle ϕ_1 of the primary side of the transformer.
12. The power factor of the secondary side depends upon the type of load connected to the transformer.

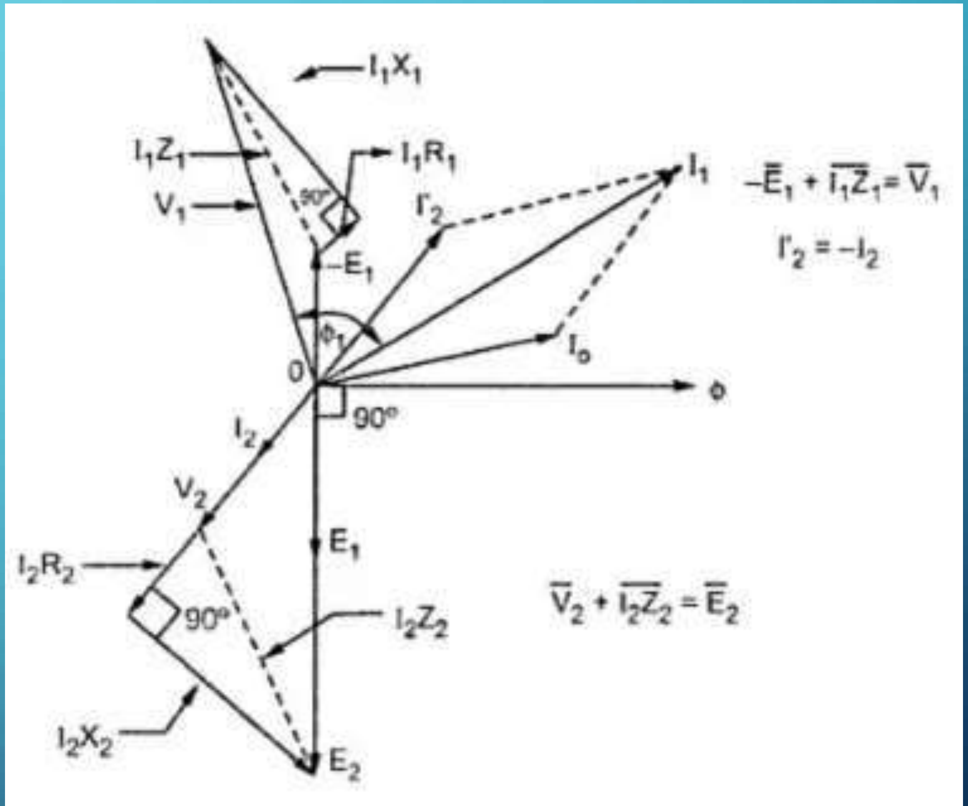


PHASOR DIAGRAM OF SINGLE PHASE TRANSFORMER

TRANSFORMER "ON-RESISTIVE LOAD" CONDITION

If the load is resistive or power factor is unity, the voltage V2 and I2 are in phase. Steps to draw the phasor diagram are

1. Consider flux Φ as reference
2. E1 lags Φ by 90 degree. Reverse E1 to get -E1.
3. E1 and E2 are in phase
4. Assume V2 in a particular direction
5. I2 is in phase with V2.
6. Add I2 R2 and I2 X2 to get E2.
7. Reverse I2 to get I2'.
8. Add Io and I2' to get I1.
9. Add I1 R1 and to -E1 to get V1.



Angle between V1 and I1 is Φ1 and cosΦ1 is primary power factor. Remember that I1X1 leads I1 direction by 90 degree and I2 X2 leads I2 by 90 o as current through inductance lags voltage across inductance by 90 degree.

MODULE:4

SINGLE PHASE TRANSFORMER

TOPIC:

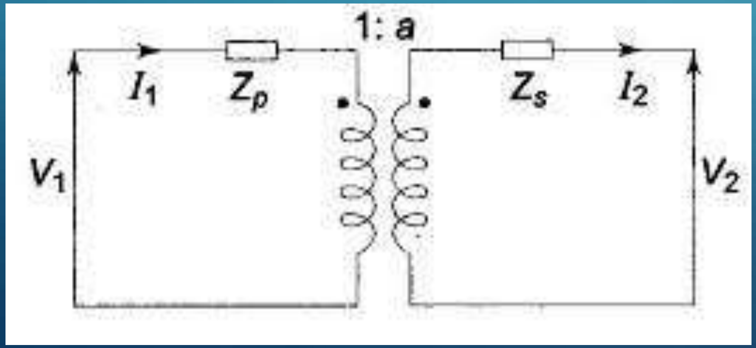
- **PUR UNIT REPRESENTATION**
- **SUMPNER'S TEST ON TRANSFORMER**
- **PROBLEM SOLVING**

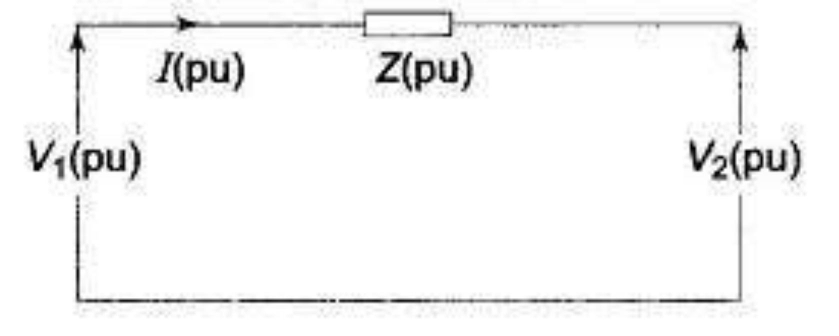
PER-UNIT SYSTEM FOR SINGLE-PHASE TRANSFORMERS

The quantities involved in power system are kVA, voltage, current and impedance of the equivalent circuits of the various system components. The equivalent circuits are at different voltages and are connected together in the system by means of transformers and interconnections.

Each apparatus is rated in kVA and its impedance in actual ohms or in percentage value referred to its rated kVA and rated voltage. In power system analysis, it is usual to express voltage, current, kVA and impedance in per unit of base or reference values of these quantities. Such a method simplifies the calculations.

$$\text{The per} - \text{unit value of any quantity is defined as } \frac{\text{the actual value of the quantity in any unit}}{\text{the base or reference value in the same unit}}$$





PER-UNIT SYSTEM FOR SINGLE-PHASE TRANSFORMERS

Another approach to solve circuits containing transformers is the per-unit system. Impedance and voltage-level conversions are avoided. Also, machine and transformer impedances fall within fairly narrow ranges for each type and construction of device while the per-unit system is employed.

The voltages, currents, powers, impedances, and other electrical quantities are measured as fractions of some base level instead of conventional units.

$$Quantity\ per\ unit = \frac{actual\ value}{base\ value\ of\ quantity}$$

Usually, two base quantities are selected to define a given per-unit system. Often, such quantities are voltage and power (or apparent power). In a 1-phase system:

$$P_{base}, Q_{base}, \ or\ S_{base} = V_{base} I_{base}$$

$$Z_{base} = \frac{V_{base}}{I_{base}} = \frac{(V_{base})^2}{S_{base}}$$

$$Y_{base} = \frac{I_{base}}{V_{base}}$$

Ones the base values of P (or S) and V are selected, all other base values can be computed from the equations

PER-UNIT SYSTEM FOR SINGLE-PHASE TRANSFORMERS

In a power system, a base apparent power and voltage are selected at the specific point in the system. Note that a transformer has no effect on the apparent power of the system, since the apparent power into a transformer equals the apparent power out of a transformer. As a result, the base apparent power remains constant everywhere in the power system.

On the other hand, voltage (and, therefore, a base voltage) changes when it goes through a transformer according to its turn ratio. Therefore, the process of referring quantities to a common voltage level is done automatically in the per unit system.

$$\text{Base current } I_B = \frac{(\text{VA})_B}{V_B} \text{ A}$$

$$\text{Base impedance } Z_B = \frac{V_B}{I_B} = \frac{V_B^2}{(\text{VA})_B} \text{ ohms}$$

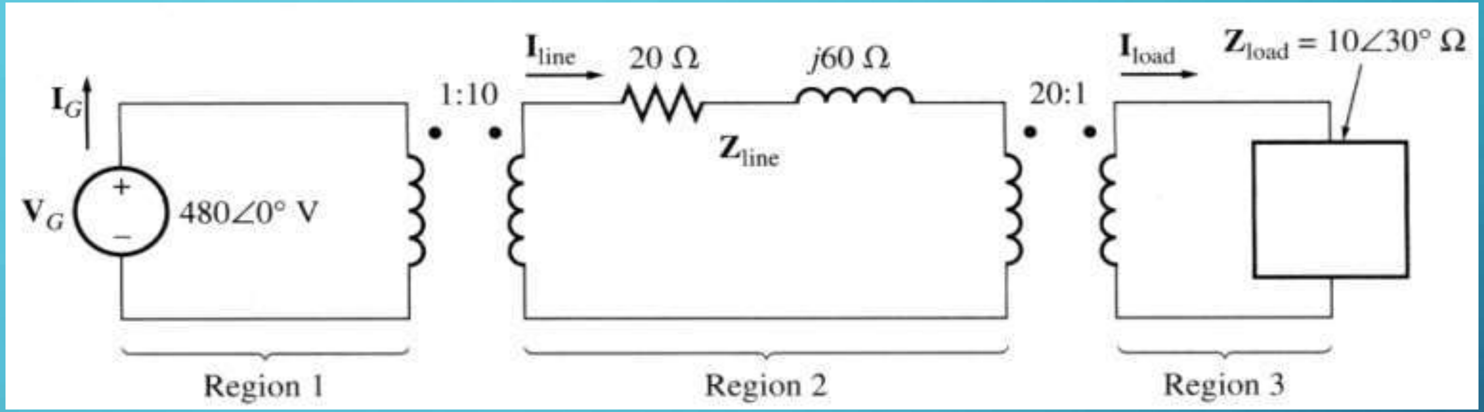
If the actual impedance is Z (ohms), its Per Unit System Definition value is given by

$$Z(\text{pu}) = \frac{Z}{Z_B} = \frac{Z(\text{ohms}) \times (\text{VA})_B}{V_B^2}$$

PER-UNIT SYSTEM FOR SINGLE-PHASE TRANSFORMERS

A simple power system is given by the circuit: The generator is rated at 480 V and 10 kVA.

Find the base voltage, current, impedance, and apparent power at every points in the power system:



In the generator region: $V_{base\ 1} = 480$ V and $S_{base} = 10$ kVA

$$I_{base1} = \frac{S_{base1}}{V_{base1}} = \frac{10\,000}{480} = 20.83\ A$$

$$Z_{base1} = \frac{V_{base1}}{I_{base1}} = \frac{480}{20.83} = 23.04\ \Omega$$

The turns ratio of the transformer T1 is a1 = 0.1; therefore, the voltage in the transmission line region is

$$V_{base2} = \frac{V_{base1}}{a_1} = \frac{480}{0.1} = 4800\ V$$

PER-UNIT SYSTEM FOR SINGLE-PHASE TRANSFORMERS

The other base quantities are

$$S_{base\,2} = 10\ kVA$$

$$I_{base\,2} = \frac{10\,000}{4800} = 2.083\ A$$

$$Z_{base\,2} = \frac{4800}{2.083} = 2304\ \Omega$$

The turns ratio of the transformer T 2 is a 2 = 20; therefore, the voltage in the load region is

$$V_{base\,3} = \frac{V_{base\,2}}{a_2} = \frac{4800}{20} = 240\ V$$

The other base quantities are

$$S_{base\,3} = 10\ kVA$$

$$I_{base\,3} = \frac{10\,000}{240} = 41.67\ A$$

$$Z_{base\,3} = \frac{240}{41.67} = 5.76\ \Omega$$

PER-UNIT SYSTEM FOR SINGLE-PHASE TRANSFORMERS

ADVANTAGES AND DRAWBACKS OF PER-UNIT (PU) METHOD

Advantages:

1. Calculations are simplified.

2. The characteristics of machines (generators, transformers, motors etc.) when described in per-unit system are specified by almost the same number, regardless of the rating of the machines. In other words, the characteristics (or parameters) tend to fall in relatively narrow range, making erroneous values conspicuous. Thus per-unit system provides a method of comparison.

3. For circuits connected by transformers, per-unit system is particularly suitable. By choosing suitable base kV’s for the circuits the per unit reactance remains the same, referred to either sides of the transformer. Therefore, the various circuits can be connected in the reactance diagram.

4. This method is useful to eliminate ideal transformers as circuit components since the typical power system contains hundreds, if not thousands of transformers, and this is a non- trivial savings.

Drawbacks:

1. Some equations that hold in the unsealed cases are modified when scaled into per-unit. Factors such as $\sqrt{3}$ and 3 are removed or added by this method.

2. Equivalent circuits of the components are modified, making them somewhat more abstract. Sometimes phase shifts that are clearly present in the unsealed circuit vanish in the per-unit circuit.

BACK-TO-BACK TEST (SUMPNER’S TEST) ON TRANSFORMER

The full load test on a small transformer is very convenient, but on the large transformer, it is very difficult. The maximum temperature rise in a large transformer is determined by the full load test. This test is called, back-to-back test, regenerative test or Sumpner’s test

The suitable load which absorbs the full load power of a large transformer will not easily be available. Hence a large amount of energy will be wasted. The back-to-back test determines the maximum temperature rise in a transformer, and hence the load is chosen according to the capability of the transformer.

The Sumpner's test is carried out on two identical transformers to compute the efficiency of each transformer.

Two identical transformers are connected back to back, such that their primaries are in parallel across the same voltage source and the secondary's in series so that one transformer is loaded on the other.

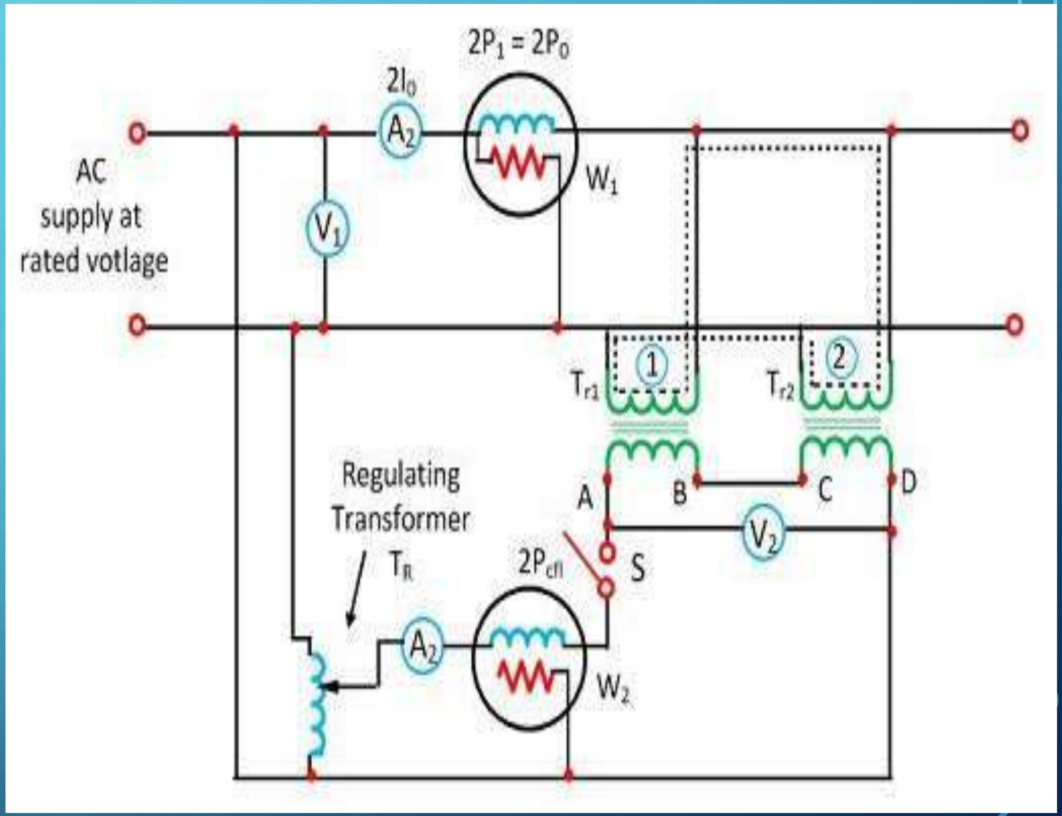
BACK-TO-BACK TEST (SUMPNER'S TEST) ON TRANSFORMER

BACK TO BACK TEST CIRCUIT

The two identical transformer is used for the back to back test. Consider the T_{r1} and T_{r2} are the primary windings of the transformer connects parallel to each other. The nominal rated voltage and frequency is supplied to their primary winding. The voltmeter and ammeter are connected on their primary side for the measurement of the input voltage and current.

The secondary winding of the transformer is connected in series with the each other but with opposite polarity. The voltmeter V_2 is connected to the terminal of the secondary winding for the measurement of the voltage.

The series opposition of the secondary winding is determined by connecting there any two terminal; the voltmeter is connected across their remaining terminals. If it is connected in series opposition, the voltmeter gives the zero reading. The open terminal is used for measuring the parameter of the transformer.



BACK-TO-BACK TEST (SUMPNER'S TEST) ON TRANSFORMER

DETERMINATION OF TEMPERATURE RISE

The temperature rise of the transformer is determined by measuring the temperature of their oil after every particular interval of time. The transformer is operating back to back for the long time which increases their oil temperature. By measuring the temperature of their oil the withstand capacity of the transformer under high temperature is determined.

DETERMINATION OF IRON LOSS

The wattmeter W_1 measures the power loss which is equal to the iron loss of the transformer. For determining the iron loss, the primary circuit of the transformer is kept closed. Because of the primary closed circuit, no current flows through the secondary windings of the transformer. The secondary winding behaves like an open circuit. The wattmeter is connected to their secondary terminal for the measurement of iron loss.

DETERMINATION OF COPPER LOSS

The copper loss of the transformer is determined when the full load current flows through their primary and secondary windings. The additional regulating transformer is used for exciting the secondary windings. The full load current flows from the secondary to the primary winding. The wattmeter W_2 measures the full load copper loss of the two transformers.

Efficiency(%) = Output (kW)/ [W1/2 + W2/2 + Output]

BACK-TO-BACK TEST (SUMPNER'S TEST) ON TRANSFORMER

DURING THIS TEST THE FOLLOWING POINT MAY BE NOTED:

1. The wattmeter's W_1 & W_2 gives the core losses and copper losses at full load of the two transformers respectively. Hence the total losses of two transformers are equal to the power required to conduct this test.

2. The total iron losses and copper losses at full load are occurring even though the transformers are not supplying any load.

3. There are two voltage supply; one is transformer regulating voltage and the other is supply voltage and in between these voltages no interference. The source voltage provides $2I_0$ while the transformer regulating voltage provides I2 and thus I_1=KI_2.

BACK-TO-BACK TEST (SUMPNER'S TEST) ON TRANSFORMER

ADVANTAGES OF THIS TEST:

1. Little much of power is required to conduct this test.

2. Under full load conditions transformers can be test using this test.

3. Simultaneously full load copper losses and iron losses are measured.

4. The secondary current I_2 can be varied at any value of the current. Hence we can determine the copper losses at full load condition or at any load.

5. The transformer temperature increase can be noted.

PROBLEM SOLVING

PROBLEM:02 The primary and secondary voltages of an autotransformer are 230V and 75V respectively. Calculate the currents in different parts of the winding when the load current is 200 A. Also calculate the saving In the use of copper.

SOLUTION:

$$I_2 N_s = I_1 N_p$$

$$I_1 = I_2 \frac{N_s}{N_p} = I_2 \frac{V_s}{V_p} = 200 \times \left[\frac{75}{230}\right]$$

Primary current, $I_1 = 65.2$ A

Load current, $I_2 = 200$ A

Current flowing through the common portion of the

winding $= I_2 - I_1 = 200 - 65.2$

$= 134.8$ A

Let weight of copper required in a two-winding transformer $= W_{TW}$ and weight of copper required in an auto transformer $= W_a$

Economy in saving in copper in percentage $= \frac{W_{TW} - W_a}{W_{TW}}$

$$= \left[1 - \frac{W_{TW}}{W_a}\right] \times 100$$

$$= \left[1 - \left(1 - \frac{N_s}{N_p}\right)\right] \times 100$$

$$= \frac{N_s}{N_p} \times 100$$

$$= \frac{V_s}{V_p} \times 100 = \frac{75 \times 100}{230}$$

$= 32.6\%$

MODULE:4

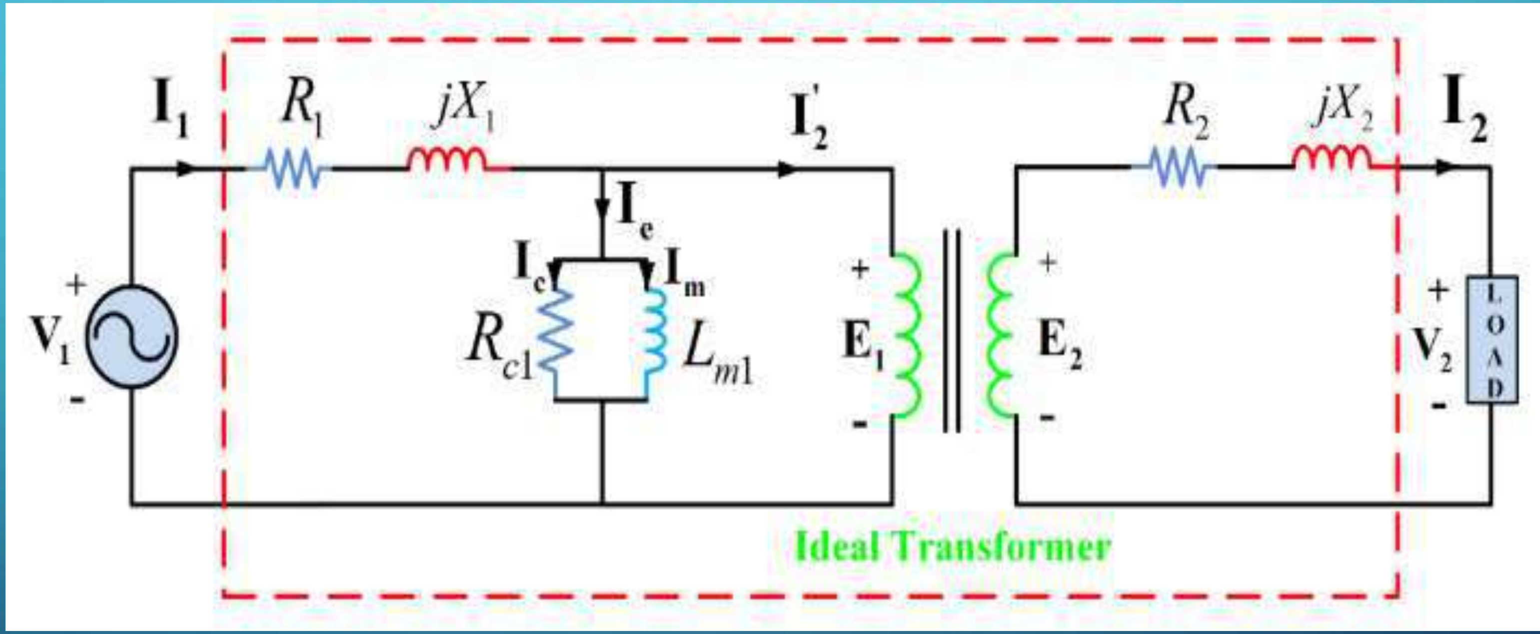
SINGLE PHASE TRANSFORMER

TOPIC:

DETERMINATION OF TRANSFORMER EQUIVALENT CIRCUIT PARAMETERS USING VIRTUAL LAB

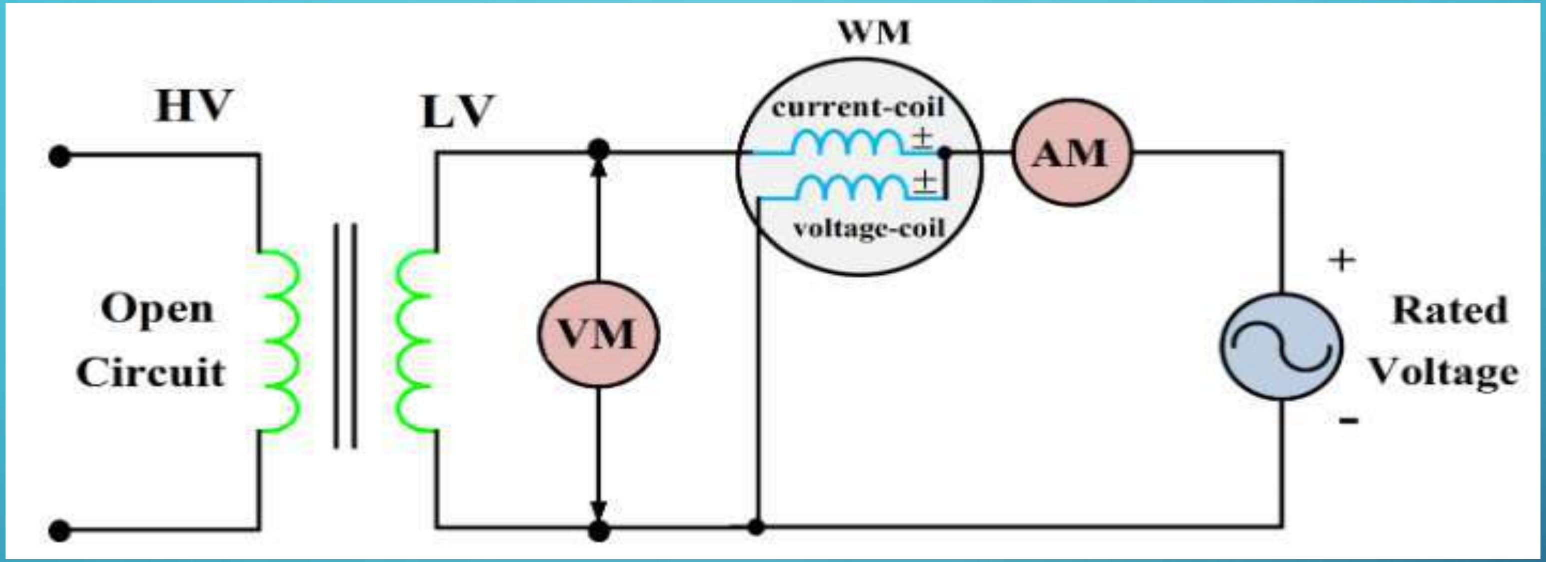
DETERMINATION OF TRANSFORMER EQUIVALENT CIRCUIT PARAMETERS

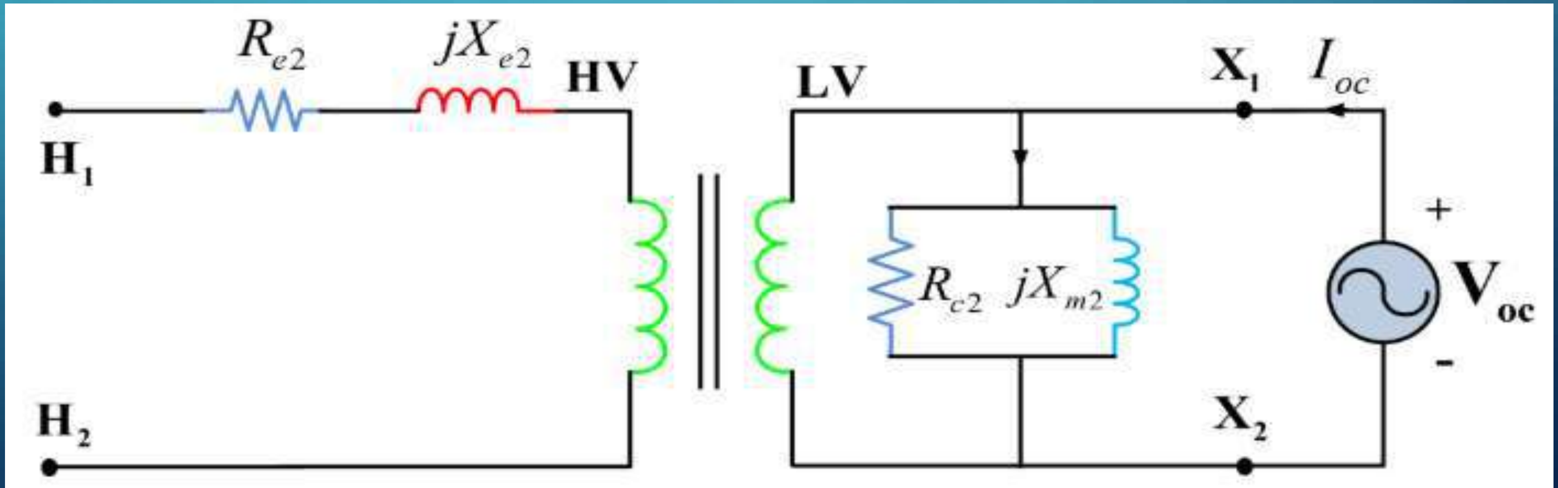
Two simple tests are used to determine the values for the parameters of the transformer equivalent circuit. The two tests are the **short-circuit** and **open-circuit** tests



DETERMINATION OF TRANSFORMER EQUIVALENT CIRCUIT PARAMETERS

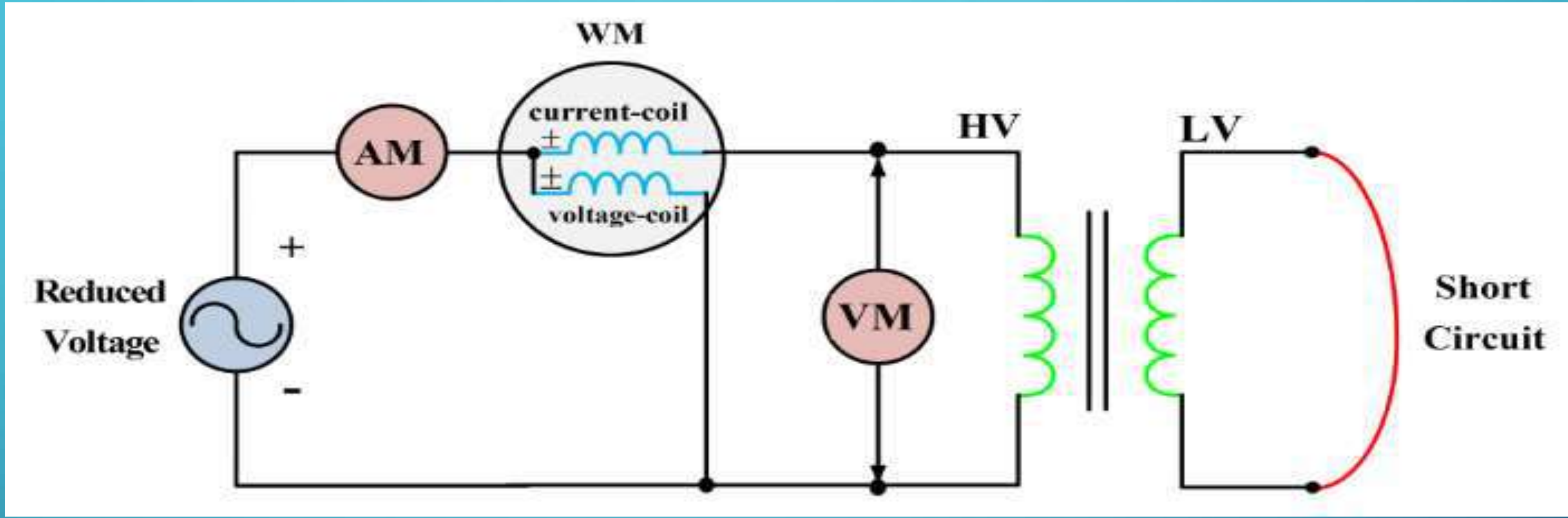
TRANSFORMER OPEN-CIRCUIT TEST

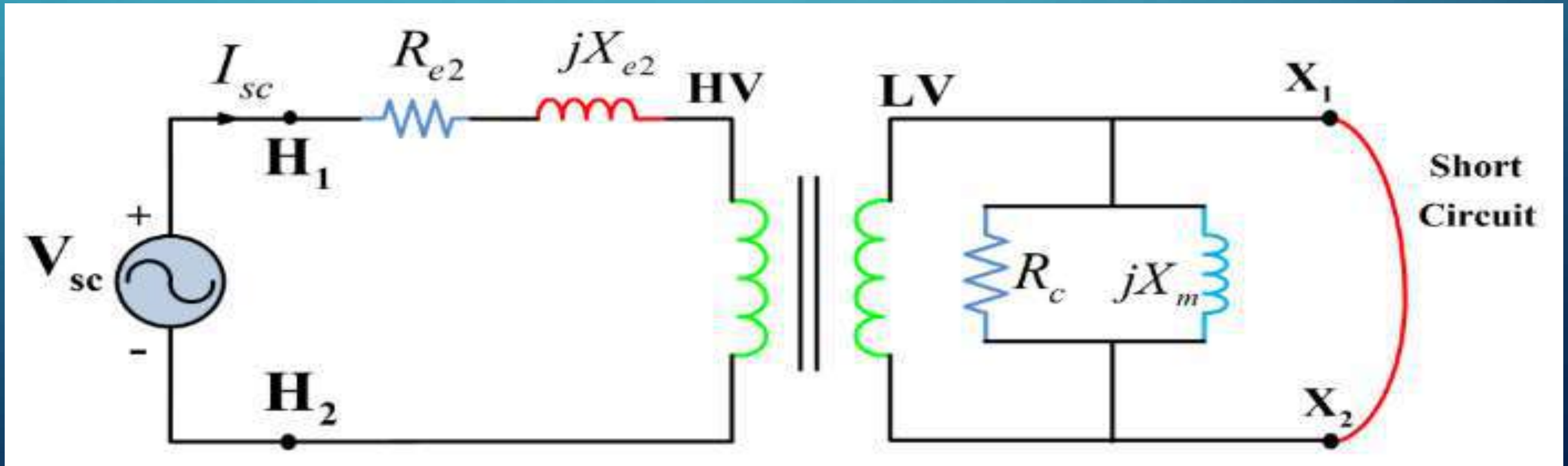




DETERMINATION OF TRANSFORMER EQUIVALENT CIRCUIT PARAMETERS

TRANSFORMER SHORT-CIRCUIT TEST





DETERMINATION OF TRANSFORMER EQUIVALENT CIRCUIT PARAMETERS

CALCULATIONS:

O.C TEST

Iron losses, $P_I = P_o$ watts.

No load P.f., $\cos\phi_o = \frac{P_o}{VI_o}$

Magnetizing current, $I_m = I_0 \sin\phi_o$

Loss component of no load current, $I_w = I_0 \cos\phi_o$

Magnetizing reactance, $X_0 = \frac{V}{I_m}$

Equivalent resistance of iron losses, $R_0 = \frac{V}{I_w}$

S.C TEST

Full load copper losses $P_{Cu} = P_{SC}$ Watts.

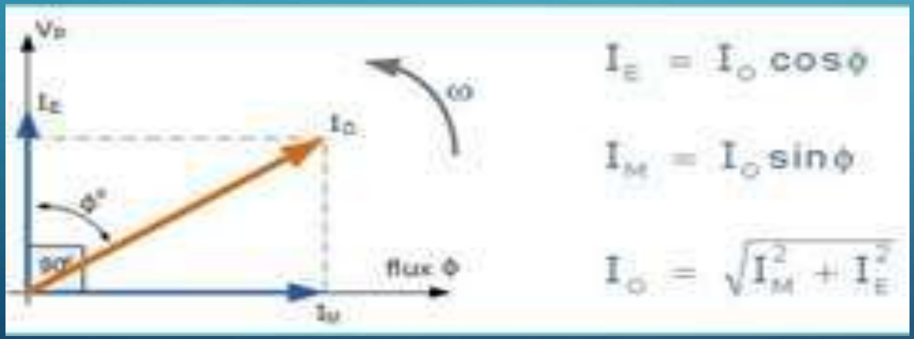
Power factor on short circuit, $\cos\phi_{SC} = \frac{P_{sc}}{V_{sc} I_{sc}}$

Short circuit impedance $Z_{01} = \frac{V_{sc}}{I_{sc}} \Omega$.

Referred to primary:

HT equivalent resistance, $R_{01} = \frac{P_{SC}}{I_{sc}^2}$

HT equivalent reactance, $X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$



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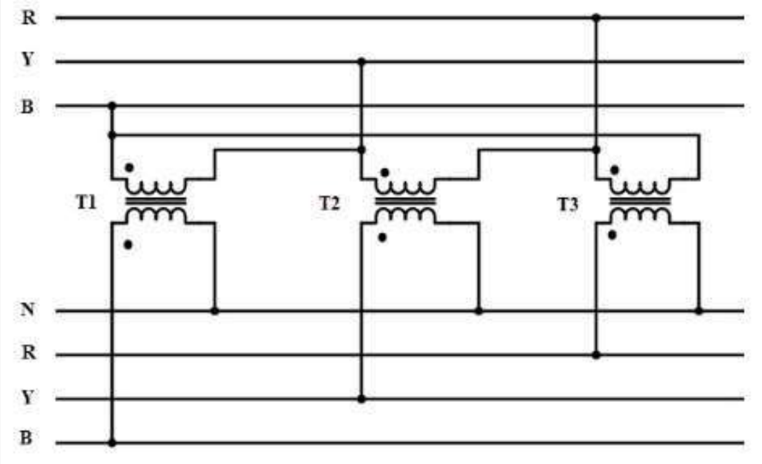
Module:5

THREE PHASE TRANSFORMER

Topic:

- INTRODUCTION TO THREE PHASE TRANSFORMER
- DIFFERENT CONNECTION OF THREE PHASE TRANSFORMER
- APPLICATION OF THREE PHASE TRANSFORMER

THREE PHASE TRANSFORMER



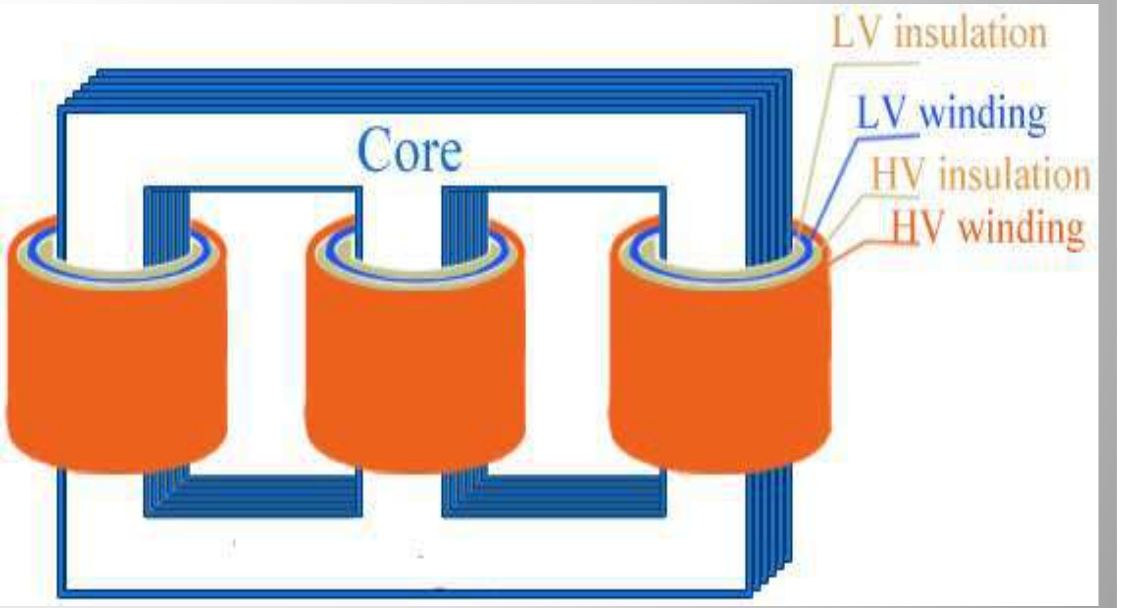
As known, a single-phase transformer is a device that is capable of transferring electrical energy from one circuit to one or more circuits based on the concept of mutual induction. It comprises two coils – a primary and a secondary coil, which helps to transform the energy. The primary coil is connected to a single-phase supply, while the secondary is connected to a load.

Similarly, a three-phase transformer consists of three primary coils and three secondary coils and is represented as 3-phase or 3ϕ. A three-phase system can be constructed using three individual identical single-phase transformers, and such a 3-phase transformer is known as the bank of three transformers. On the other hand, the three-phase transformer can be built on a single core. The windings of a transformer can be connected in either delta or wye configurations. The working of the 3-phase system is similar to a single-phase transformer, and they are normally employed in power generation plants.

THREE PHASE TRANSFORMER

Three phase transformers are used to step-up or step-down the high voltages in various stages of power transmission system. The power generated at various generating stations is in three phase nature and the voltages are in the range of 13.2KV or 22KV. In order to reduce the power loss to the distribution end, the power is transmitted at somewhat higher voltages like 132 or 400KV. Hence, for transmission of the power at higher voltages, three phase step-up transformer is used to increase the voltage. Also at the end of the transmission or distribution, these high voltages are step-down to levels of 6600, 400, 230 volts, etc. For this, a three phase step down transformer is used.

Instead of using three single phase transformers, a three phase bank can be constructed with a single three phase transformer consisting of six windings on a common multi-legged core. Due to this single unit, weight as well as the cost is reduced as compared to three units of the same rating and also windings, the amount of iron in the core and insulation materials are saved. Space required to install a single unit is less compared with three unit bank. But the only disadvantage with single unit three phase transformer is if the fault occurs in any one of the phase, then entire unit must be removed from the service.



THREE PHASE TRANSFORMER

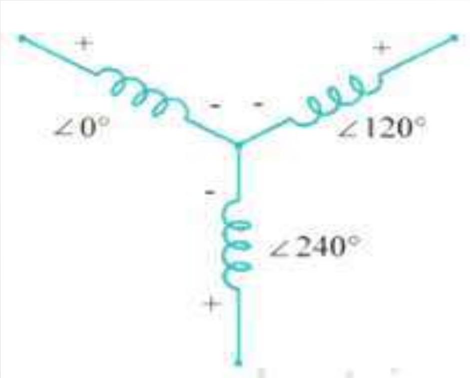
EASY UNDERSTANDING OF 3-PHASE TRANSFORMER CONNECTIONS

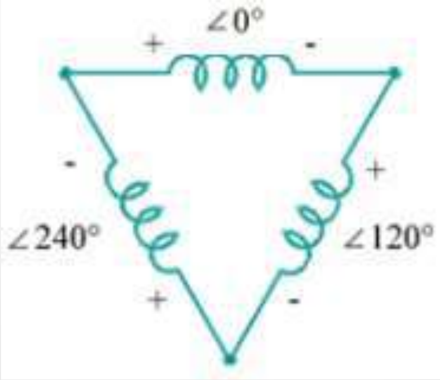
The two most commonly used three-phase winding configurations are delta and Star. In a delta configuration, the three windings are connected end-to-end to form a closed path. A phase is connected to each corner of the delta.

In any of these configurations, there will be a phase difference of 120° between any two phases.

Although delta windings are often operated ungrounded, a leg of the delta can be center tapped and grounded, or a corner of the delta can be grounded. In a wye configuration, one end of each of the three windings is connected to form a neutral. A phase is connected to the other end of the three windings. The neutral is usually grounded.

Star/wye Configuration





Delta Configuration

THREE PHASE TRANSFORMER

EASY UNDERSTANDING OF 3-PHASE TRANSFORMER CONNECTIONS

Windings of a three phase transformer can be connected in various configurations as:

(i) **Delta- Delta**

(ii) **Delta-Star**

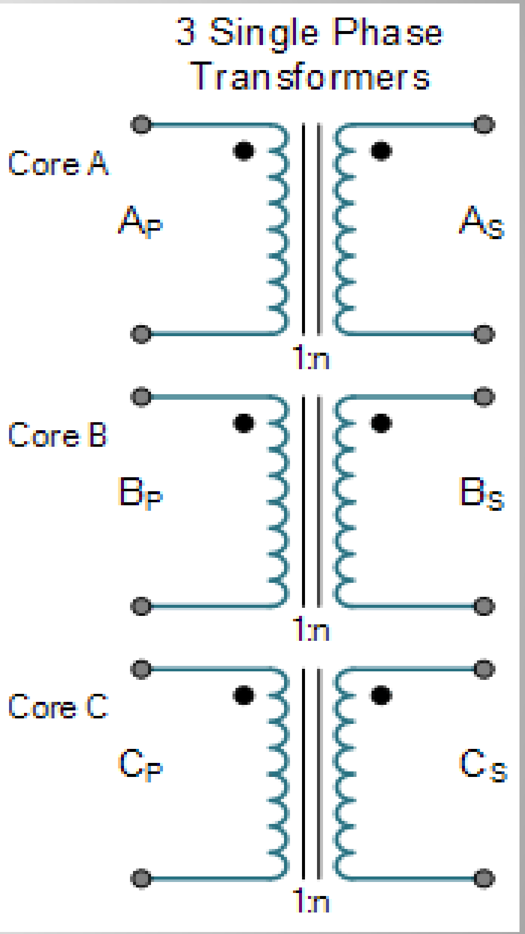
(iii) **Star-delta**

(iv) **Star-Star**

(v) **Open delta Connection**

(vi) **Scott connection**

Primary Configuration	Secondary Configuration
Delta (Mesh) △	Delta (Mesh) △
Delta (Mesh) △	Star (Wye) Y
Star (Wye) Y	Delta (Mesh) △
Star (Wye) Y	Star (Wye) Y
Interconnected Star	Delta (Mesh) △
Interconnected Star	Star (Wye) Y



THREE PHASE TRANSFORMER

EASY UNDERSTANDING OF 3-PHASE TRANSFORMER CONNECTIONS

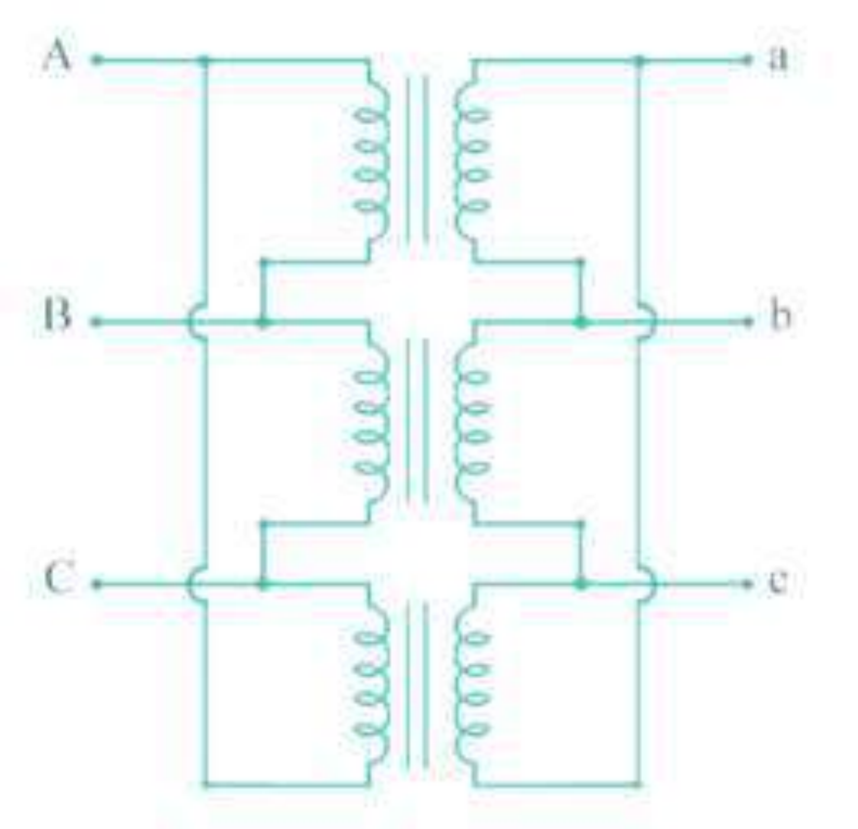
1. DELTA-DELTA (Δ-Δ) CONNECTION:

1. This connection is generally used for large, low-voltage transformers. Number of required phase/turns is relatively greater than that for star-star connection.

2. The ratio of line voltages on the primary and the secondary side is equal to the transformation ratio of the transformers.

3. This connection can be used even for unbalanced loading.

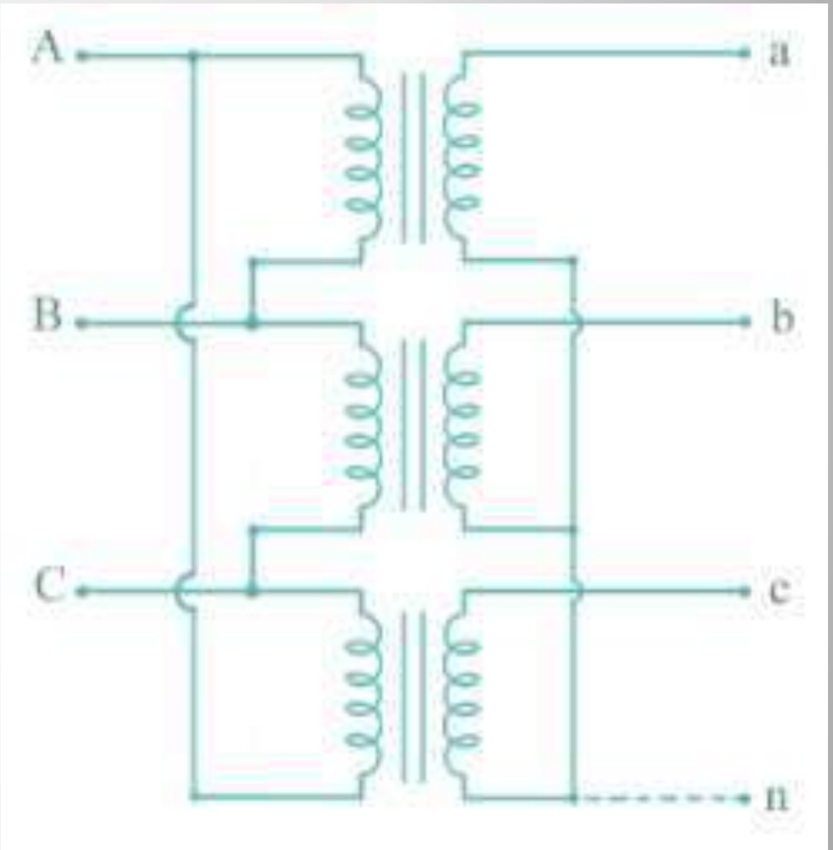
4. Another advantage of this type of connection is that even if one transformer is disabled, system can continue to operate in open delta connection but with reduced available capacity.



THREE PHASE TRANSFORMER

EASY UNDERSTANDING OF 3-PHASE TRANSFORMER CONNECTIONS

2. DELTA-STAR OR DELTA-WYE (Δ-Y) CONNECTION:



1. The primary winding is connected in delta and the secondary winding is connected in star with neutral grounded. Thus it can be used to provide 3-phase 4-wire service.

2. This type of connection is mainly used in step-up transformer at the beginning of transmission line.

3. The ratio of secondary to primary line voltage is $\sqrt{3}$ times the transformation ratio.

4. There is 30° shift between the primary and secondary line voltages.

THREE PHASE TRANSFORMER

EASY UNDERSTANDING OF 3-PHASE TRANSFORMER CONNECTIONS

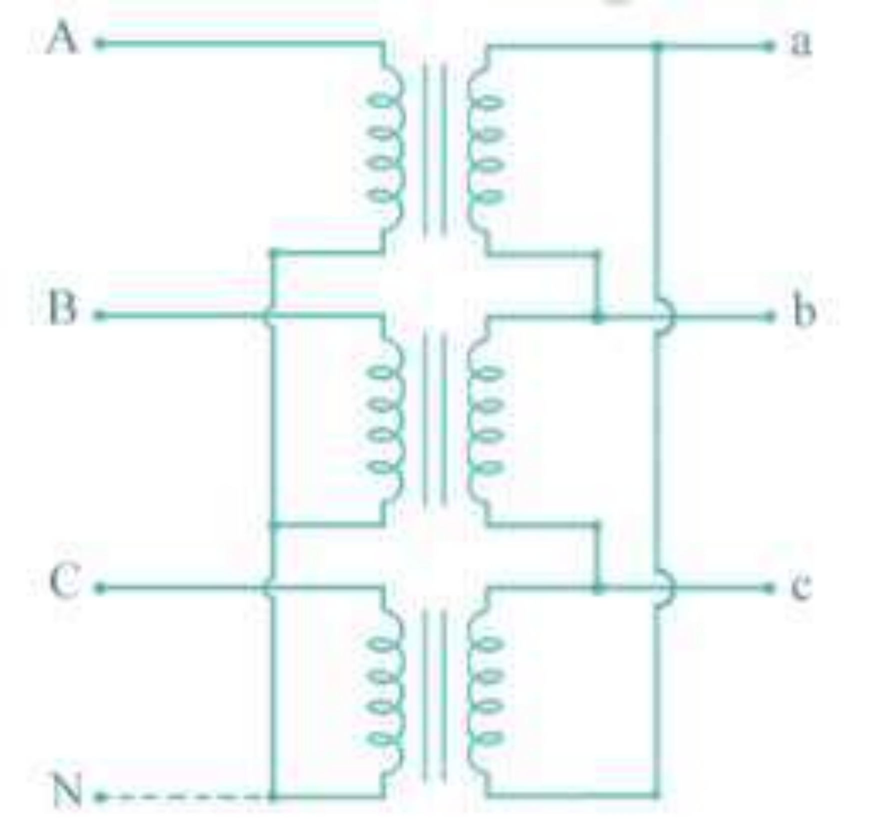
3. STAR-DELTA OR WYE-DELTA (Y-Δ) CONNECTION:

1. The primary winding is star (Y) connected with grounded neutral and the secondary winding is delta connected.

2. This connection is mainly used in step down transformer at the substation end of the transmission line.

3. The ratio of secondary to primary line voltage is 1/√3 times the transformation ratio.

4. There is 30° shift between the primary and secondary line voltages.



THREE PHASE TRANSFORMER

EASY UNDERSTANDING OF 3-PHASE TRANSFORMER CONNECTIONS

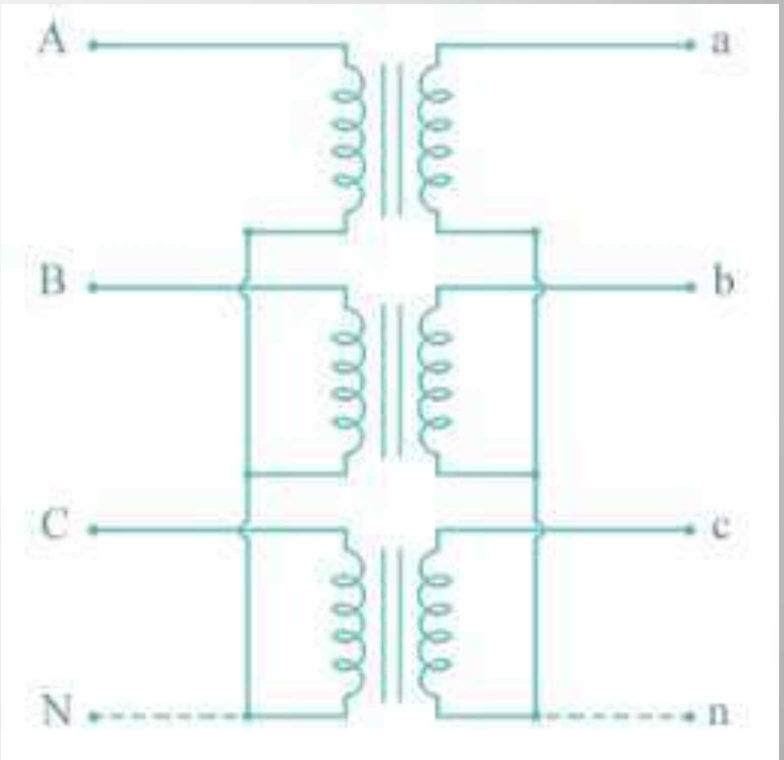
4. STAR-STAR (Y-Y) CONNECTION:

1. Star-star connection is generally used for small, high-voltage transformers. Because of star connection, number of required turns/phase is reduced (as phase voltage in star connection is 1/√3 times of line voltage only). Thus, the amount of insulation required is also reduced.

2. The ratio of line voltages on the primary side and the secondary side is equal to the transformation ratio of the transformers.

3. Line voltages on both sides are in phase with each other.

4. This connection can be used only if the connected load is balanced.

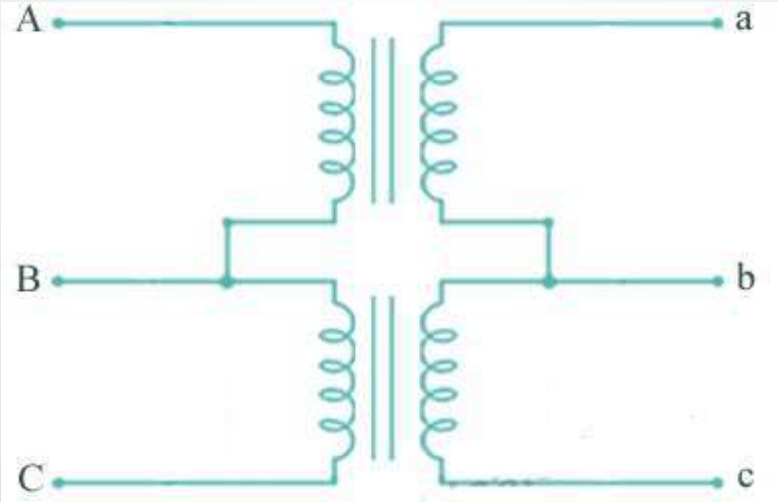


THREE PHASE TRANSFORMER

EASY UNDERSTANDING OF 3-PHASE TRANSFORMER CONNECTIONS

5. OPEN DELTA (V-V) CONNECTION:

Two transformers are used and primary and secondary connections are made as shown in the figure below. Open delta connection can be used when one of the transformers in Δ-Δ bank is disabled and the service is to be continued until the faulty transformer is repaired or replaced. It can also be used for small three phase loads where installation of full three transformer bank is un-necessary. The total load carrying capacity of open delta connection is 57.7% than that would be for delta-delta connection.

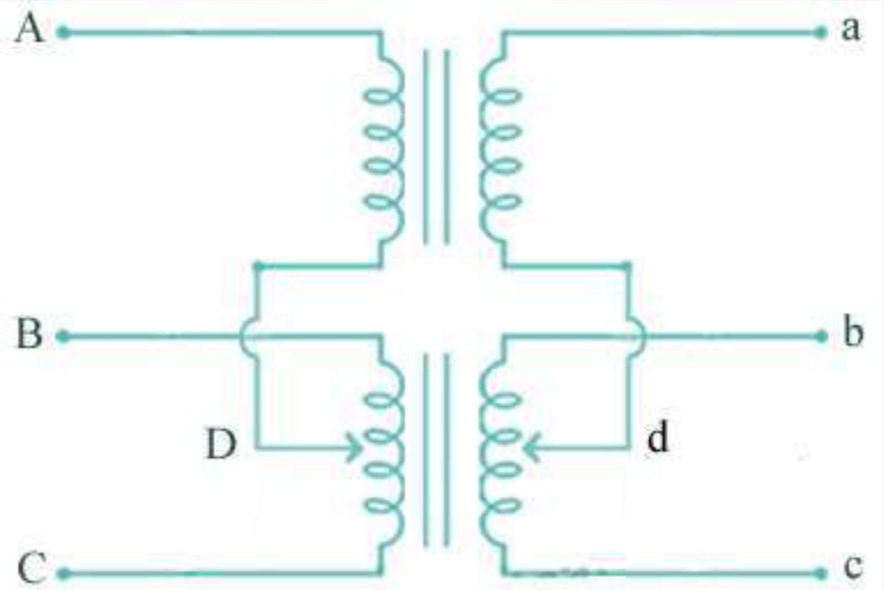


THREE PHASE TRANSFORMER

EASY UNDERSTANDING OF 3-PHASE TRANSFORMER CONNECTIONS

6. SCOTT (T-T) CONNECTION:

Two transformers are used in this type of connection. One of the transformers has centre taps on both primary and secondary windings (which is called as main transformer). The other transformer is called as teaser transformer. Scott connection can also be used for three phase to two phase conversion. The connection is made as shown in the figure below.



THREE PHASE TRANSFORMER

TRANSFORMER WINDING IDENTIFICATION

We now know that there are four different ways in which three single-phase transformers may be connected together between their primary and secondary three-phase circuits. These four standard configurations are given as: Delta-Delta (Dd), Star-Star (Yy), Star-Delta (Yd), and Delta-Star (Dy).

Transformers for high voltage operation with the star connections has the advantage of reducing the voltage on an individual transformer, reducing the number of turns required and an increase in the size of the conductors, making the coil windings easier and cheaper to insulate than delta transformers.

Connection	Primary Winding	Secondary Winding
Delta	D	d
Star	Y	y
Interconnected	Z	z

The delta-delta connection nevertheless has one big advantage over the star-delta configuration, in that if one transformer of a group of three should become faulty or disabled, the two remaining ones will continue to deliver three-phase power with a capacity equal to approximately two thirds of the original output from the transformer unit.

THREE PHASE TRANSFORMER

ADVANTAGES/DISADVANTAGES OF A THREE-PHASE TRANSFORMER

The advantages and disadvantages of a three-phase transformer are discussed below.

Advantages of a three-phase transformer

1. Needs less space to install and it is easier to install
2. Less weight and reduced size
3. Higher efficiency
4. Low cost
5. Transportation cost is low

Disadvantages of a three-phase transformer

1. The entire unit shuts down in case of fault or loss occurs in any one unit of a transformer as a common core is shared by all three units.
2. Repair costs are higher
3. Cost of spare units are high

THREE PHASE TRANSFORMER

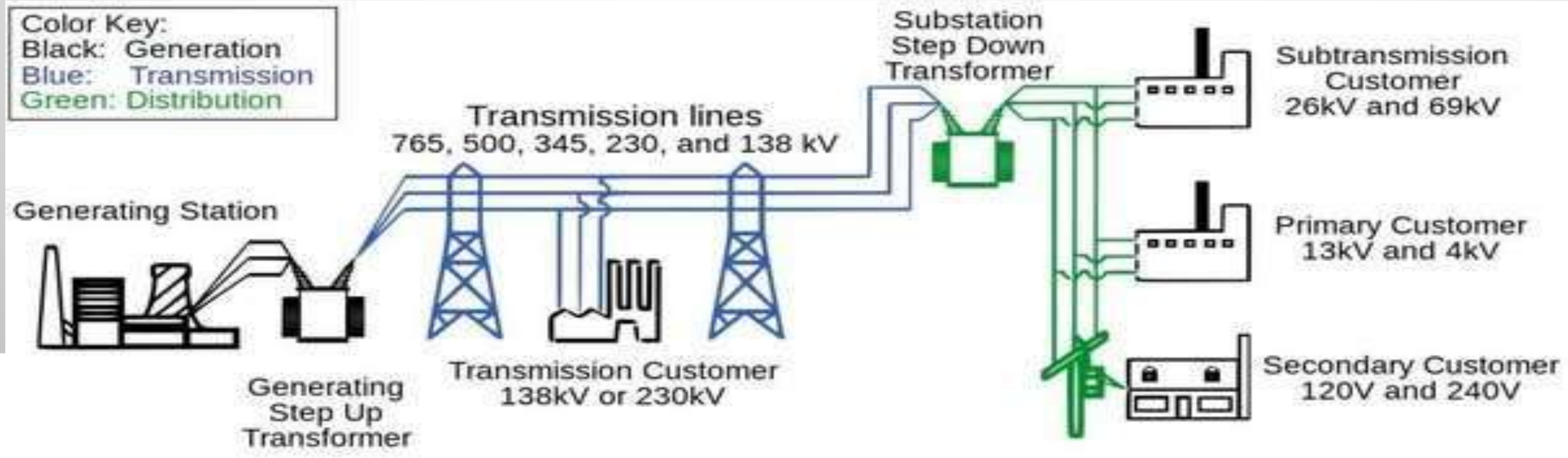
THREE PHASE TRANSFORMER APPLICATION

Three Phase transformers are widely used as Power transformers, Distribution transformers and in Electrical Grids.

1. When we generate the Power using an alternator(AC), the voltage at which it is generated is of mostly 11KV(Sometimes a bit more than that but not too high due to insulation constraints). For transmitting purpose we install a transformer just after the generator so that it can step up/down the voltage). Moreover, it is better to generate in 3 phase rather than 1 phase due to many advantages. Therefore, the transformer you have to use should be a 3 phase one.

2. Some loads such as industrial, and commercial require 3 phase transformers to meet their demand.

3. The transmission voltage such as 132/220 KV, we need step up/down in the both ends of Transmission lines. There are lots of applications of 3 phase transformers, I am just giving an idea of its major application. Hope it'll help you.



Module:5

THREE PHASE TRANSFORMER

Topic:

- TYPES OF THREE PHASE TRANSFORMER
- DIFFERENT CONSTRUCTIONAL PARTS OF THREE PHASE TRANSFORMER

THREE PHASE TRANSFORMER

TYPES OF THREE PHASE TRANSFORMERS

There are different types of transformer based on their usage, design, construction as follow.

A. Types of Transformers based on its Phases

1. Single Phase Transformer
2. Three Phase Transformer

B. Types of Transformers based on its Core Design

1. Core Type Transformer
2. Shell Type Transformer
3. Berry Type Transformer

C. Types of Transformers based on its Core

1. Air core Transformer
2. Ferromagnetic/Iron Core Transformer

THREE PHASE TRANSFORMER

TYPES OF THREE PHASE TRANSFORMERS

D. Types of Transformers based on Voltage level

1. Step Up Transformer
2. Step Down Transformer
3. Isolation Transformer

E. Types of Transformer based on its uses

1. Large Power Transformer
2. Distribution Transformer
3. Small Power Transformer
4. Sign Lighting Transformer
5. Control & Signaling Transformer
6. Gaseous Discharge Lamp Transformer
7. Bell Ringing Transformer
8. Instrument Transformer
9. Constant Current Transformer
10. Series Transformer for Street Lighting

THREE PHASE TRANSFORMER

TYPES OF THREE PHASE TRANSFORMERS

F. Types of Instrument Transformer

1. Current Transformer
2. Potential Transformer
3. Constant Current Transformer
4. Rotating Core Transformer or Induction regulator
5. Autotransformer

G. Types of Transformer based on Insulation & Cooling

1. Self Air Cooled or Dry Type Transformer
2. Air Blast-Cooled Dry Type
3. Oil Immersed, Self Cooled (OISC) or ONAN (Oil natural, Air natural)
4. Oil Immersed, Combination of Self Cooled and Air blast (ONAN)
5. Oil Immersed, Water Cooled (OW)
6. Oil Immersed, Forced Oil Cooled
7. Oil Immersed, Combination of Self Cooled and Water Cooled (ONAN+OW)
8. Oil Forced, Air forced Cooled (OFAC)
9. Forced Oil, Water Cooled (FOWC)
10. Forced Oil, Self Cooled (OFAN)

TYPES OF THREE PHASE TRANSFORMERS

H. According to the winding connection

Windings of a three phase transformer can be connected in various configurations as:

(i) Delta- Delta

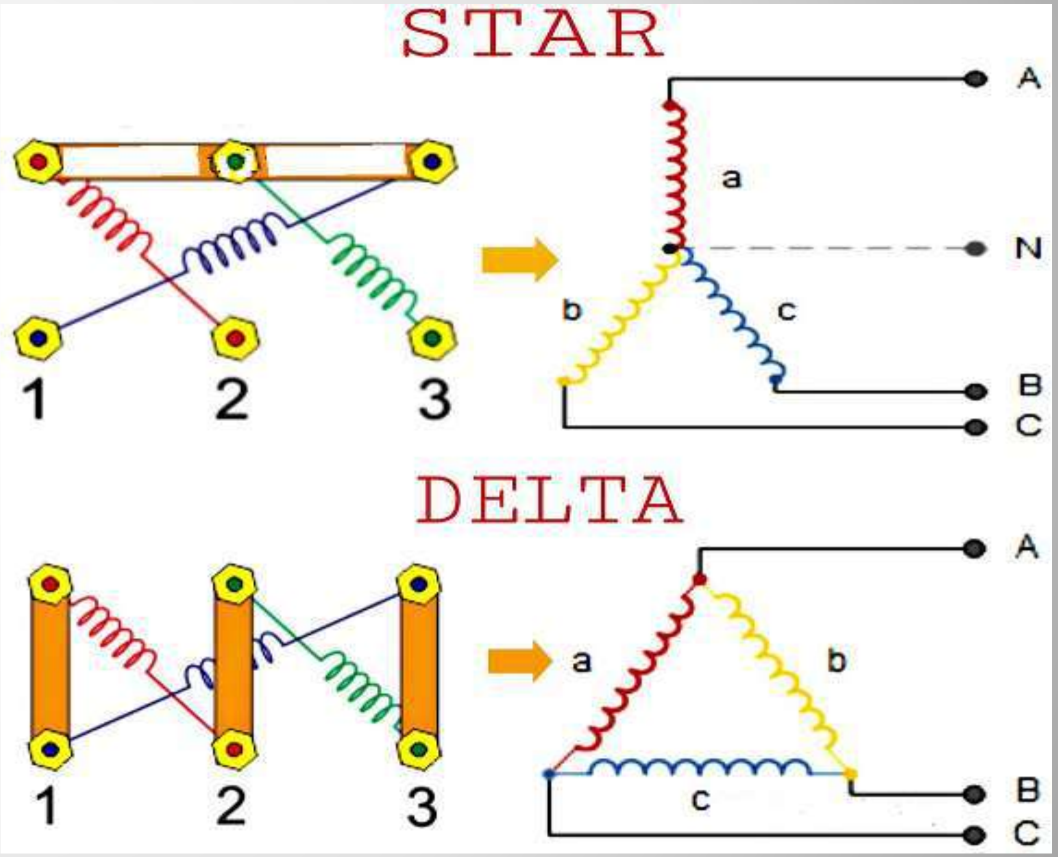
(ii) Delta-Star

(iii) Star-delta

(iv) Star-Star

(v) Open delta Connection

(vi) Scott connection



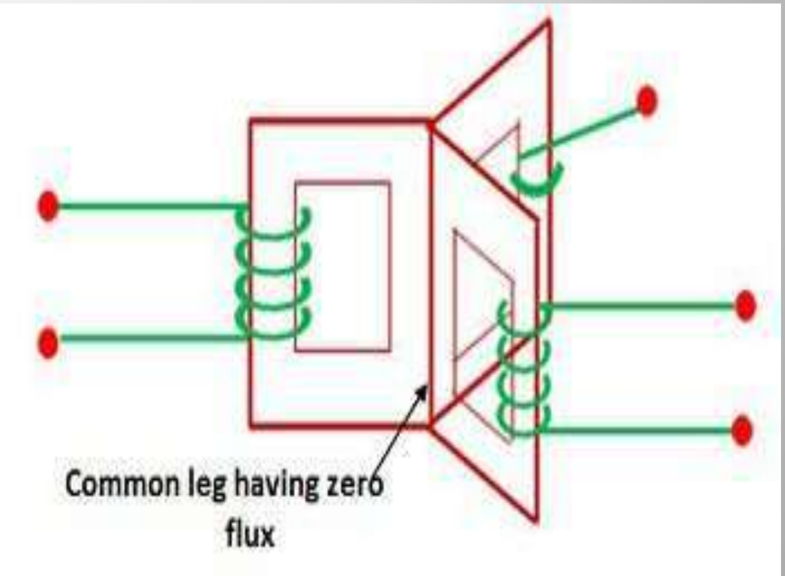
THREE PHASE TRANSFORMER

THREE-PHASE TRANSFORMER CONSTRUCTION

A three phase transformer is used to transfer a large amount of power. The three phase transformer is required to step-up and step-down the voltages at various stages of a power system network. The three phase transformer is constructed in two ways.

1. Three separate single phase transformer is suitably connected for three phase operation.

2. A single three-phase transformer in which the cores and windings for all the three phases are merged into a single structure.



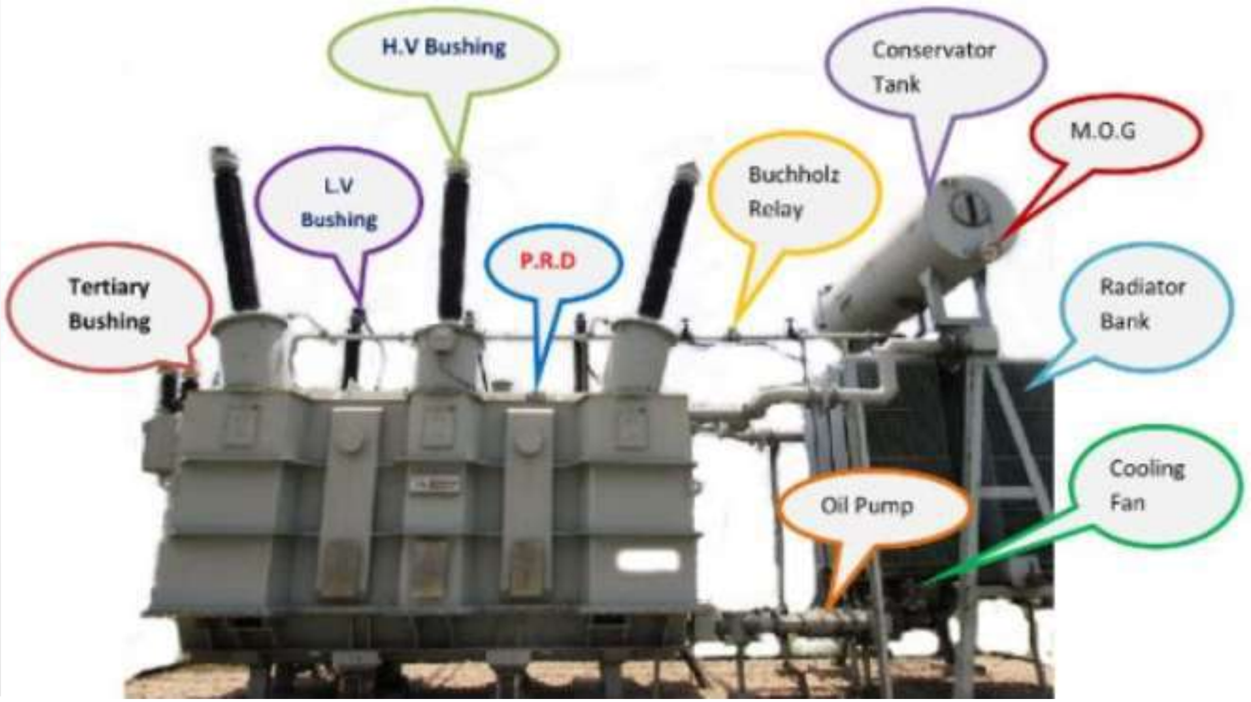
The three single-phase transformer can be used as a three-phase transformer when their primary and secondary winding are connected to each other. The three phase transformer supply has many advantages as compared to three single phase units like it requires very less space and also very lighter smaller and cheaper in size. The three phase transformer is mainly classified into two types, i.e., the core type transformer and the shell type transformer.

THREE PHASE TRANSFORMER

THREE-PHASE TRANSFORMER CONSTRUCTION

The transformer mainly consists of the Magnetic circuit, electric circuit, dielectric circuit, tanks, and accessories. The main elements of the transformer are the primary and secondary windings and the steel core. The core of the transformer is made up of silicon steel in order to provide a continuous magnetic path. Usually, the core of the transformer is laminated for minimizing the eddy current loss.

1. Magnetic circuit
2. Electric circuit
3. Core Type Transformer
4. Shell Type Transformer
5. Dielectric Circuit
6. Tanks and Accessories



THREE PHASE TRANSFORMER

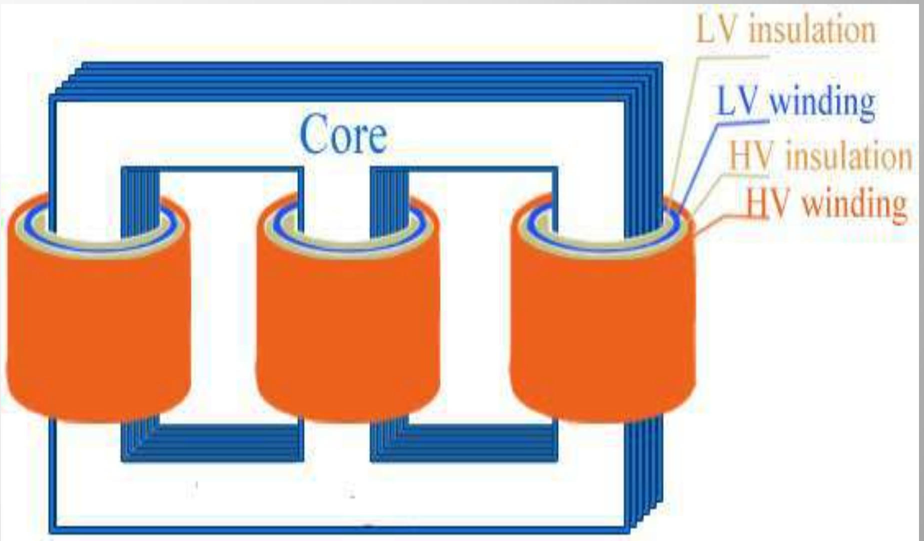
THREE-PHASE TRANSFORMER CONSTRUCTION

1. Magnetic Circuit

The magnetic circuit of a transformer consists of core and yoke. The circuit provides the path to the flow of magnetic flux. The transformer consists of a laminated steel core and the two coils. The two coils are insulated from each other and also from the core. The vertical position on which the coil is wound is called the limb while the horizontal position is known as the yoke.

2. Electric circuit

Construction of the electric circuit of the transformer consists of primary and secondary windings usually made of copper. The Conductors of the rectangular cross-section are generally used for low voltages winding and also for the high voltage winding for large transformers. Conductors of the circular cross-sectional area are used for high voltage winding in the small transformer.

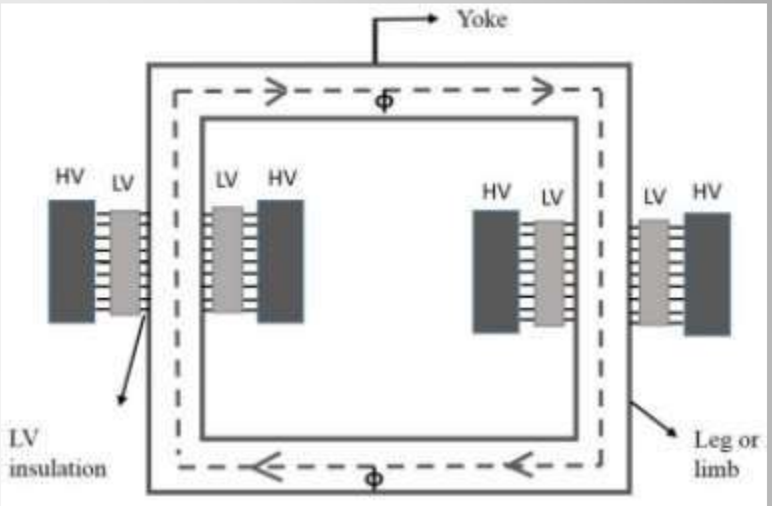


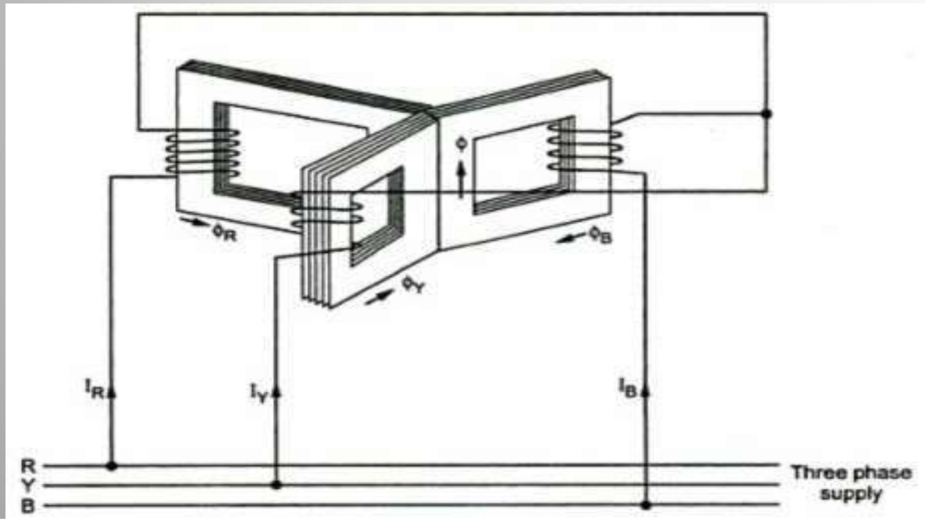
THREE PHASE TRANSFORMER

THREE-PHASE TRANSFORMER CONSTRUCTION

3. Core Type Three Phase Transformer

The core of the three phase transformer is usually made up of three limbs in the same plane. This can be built using stack lamination. The each leg of this core carries the low voltage and high voltage winding. The low voltage windings are insulated from the core than the high voltage windings.



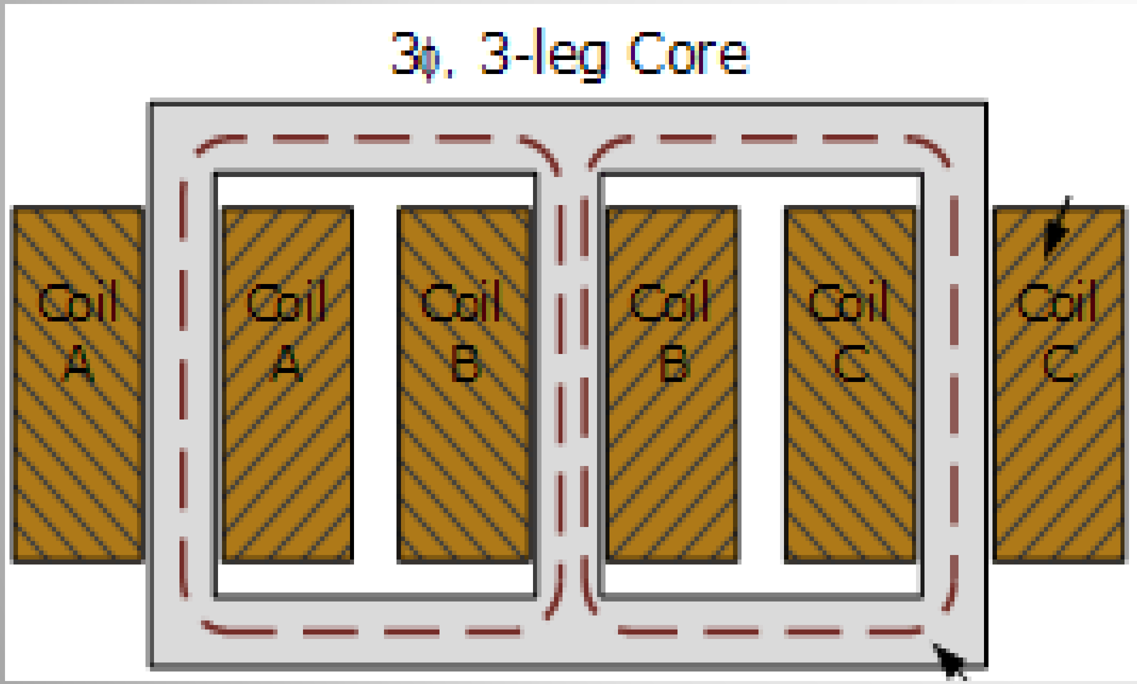


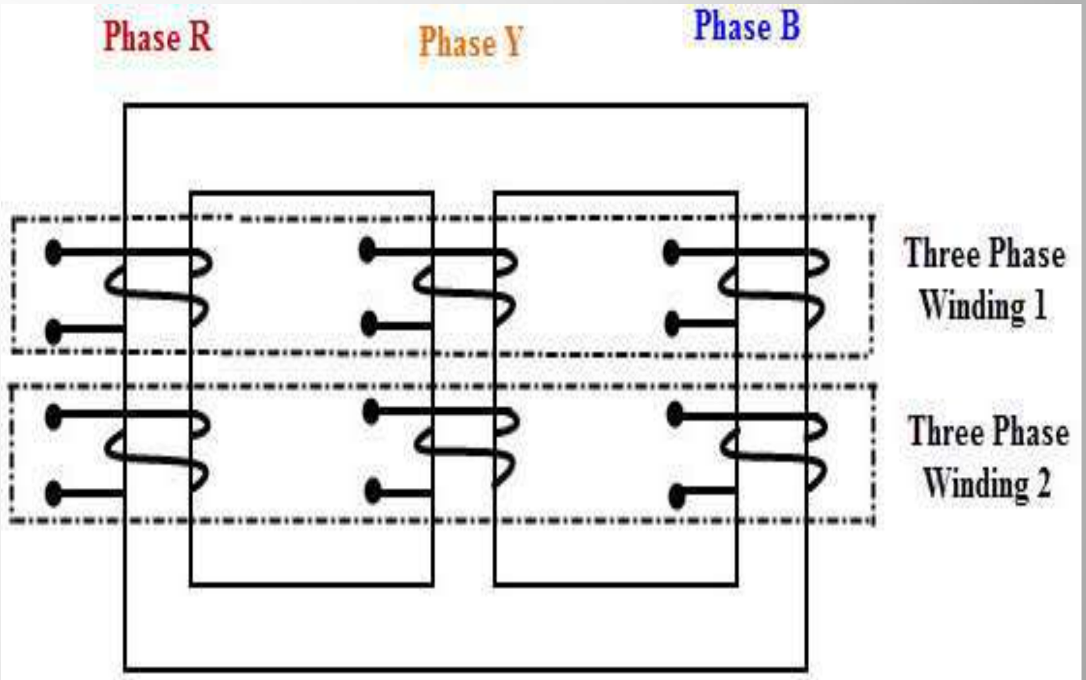
The low windings are placed next to the core with suitable insulation between the core and the low voltage windings. The high voltage windings are placed over the low voltage windings with suitable insulation between them. The magnetic paths of the leg a and c are greater than that of leg b, the construction is not symmetrical, and there is a resultant imbalance in the magnetizing current.

THREE PHASE TRANSFORMER

THREE-PHASE TRANSFORMER CONSTRUCTION

The LV windings are positioned near the core with appropriate insulation and oil ducts in between them whereas, the HV windings are placed above the LV windings with appropriate insulation and oil ducts between them.



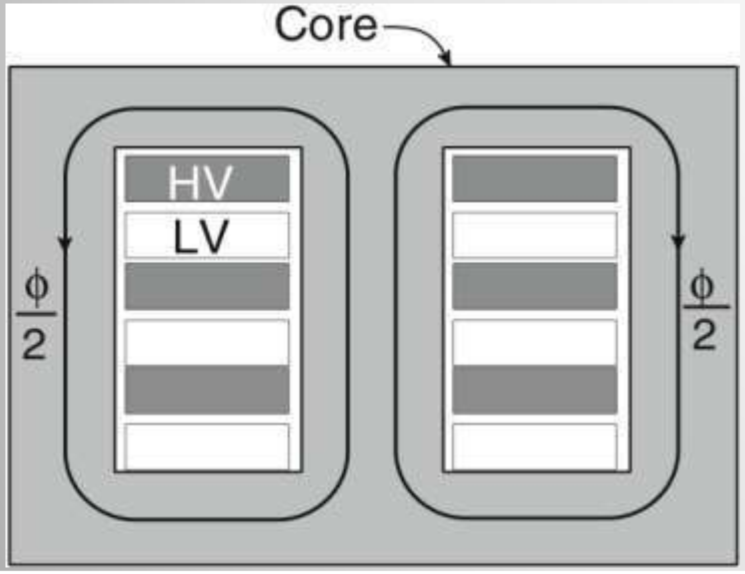


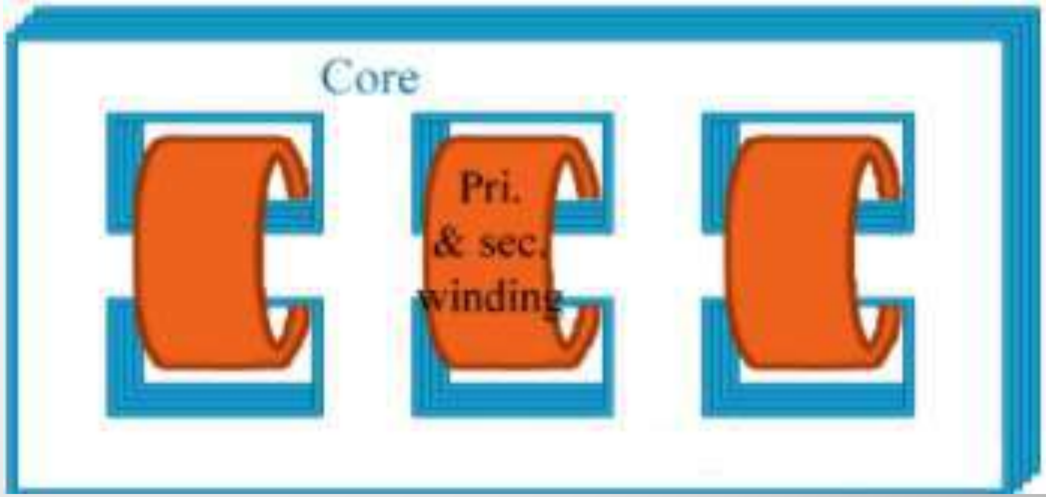
THREE PHASE TRANSFORMER

THREE-PHASE TRANSFORMER CONSTRUCTION

4. Shell Type Transformer

The three-phase shell type transformer is generally constructed by stacking three individual single-phase transformers. Three phases of a shell-type transformer are independent than the core-type transformer, while each phase has an individual magnetic circuit. These magnetic circuits are parallel to each other and flux induced by each winding is in phase. Shell type transformer is highly preferred as the voltage waveforms are less distorted.

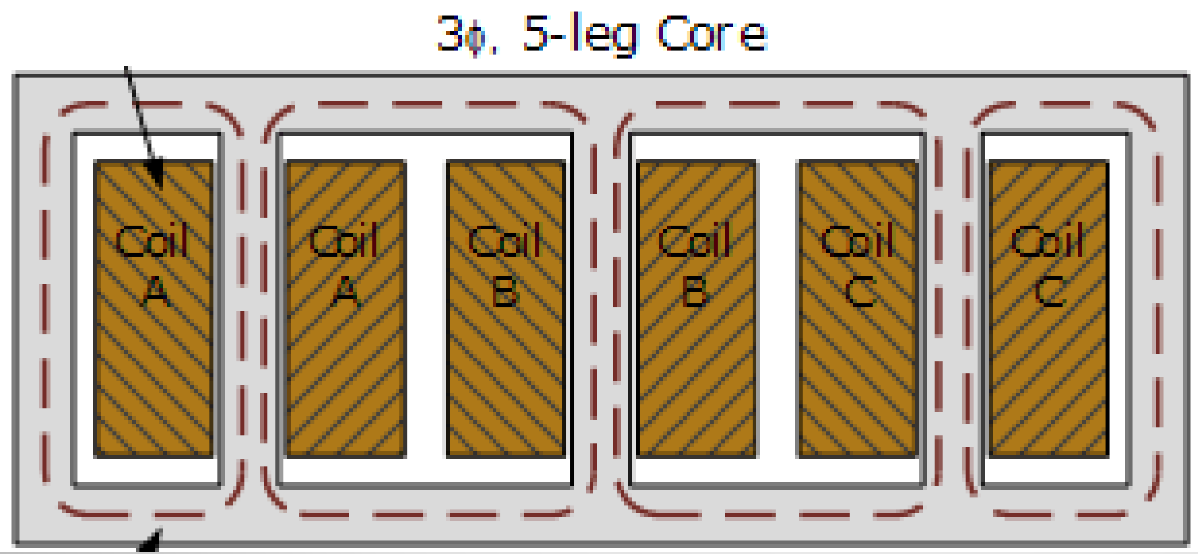


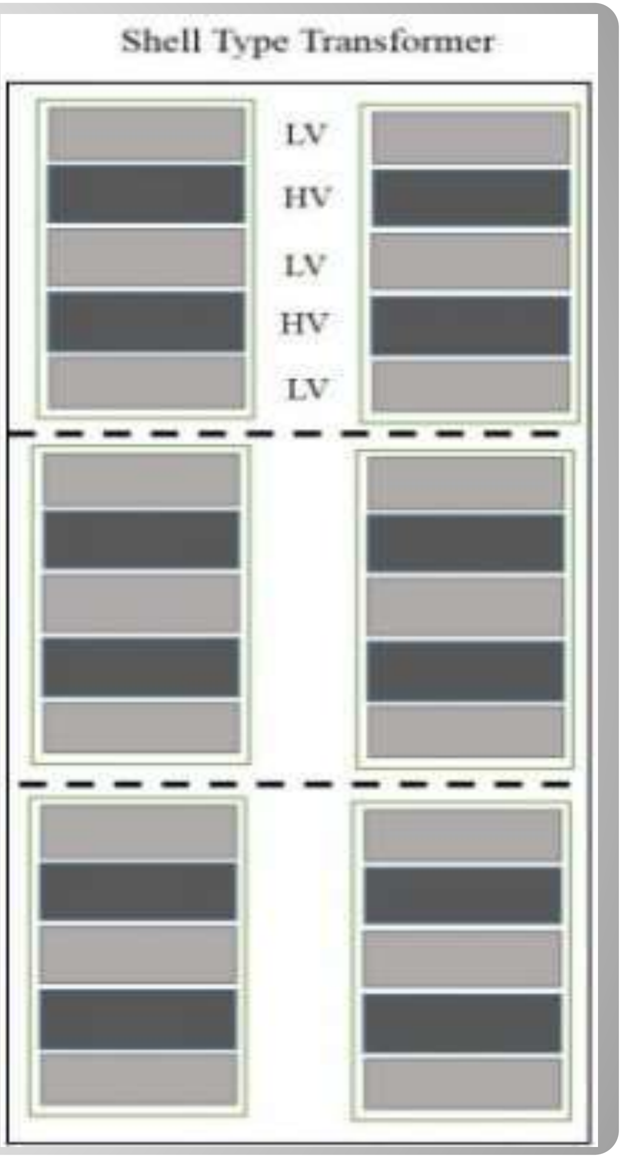


THREE PHASE TRANSFORMER

THREE-PHASE TRANSFORMER CONSTRUCTION

In shell type, three phases are more independent because each phase has independent magnetic circuit compared with core type transformer. The magnetic circuits of this type of transformer are in parallel. Due to this, the saturation effects in common magnetic paths are neglected. However, shell type constructed transformers are rarely used in practice.





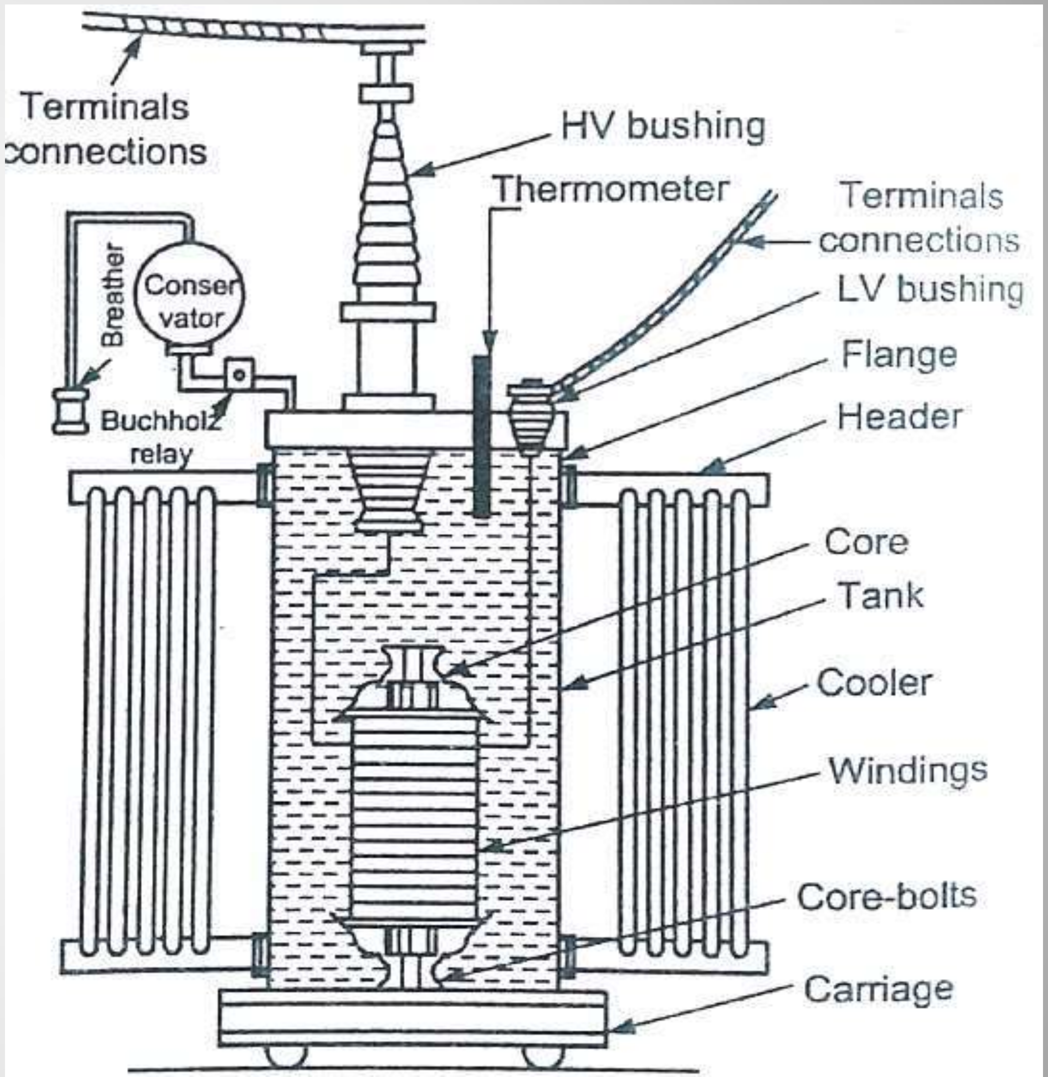
THREE PHASE TRANSFORMER

THREE-PHASE TRANSFORMER CONSTRUCTION

5. Accessories of Transformers:

The various accessories used in the transformer are :

1. Conservator Tank
2. High voltage and Low voltage bushings
3. Breather
4. Buchholz relay
5. Tap changers



THREE PHASE TRANSFORMER

THREE-PHASE TRANSFORMER CONSTRUCTION

1. Conservator Tank

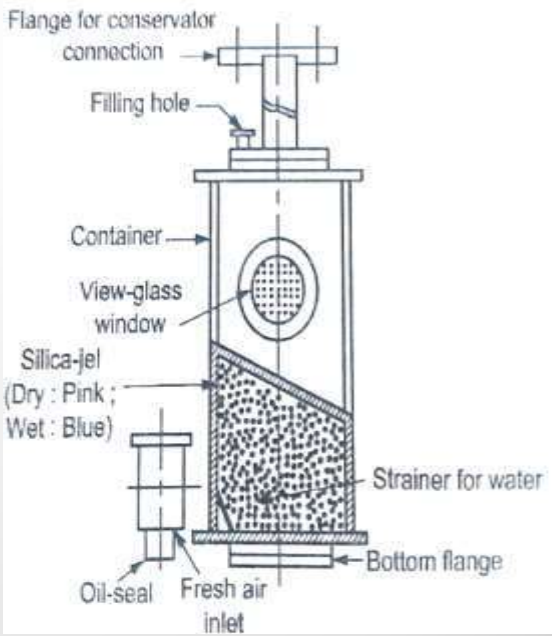
- It is a large size cylindrical tank which is connected by pipe to the transformer.
- The conservator tank is filled with transformer oil up to a certain level.
- The remaining portion of the tank is filled with air.
- Conservator oil is in communication with tank oil.

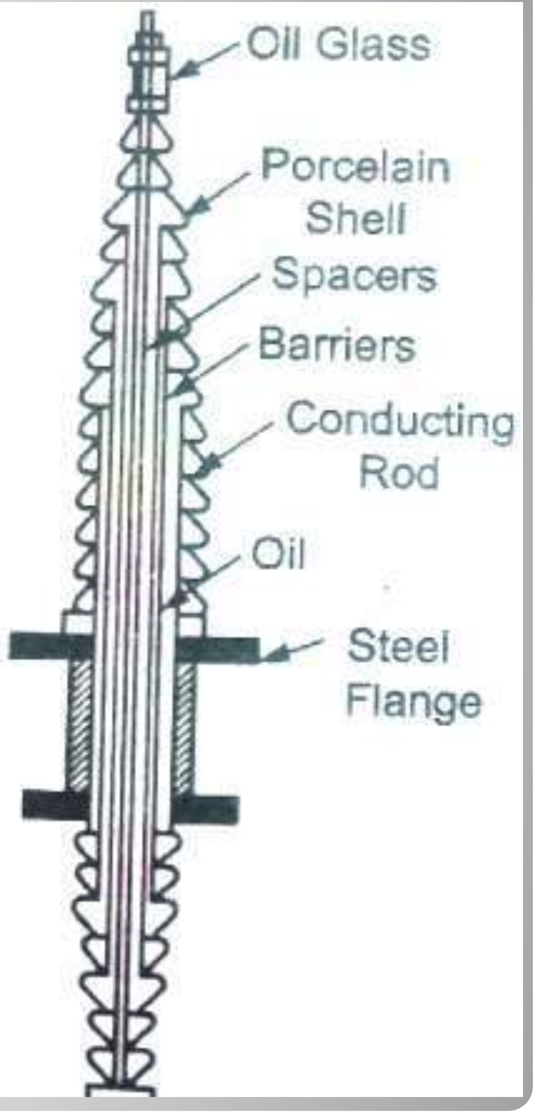
2. High voltage bushings

- The function of high voltage bushings is to provide insulating support to a conductor passing through earthen tank.
- Porcelain bushing can be used up to 20 kV. Such a bushing consists of a single porcelain bushing, through which a single conductor is taken out.
- Oil filled bushing is used for 33 kV applications. For 132 kV and above, oil impregnated paper condenser bushings are used.

3. Breather

The breather is filled with silica gel. the function of silica gel is to absorb moisture.



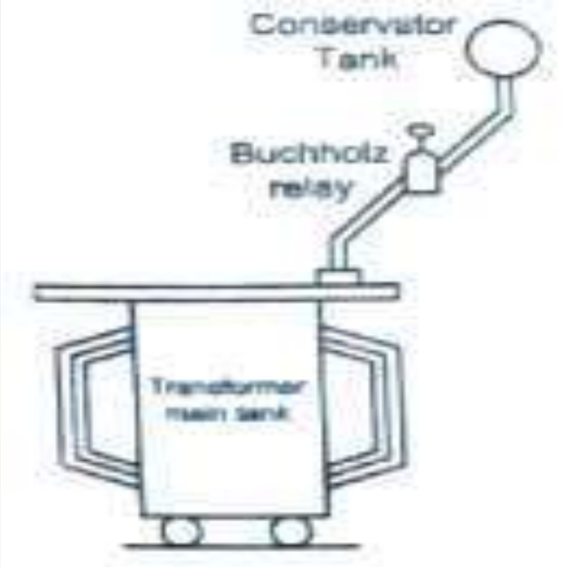


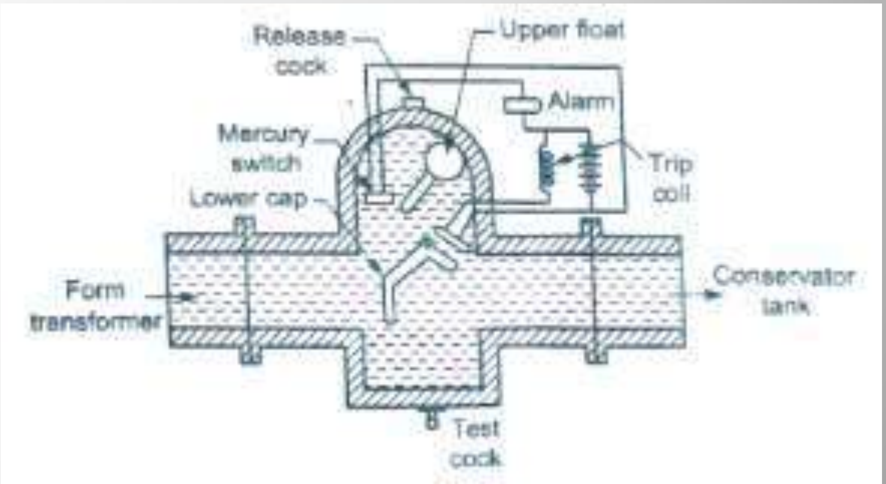
THREE PHASE TRANSFORMER

THREE-PHASE TRANSFORMER CONSTRUCTION

4. Buchholz relay

- These relays are used for the protection of oil immersed transformers against all kinds of internal faults having rating more than 750 kVA.
- It is a gas operated relay which is installed in the pipe connecting the conservator with the main tank.
- Whenever any minor fault occurs, current leaks and heat is produced. Due to this heat some oil evaporates in the transformer tank(about 70%hydrogen).
- Since hydrogen gas is light, it tries to go into the conservator tank via relay. During the process, some gas and oil vapors are collected in the top chamber while passing to the conservator and the oil level in the tank falls.
- The mercury type switch attached to the float is tilted, thereby closing the alarm circuit and the bell rings in the control room.
- This gives a warning to the attendant that some serious fault is going to occur inside the transformer.



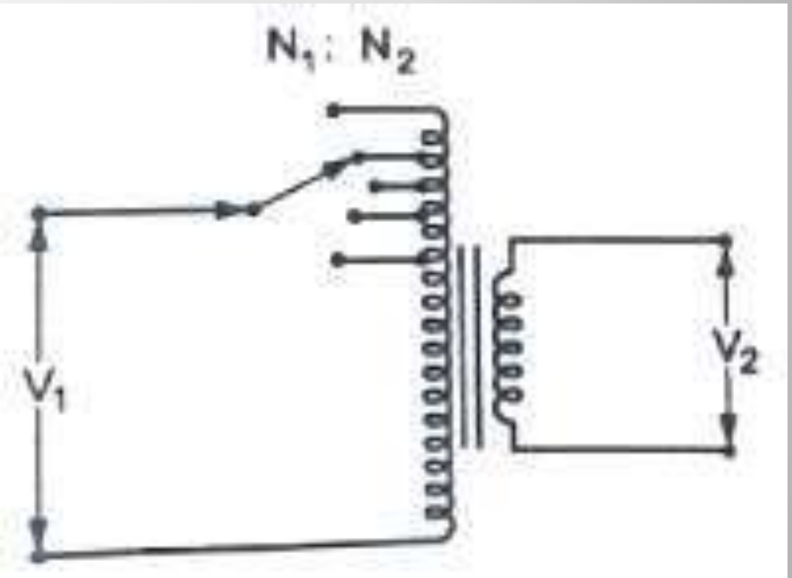


THREE PHASE TRANSFORMER

THREE-PHASE TRANSFORMER CONSTRUCTION

5. Tap Changers

- Tap changer is fitted with the transformer for adjusting the secondary voltage. The adjustments in secondary voltage can be made by OFF circuit tap changer. Such adjustments are for seasonal load variations.
- The tap is changed only after opening the circuit breaker on the supply side. Daily or short time voltage adjustment is made by means of ON load tap changer.
- The tapping of ON-load tap changer can be changed without interruption in load current.
- The modern practice is to install the tap changer within the transformer tank.



Module:5

THREE PHASE TRANSFORMER

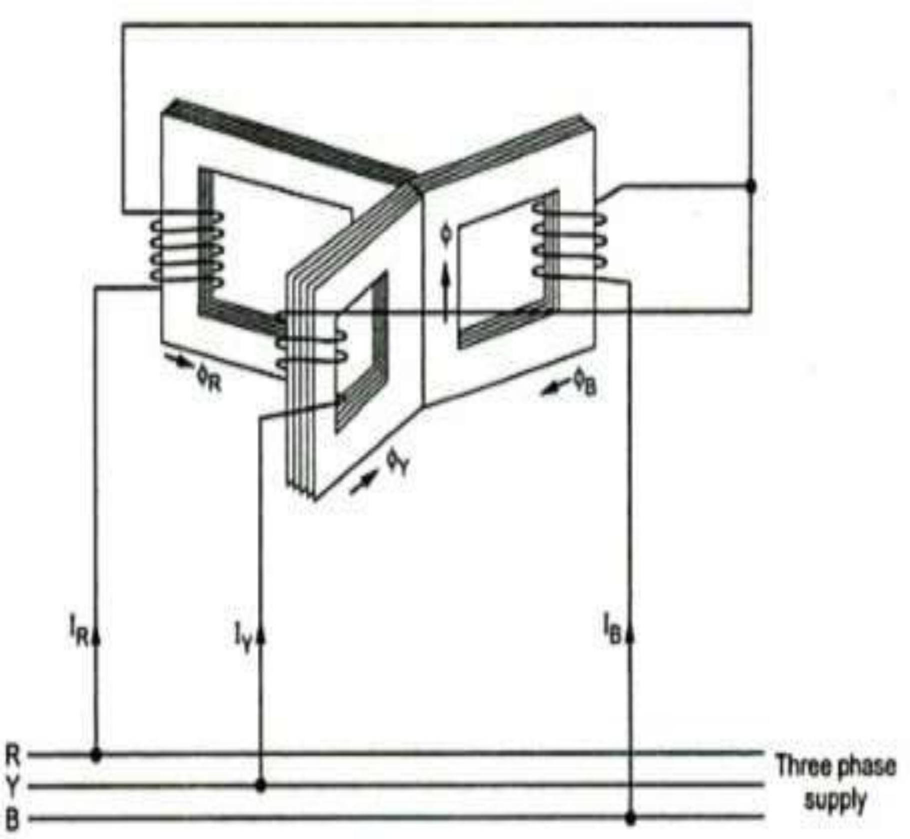
Topic:

- BASIC PRINCIPLE OF THREE PHASE TRANSFORMER
- COMPARISON BETWEEN A SINGLE THREE-PHASE UNIT AND A BANK OF THREE SINGLE-PHASE UNITS
- NAME PLATE DETAILS OF THREE PHASE TRANSFORMER

THREE PHASE TRANSFORMER

OPERATING PRINCIPLE OF THREE PHASE TRANSFORMER

Consider the below figure in which the primary of the transformer is connected in star fashion on the cores. For simplicity, only primary winding is shown in the figure which is connected across the three phase AC supply. The three cores are arranged at an angle of 120 degrees to each other. The empty leg of each core is combined in such that they form center leg as shown in figure.



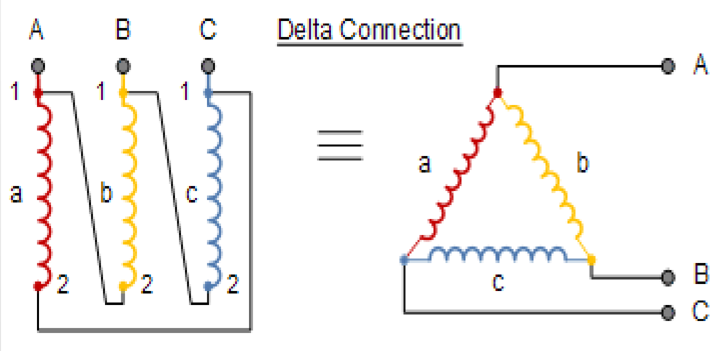
When the primary is excited with the three phase supply source, the currents IR, IY and IB are starts flowing through individual phase windings. These currents produce the magnetic fluxes ΦR, ΦY and ΦB in the respective cores. Since the center leg is common for all the cores, the sum of all three fluxes are carried by it. In three phase system, at any instant the vector sum of all the currents is zero. In turn, at the instant the sum of all the fluxes is same. Hence, the center leg doesn’t carry any flux at any instant. So even if the center leg is removed it makes no difference in other conditions of the transformer.

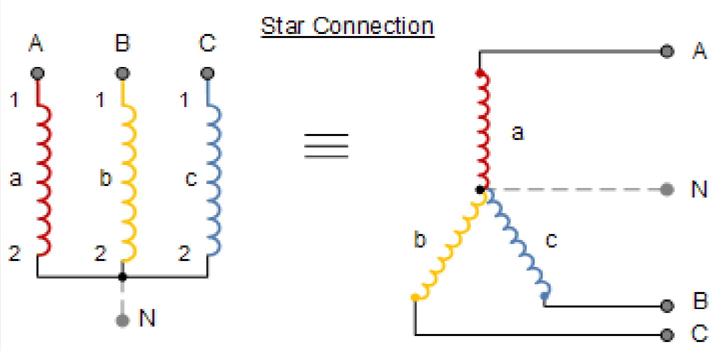
THREE PHASE TRANSFORMER

Three-phase Voltage and Current

Connection	Phase Voltage	Line Voltage	Phase Current	Line Current
Star	$V_P = V_L \div \sqrt{3}$	$V_L = \sqrt{3} \times V_P$	$I_P = I_L$	$I_L = I_P$
Delta	$V_P = V_L$	$V_L = V_P$	$I_P = I_L \div \sqrt{3}$	$I_L = \sqrt{3} \times I_P$

Where again, V_L is the line-to-line voltage, and V_P is the phase-to-neutral voltage on either the primary or the secondary side.





THREE PHASE TRANSFORMER

Three-phase Transformer Line Voltage and Current

Primary-Secondary Configuration	Line Voltage Primary or Secondary	Line Current Primary or Secondary
Delta – Delta	$V_L = n V_p$	$I_L = I_p/n$
Delta – Star	$V_L = \sqrt{3}\, n V_p$	$I_L = I_p/\sqrt{3}\, n$
Star – Delta	$V_L = n V_p/\sqrt{3}$	$I_L = \sqrt{3}\, I_p/n$
Star – Star	$V_L = n V_p$	$I_L = I_p/n$

THREE PHASE TRANSFORMER

Three Phase Transformer Example

The primary winding of a delta-star (Dy) connected 50VA transformer is supplied with a 100 volt, 50Hz three-phase supply. If the transformer has 500 turns on the primary and 100 turns on the secondary winding, calculate the secondary side voltages and currents.

Solution:

$$n = \frac{N_S}{N_P} = \frac{100}{500} = 0.2$$

Given Data: transformer rating, 50VA, supply voltage, 100v, primary turns 500, secondary turns, 100.

$$V_{L(sec)} = \sqrt{3} \times n \times V_{L(pri)}$$
$$= \sqrt{3} \times 0.2 \times 100$$
$$= 34.64\text{Volts}$$

$$V_{P(sec)} = \frac{V_{L(sec)}}{\sqrt{3}} = \frac{34.64}{\sqrt{3}} = 20\text{Volts}$$

Then the secondary side of the transformer supplies a line voltage, V_L of about 35v giving a phase voltage, V_P of 20v at 0.834 amperes.

$$I_{L(pri)} = \frac{VA}{\sqrt{3}\,V_{L(pri)}} = \frac{50}{\sqrt{3} \times 100} = 0.289\text{Amps}$$

$$I_{sec} = \frac{I_{L(pri)}}{\sqrt{3} \times n} = \frac{0.289}{\sqrt{3} \times 0.2} = 0.834\text{Amps}$$

THREE PHASE TRANSFORMER

COMPARISON BETWEEN A SINGLE THREE-PHASE UNIT AND A BANK OF THREE SINGLE-PHASE UNITS

It is found that generation, transmission, and distribution of electrical power are more economical in three phase system than a single phase system. Three phase transformation can be done in two ways, by using a single three-phase transformer or by using a bank of three single phase transformers.

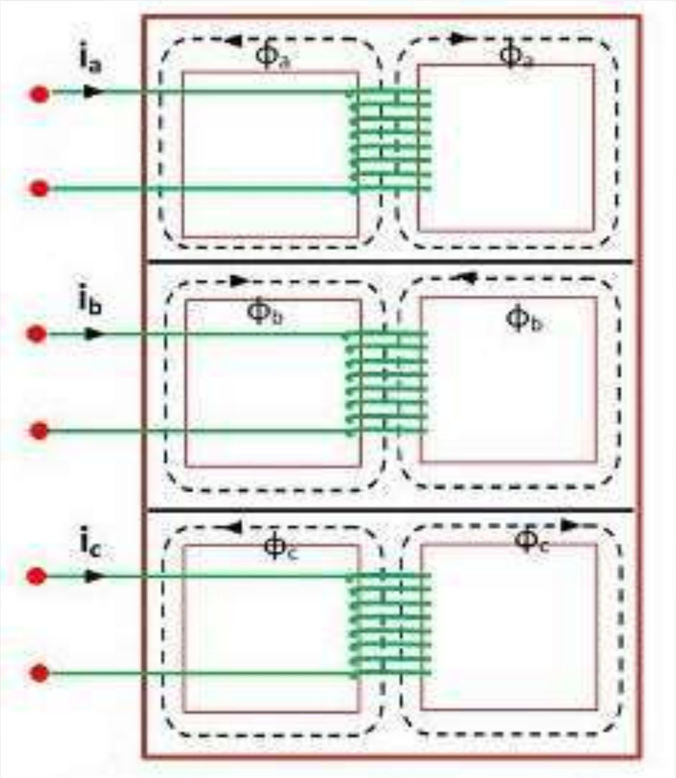
We know that the very basic purpose of Transformer is to transmit power at two different voltage levels. For example, if a generating station is generating electrical power at 11 kV and evacuates it power at 440 kV then a three phase transformer of voltage rating 11 kV / 440 kV is used.

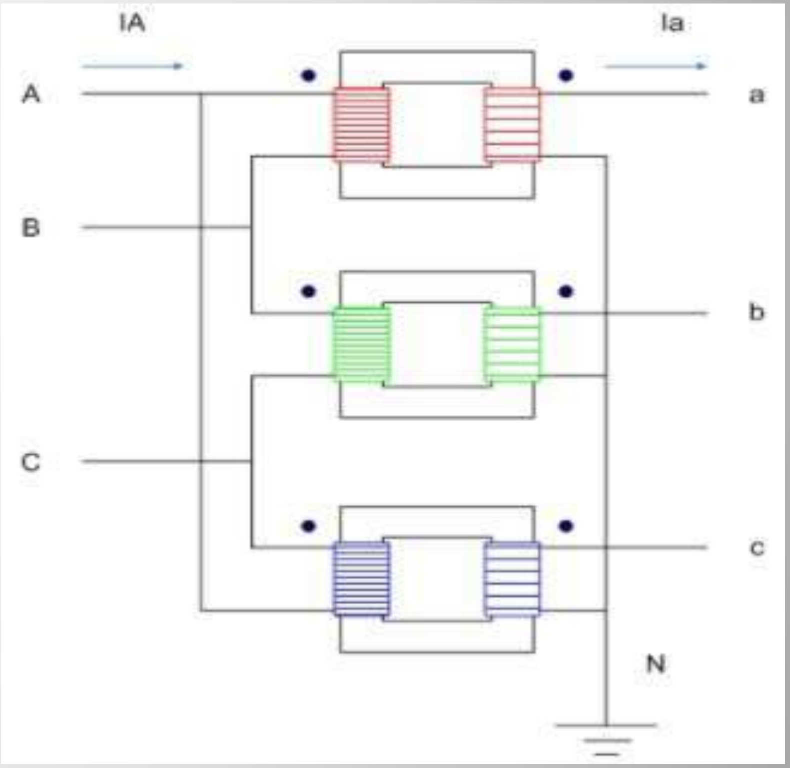
Well, mostly you might have seen a single three phase transformer due to economy. But this does not mean that bank of three single phase transformer is never used. If ever you get a chance to visit 700 MW or 1000 MW power plant, you will see the use of bank of three single phase transformer instead of a single three phase transformer.

THREE PHASE TRANSFORMER

COMPARISON BETWEEN A SINGLE THREE-PHASE UNIT AND A BANK OF THREE SINGLE-PHASE UNITS

A single 3 phase transformer costs around 15 % less than a bank of three single phase transformers. Again former occupies less space than later. For a very big transformer, it is impossible to transport a large three-phase transformer to the site and is instead easier to transport three single-phase transformers, which are erected separately to form a three-phase unit.





THREE PHASE TRANSFORMER

COMPARISON BETWEEN A SINGLE THREE-PHASE UNIT AND A BANK OF THREE SINGLE-PHASE UNITS

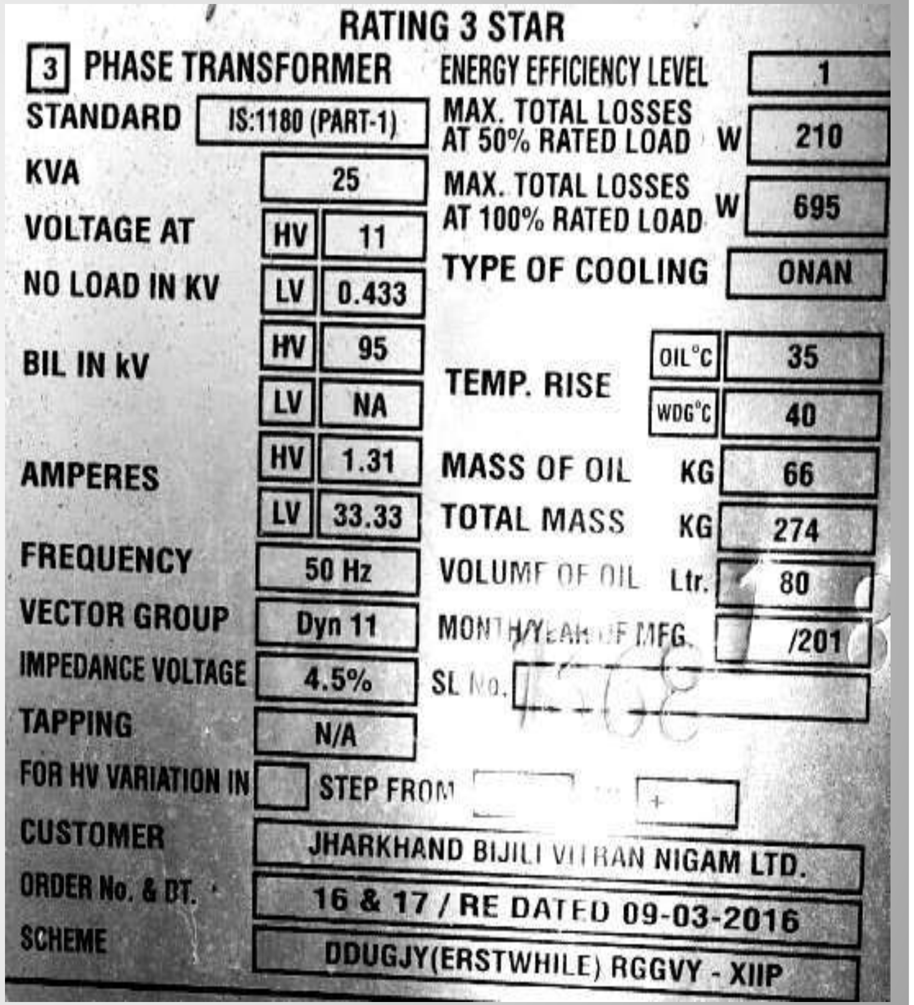
Bank of 3 Single Phase Transformer	Single Three Phase Transformer
It is more expensive due to requirement of 3 single phase transformer. 3 single phase transformer means requirement of more iron for core, oil and accessories.	It is quite economic due to the use of less iron core, less volume of tank and hence less volume of Transformer Oil.
In such case star or delta connection on HV side requires six different HV Bushings to bring out the HV terminals of 3 single phase transformers.	This only requires three / four HV Bushings as the delta / star connection is done inside the tank of transformer.
Space requirement is more for installation.	Less space requirement for installation.
It offers greater flexibility in erection and installation.	Due to single unit, it doesn’t have any flexibility in erection and installation.
The spare inventory cost is less. Only one single phase transformer is required as spare which is less costly. Suppose a generating station has 2 generating units. For both the generating units (2xbank of three single phase transformer), only one single phase transformer is required as spare.	The cost of single three phase transformer as spare is quite high when compared with a single unit of single phase transformer.
The maintenance becomes easier due to separate units. Replacement of single unit is also easy.	It is quite difficult to repair and replace.
This is less efficient due to losses in the three units. The losses are more due to use of more iron core.	It is more efficient and losses are less due to lesser requirement of iron core.

THREE PHASE TRANSFORMER

TRANSFORMER NAMEPLATE DETAILS

Transformer nameplates contain several standard items of information and other optional information. Transformer nameplate must specify the following parameters:

1. Name of manufacturer
2. Serial number
3. year of manufacture
4. Number of phases
5. kVA or MVA rating
6. Frequency
7. Voltage ratings.
8. Tap voltages.
9. Connection diagram.
10. Cooling class
11. Rated temperature in °C
12. Polarity (for Single Phase Transformers)
13. % impedance.
14. Approximate mass or weight of the transformer
15. Type of insulating liquid.
16. Conductor material of each winding.
17. Oil volume (of each transformer Container/Compartment)
18. Instruction for Installation and Operation



THREE PHASE TRANSFORMER

TRANSFORMER NAMEPLATE DETAILS

==

S.No.	Description of Data to be given	Ra-marks for example
======	======	======
[1]	[2]	[3]
1.	Manufacturer's Name:	ABB/206788
2.	Manufacture's Serial Number	224106
3.	Kind of Transformer	Power Transformer
4.	236839Relevent Standard Year	I.S/P.S/B.S/ IEC /DIS/JIS NEMA
5.	Year of Manufacture	2013
6.	Number of Phase	3
7.	Rated Power	1000kVA = 1MVA
8.	Rated Frequency:	50Hz
9.	Rated Voltages:	HV 33 kV, LV 11 kV,
10.	Rated Currents	HV_______,LV________.
11.	Vector Group Symbol	______________________
12	% Impedance Voltage (At Raed Current)	______________________
13.	% Reactance Voltage in % :	______________________
14.	Types of Cooling	ONAM
15	.Total Weight	____________Kg
	..Mass or insulating Oil	____________Kg
	..Transportation Weight	____________Kg
	..Untanking Weight	____________Kg
16.	Insulating liquid (if Not Oil) Types:	_________________
17.	Quantity of Oil (Liters):	____________
18.	Details about Tap-Changer	____________
19.	Rated insulation Level:	____________
	..Power-Frequency withstand Voltage	kV(rms)
20.	Other	....

Module:5

THREE PHASE TRANSFORMER

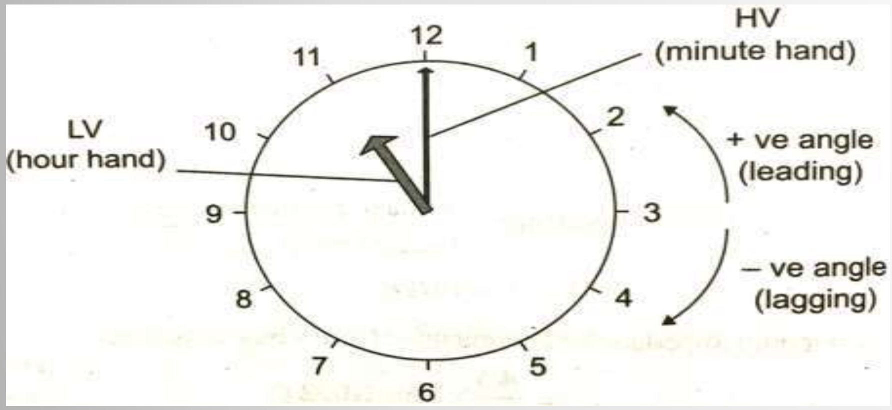
Topic:

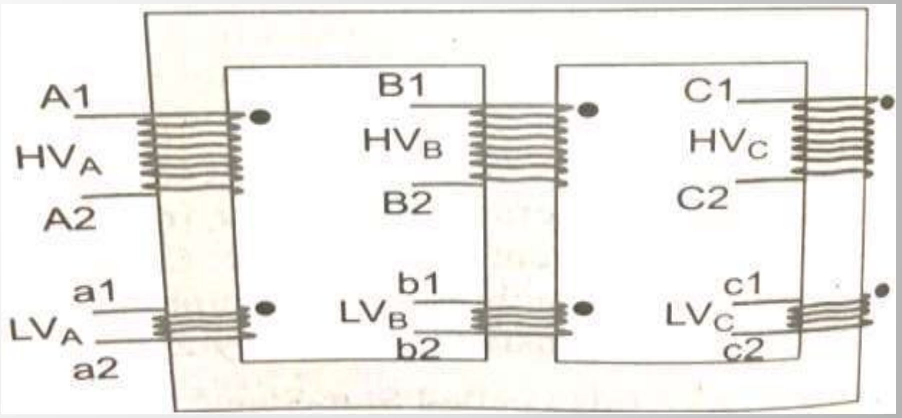
- VECTOR GROUP OF 3-PHASE TRANSFORMER

THREE PHASE TRANSFORMER

TRANSFORMER VECTOR GROUPS

The primary windings are connected in one of several ways. The two most common configurations are the delta, in which the polarity end of one winding is connected to the non-polarity end of the next, and the star, in which all three non-polarities (or polarity) ends are connected together. The secondary windings are connected similarly. This means that a 3-phase transformer can have its primary and secondary windings connected the same (delta-delta or star-star), or differently (delta-star or star-delta).





It's important to remember that the secondary voltage waveforms are in phase with the primary waveforms when the primary and secondary windings are connected the same way. This condition is called "no phase shift." But when the primary and secondary windings are connected differently, the secondary voltage waveforms will differ from the corresponding primary voltage waveforms by 30 electrical degrees. This is called a 30 degree phase shift. When two transformers are connected in parallel, their phase shifts must be identical; if not, a short circuit will occur when the transformers are energized."

THREE PHASE TRANSFORMER

TRANSFORMER VECTOR GROUPS

Vector Grouping is a theoretical approach to identify or understand the nature of the connection between three phases of the primary and secondary winding along with the phase shift between the primary and secondary winding voltage of a three-phase transformer.

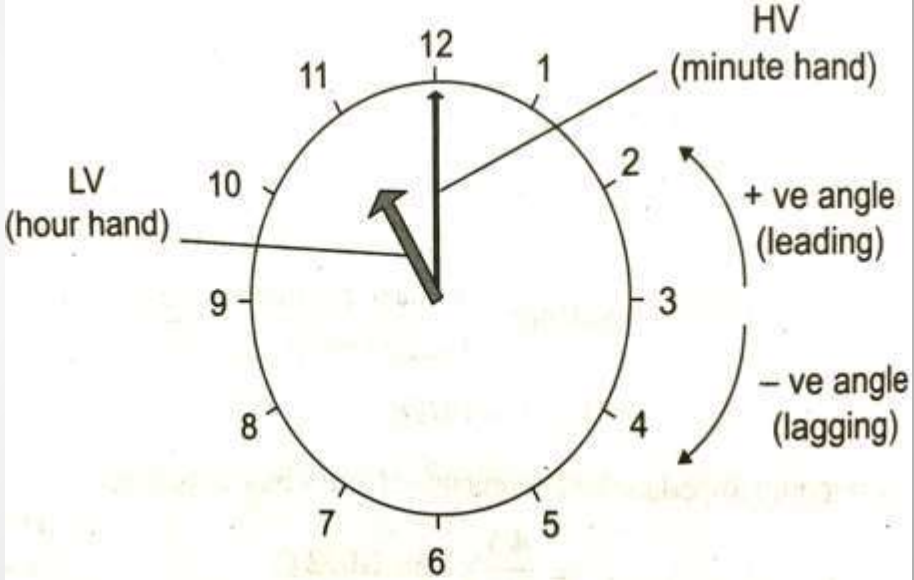
For example, 'Dyn11' implies that,

'D' indicates the high voltage winding of the transformer is Delta connected.

'y' indicates the low voltage winding of the transformer is Star connected.

Here, 'n' indicates that a terminal is brought out from the Star point of the star connection or in simple word it has a neutral terminal.

'11' indicates that the phase shift between the high voltage and low voltage winding is 30 degree leading.



A vector group is the International Electro technical Commission (IEC) method of categorizing the high voltage (HV) windings and low voltage (LV) winding configurations of three-phase transformers.
The vector group designation indicates the windings configurations and the difference in phase angle between them.
Example: a wye HV winding and delta LV winding with a 30-degree lead is denoted as "Yd11".

THREE PHASE TRANSFORMER

TRANSFORMER VECTOR GROUPS

NEED OF VECTOR GROUPING IN THREE PHASE TRANSFORMER

1. The vector group of a transformer indicates what type of connection is made between the windings of that transformer. It also indicates what is the phase difference between the primary and secondary winding voltage of that transformer.

2. So we must know the vector group when connecting two or more transformers in parallel. Because if we connect two transformers of different vector groups in parallel, a large amount of circulating current will flow between those two transformers which will affect the transformers and their working.

3. If we do not know the vector group of a transformer, then we cannot find out the no-load current, iron loss properly.

4. If we do not know the vector group of the transformer, then we also cannot draw the proper input, output voltage, and current waveforms.

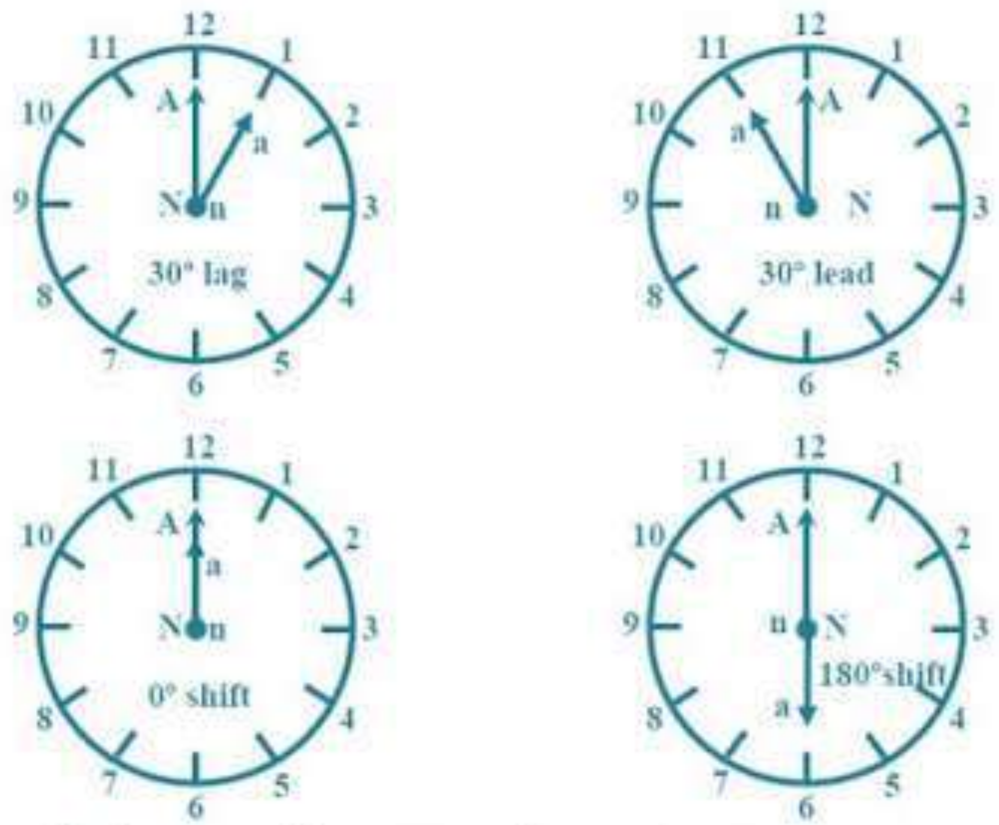
THREE PHASE TRANSFORMER

TRANSFORMER VECTOR GROUPS

As we know that the secondary voltages of a 3-phase transformer may undergo a phase shift of either +30° leading or -30° lagging or 0° i.e. no phase shift or 180° reversal with respective line or phase to neutral voltages.

On the name plate of a three phase transformer, the vector group is written as Yd11, Dyn11 etc. Typical representation of the vector group could be Yd1 or Dy11 etc

The minute hand is used to represent the primary phase to neutral voltage and always shown to occupy the position 12. The hour hand represents the secondary phase to neutral voltage and may, depending upon phase shift, occupy position other than 12.



Clock convention representing vector groups.

The angle between two consecutive numbers on the clock is 30°.

THREE PHASE TRANSFORMER

TRANSFORMER VECTOR GROUPS

BASIC IDEA ABOUT TRANSFORMER VECTOR GROUP

Based on this, it is theoretically possible to connect any pair of windings in a 3 phase transformer in the following pairs of combinations: Dd, Dy, Dz, Yd, Yy, Yz, Zd, Zyand Zz; of this, the first six, are the most commonly encountered ones in practice.

Y => Primary star connection

y => Secondary star connection

D => Delta winding on Primary side

d => Secondary delta winding connection

Z => Primary Zig-Zag connection

z => Secondary Zig-Zag connection

THREE PHASE TRANSFORMER

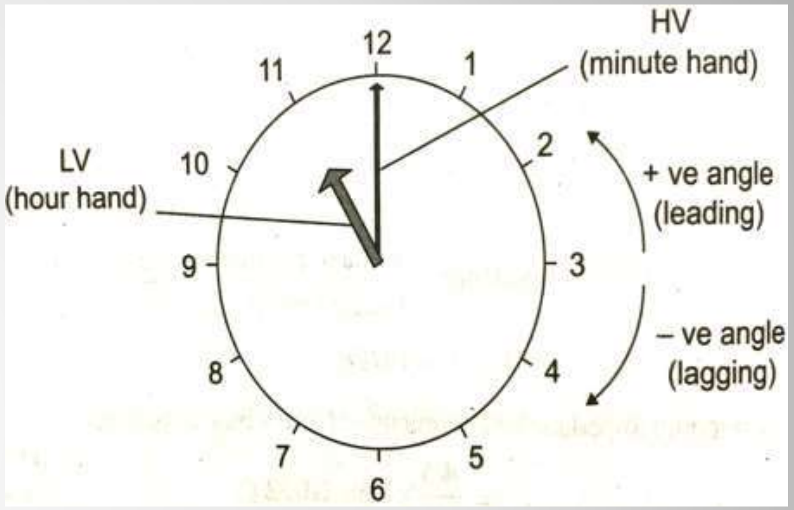
TRANSFORMER VECTOR GROUPS

NUMERICAL IDENTITY

Here the numerical identity indicates the clock position of the phase displacement. It's may be clock wise or anti clockwise. i.e

1. Here the hour indicates phase displacement in angle. Because there are 12 hours on a clock, and a circle consists out of 360°, each hour (I mean one hour) represents 30°.Thus 1 = 30°, 2 = 60°, 3 = 90°, 6 = 180° and 12 = 0° or 360° and so on.

2. The minute hand is set on 12 o'clock and replaces the line to neutral voltage (sometimes imaginary) of the HV winding. This position is always the reference point.



Example:

Digit 0 =0° that the LV phasor is in phase with the HV phasor
Digit 1 =30° lagging (LV lags HV with 30°) because the rotation is anti-clockwise.
Digit 11 = 330° lagging or 30° leading (LV leads HV with 30°)
Digit 5 = 150° lagging (LV lags HV with 150°)
Digit 6 = 180° lagging (LV lags HV with 180°)

THREE PHASE TRANSFORMER

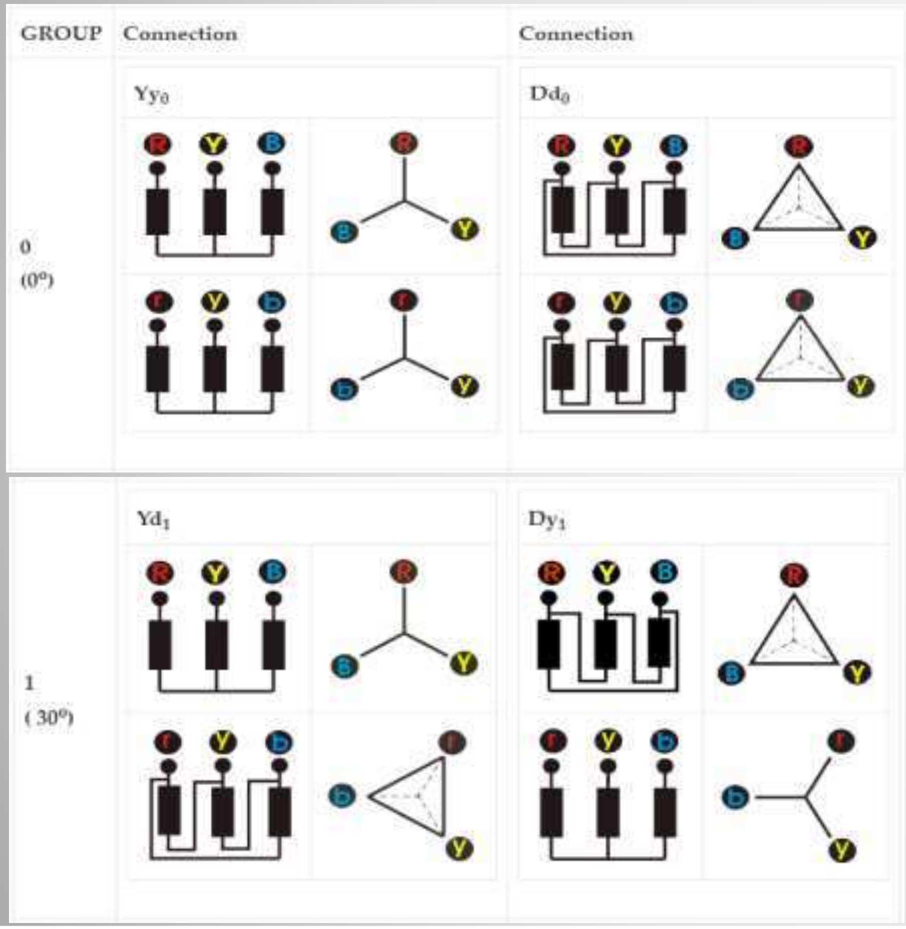
TRANSFORMER VECTOR GROUPS

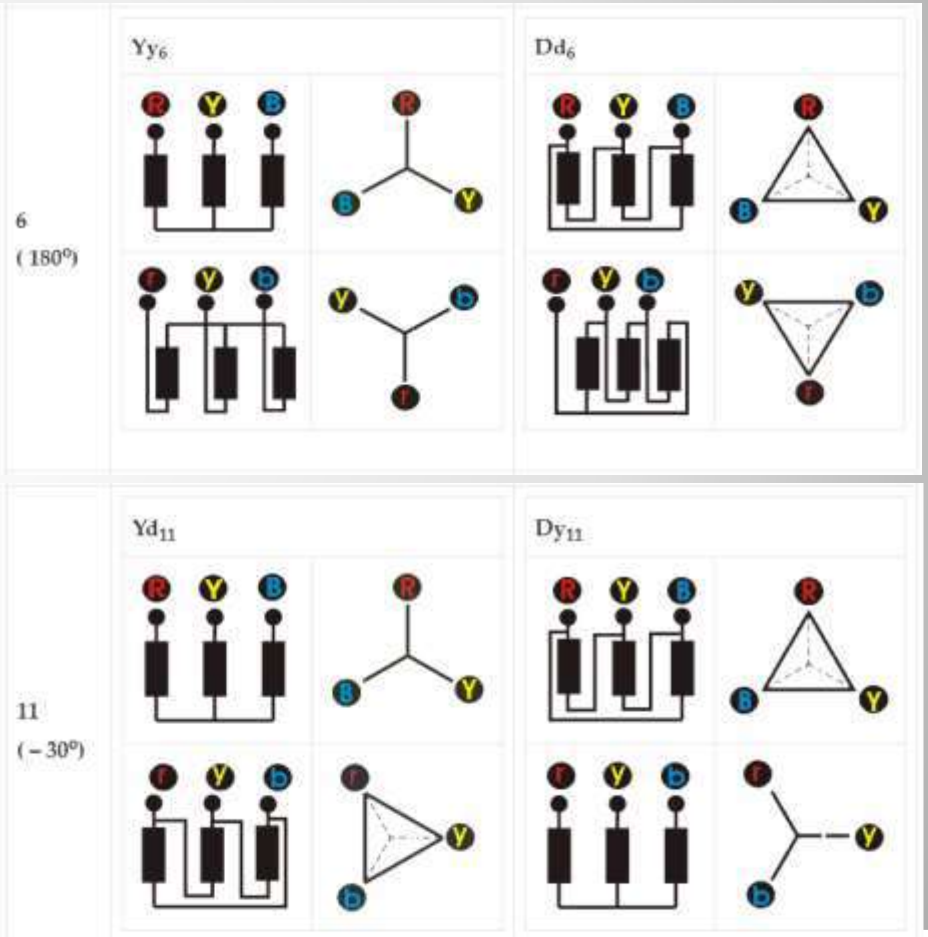
The phase-bushings on a three-phase transformer are marked either ABC, UVW or 123 (HV-side capital, LV-side small letters). Two winding, three-phase transformers can be divided into four main categories

Group	O'clock	TC
Group I	0 o'clock, 0°	delta/delta, star/star
Group II	6 o'clock, 180°	delta/delta, star/star
Group III	1 o'clock, -30°	star/delta, delta/star
Group IV	11 o'clock, +30°	star/delta, delta/star

THREE PHASE TRANSFORMER

TRANSFORMER VECTOR GROUPS





THREE PHASE TRANSFORMER

TRANSFORMER VECTOR GROUPS

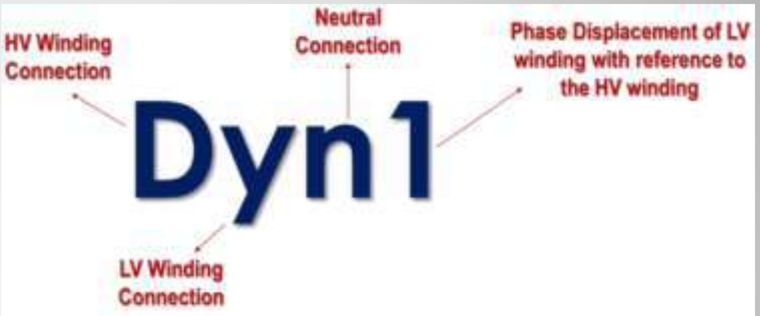
When transformers are operated in parallel it is important that any phase shift is the same through each. Paralleling typically occurs when transformers are located at one site and connected to a common bus bar (banked) or located at different sites with the secondary terminals connected via distribution or transmission circuits consisting of cables and overhead lines.

Phase Shift (Deg)	Connection		
0	Yy0	Dd0	Dz0
30 lag	Yd1	Dy1	Yz1
60 lag		Dd2	Dz2
120 lag		Dd4	Dz4
150 lag	Yd5	Dy5	Yz5
180 lag	Yy6	Dd6	Dz6
150 lead	Yd7	Dy7	Yz7
120 lead		Dd8	Dz8
60 lead		Dd10	Dz10
30 lead	Yd11	Dy11	Yz11

THREE PHASE TRANSFORMER

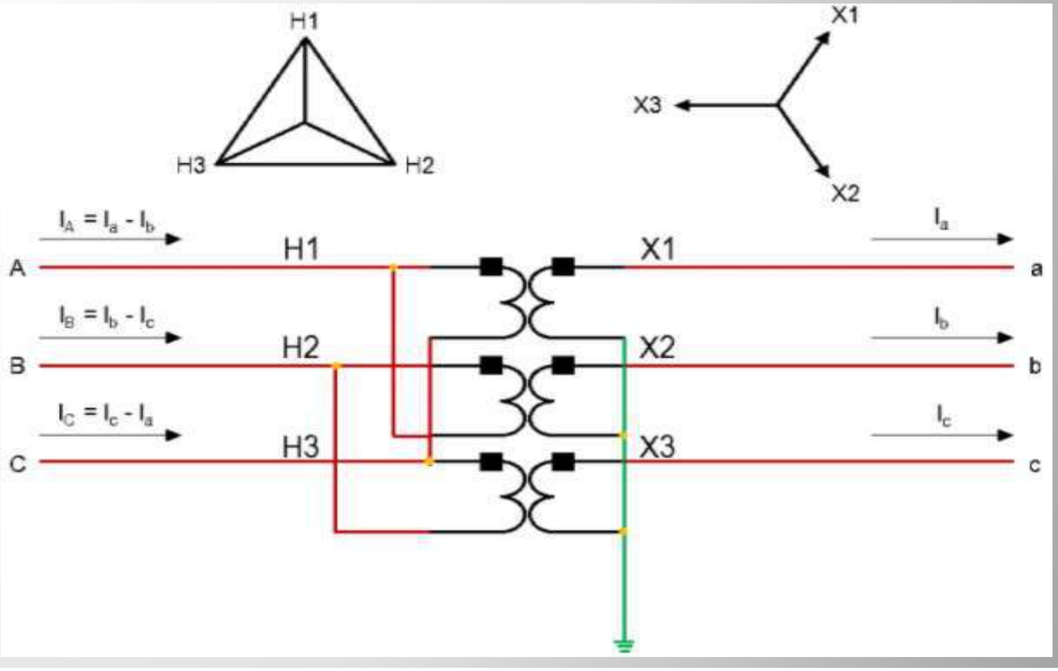
TRANSFORMER VECTOR GROUPS

VECTOR GROUP OF TRANSFORMER Dyn1

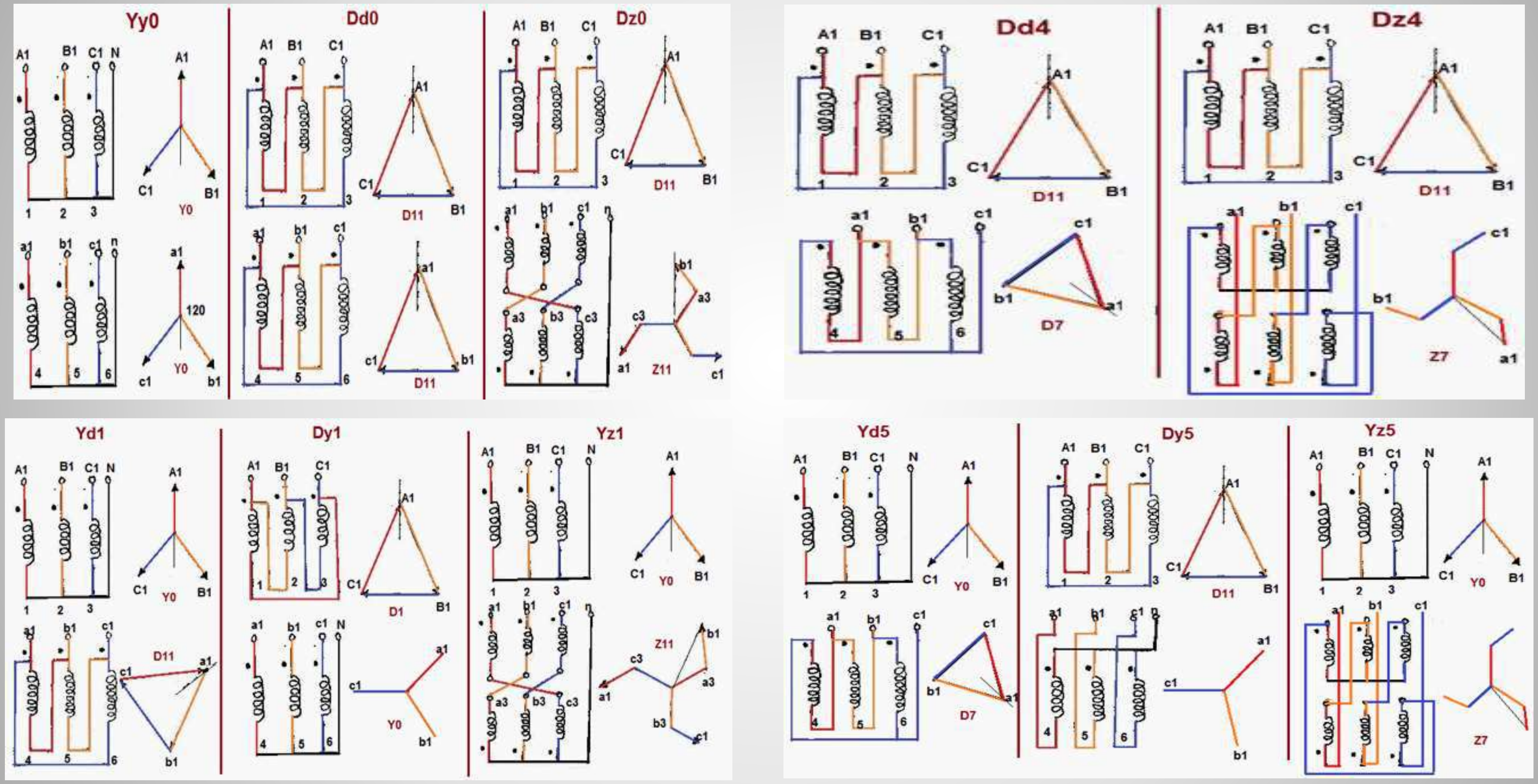


Y or y – star winding
D or d – delta winding
N or n – neutral

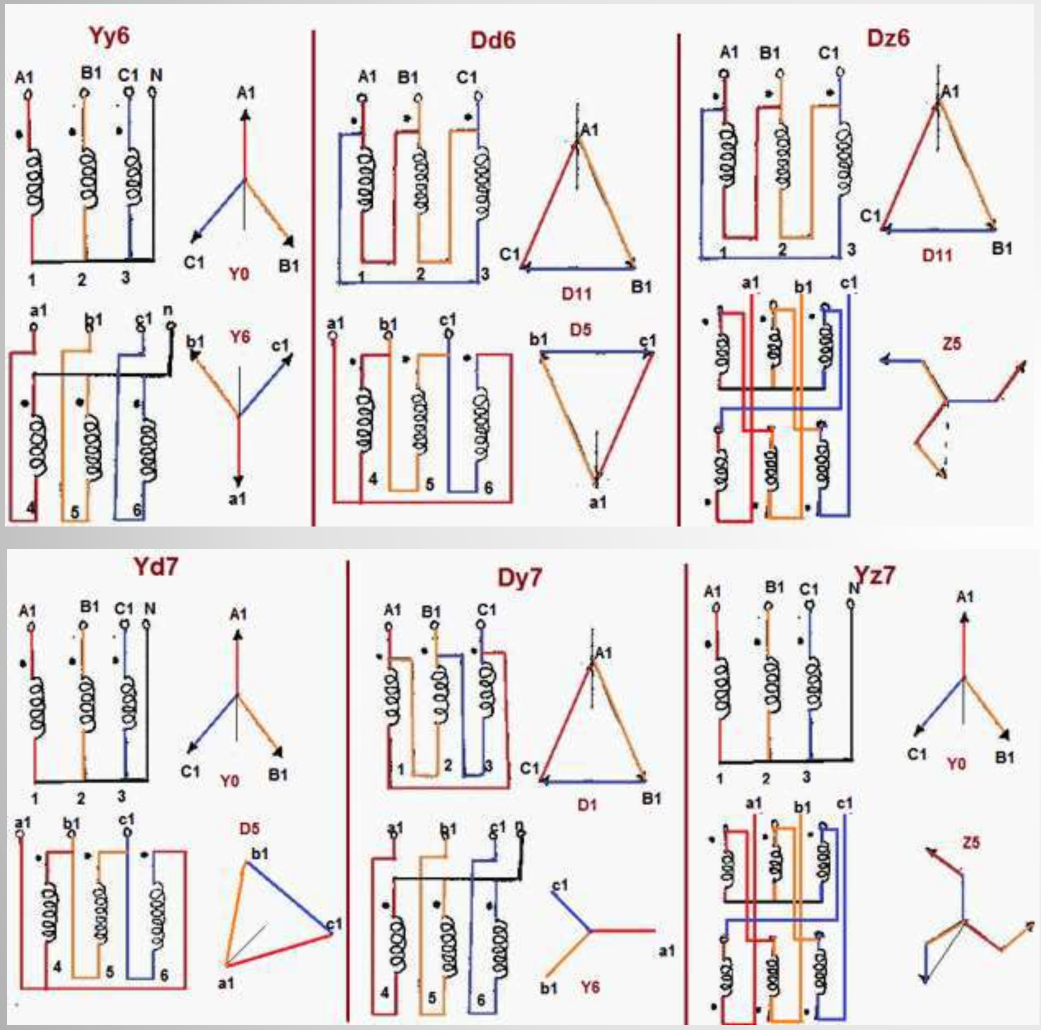
0 to 12 – phase displacement in terms of clock position in multiples of 30°

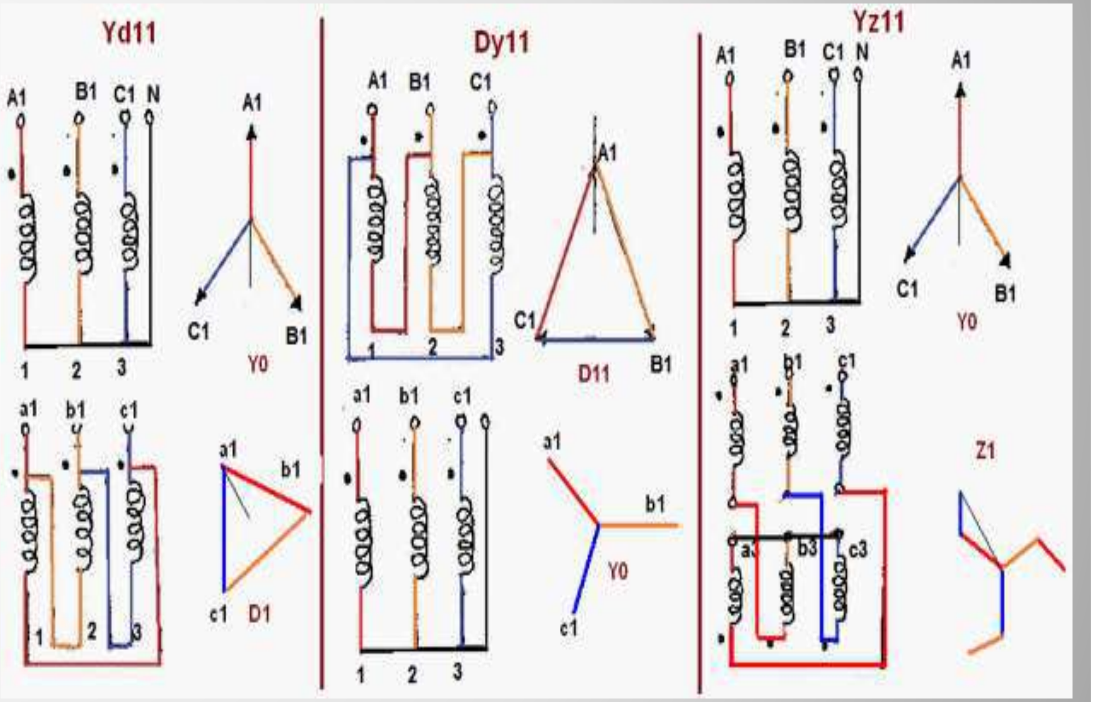


TRANSFORMER VECTOR GROUPS



TRANSFORMER VECTOR GROUPS





THREE PHASE TRANSFORMER

TRANSFORMER VECTOR GROUPS

USE OF A TRANSFORMER VECTOR GROUP

Basically transformer vector group is used to find the high voltage and low voltage windings arrangement of three-phase transformers. The three-phase transformer can be connected in various ways and the transformer's connection is determined using its vector group.

The transformer's vector group is depending on the following factor:

1. **Removing harmonics:** The star winding of the three-phase transformer is used to reduce third harmonics.

2. **Parallel operations:** To perform parallel operation All the transformer's vector group and polarity should be same.

Module:5

THREE PHASE TRANSFORMER

Topic:

- PARALLEL OPERATION OF TRANSFORMER

THREE PHASE TRANSFORMER

PARALLEL OPERATION OF TRANSFORMERS

The Transformer is said to be in Parallel Operation when its primary winding is connected to a common voltage supply, and the secondary winding is connected to a common load.

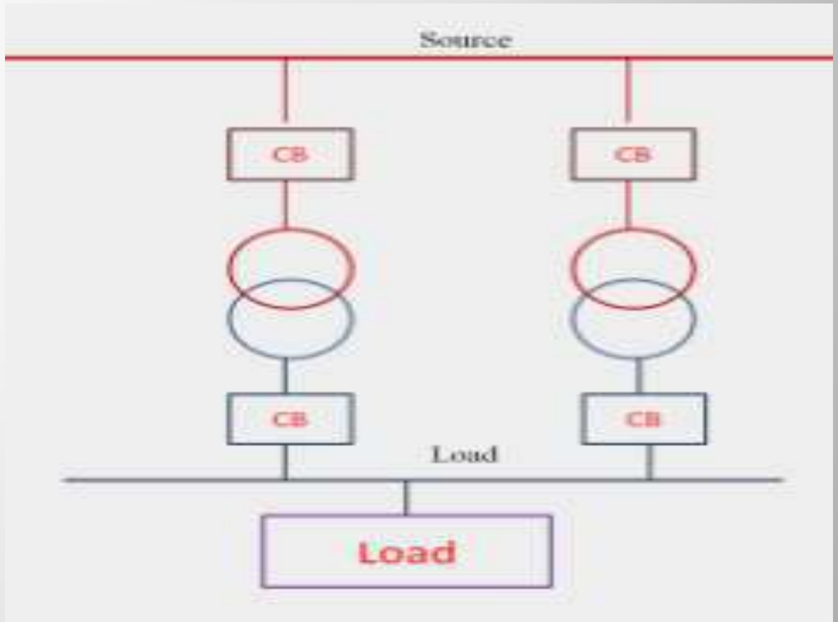
Three phase transformers are the heart of an electrical power distribution system which is used to set voltage up or down. It consists of primary and secondary windings. When it comes to three-phase power generation, transmission and distribution, the parallel operation of three phase transformers are common. Using two or more transformer units in parallel is more beneficial than using a single large unit due to its adjustability in maintenance and operation.

THREE PHASE TRANSFORMER

PARALLEL OPERATION OF TRANSFORMERS

For supplying a load in excess of the rating of an existing transformer, two or more transformers may be connected in parallel with the existing transformer. The transformers are connected in parallel when load on one of the transformers is more than its capacity. The reliability is increased with parallel operation than to have single larger unit. The cost associated with maintaining the spares is less when two transformers are connected in parallel.

It is usually economical to install another transformer in parallel instead of replacing the existing transformer by a single larger unit. The cost of a spare unit in the case of two parallel transformers (of equal rating) is also lower than that of a single large transformer. In addition, it is preferable to have a parallel transformer for the reason of reliability. With this at least half the load can be supplied with one transformer out of service.



THREE PHASE TRANSFORMER

PARALLEL OPERATION OF TRANSFORMERS

Reasons For Parallel Operation

Parallel operation of a transformer is necessary because of the following reasons are given below:

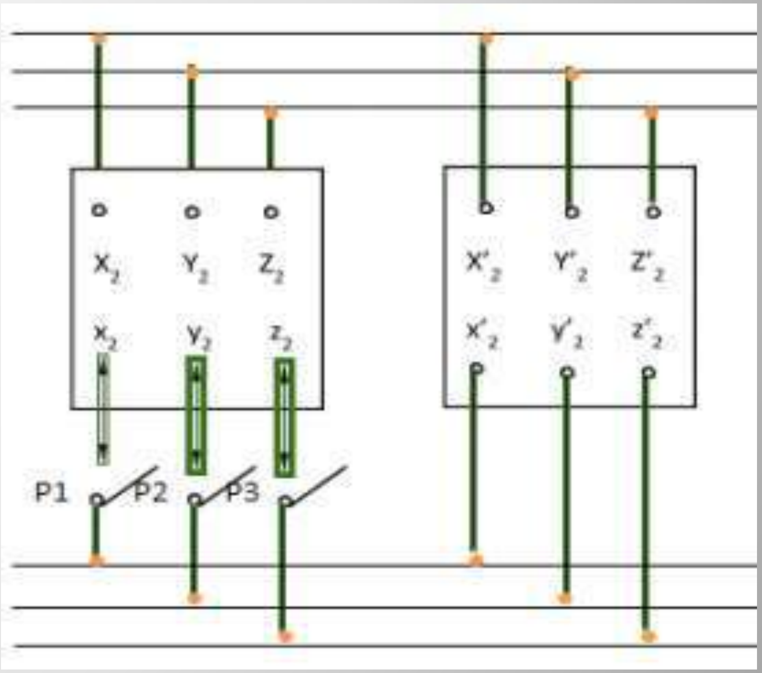
1. It is impractical and uneconomical to have a single large transformer for heavy and large loads. Hence, it will be a wise decision to connect a number of transformers in parallel.

2. In substations, the total load required may be supplied by an appropriate number of the transformer of standard size. As a result, this reduces the spare capacity of the substation.

3. If the transformers are connected in parallel, so there will be scope in future, for expansion of a substation to supply a load beyond the capacity of the transformer already installed.

4. If there will be any breakdown of a transformer in a system of transformers connected in parallel, there will be no interruption of power supply, for essential services.

5. If any of the transformer from the system is taken out of service for its maintenance and inspection, the continuity of the supply will not get disturbed.



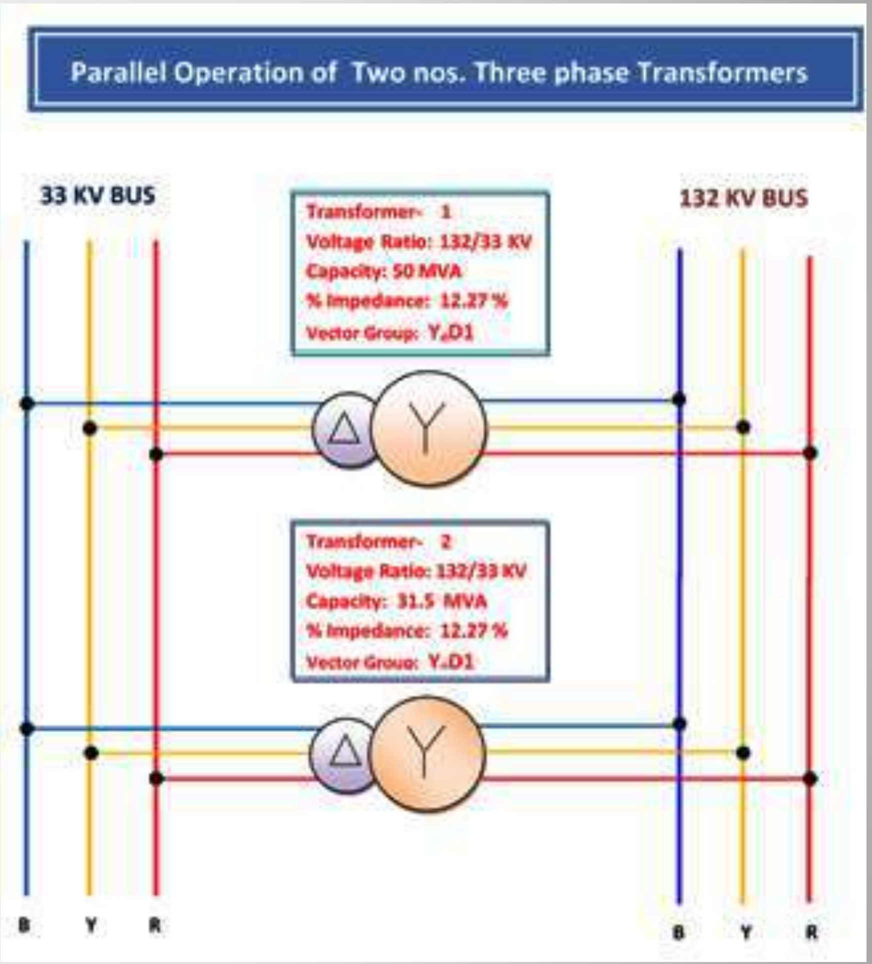
THREE PHASE TRANSFORMER

PARALLEL OPERATION OF TRANSFORMERS

Conditions For Parallel Operation

For parallel connection of transformers, primary windings of the transformers are connected to source bus-bars and secondary windings are connected to the load bus-bars. Various conditions that must be fulfilled for the successful parallel operation of transformers are:

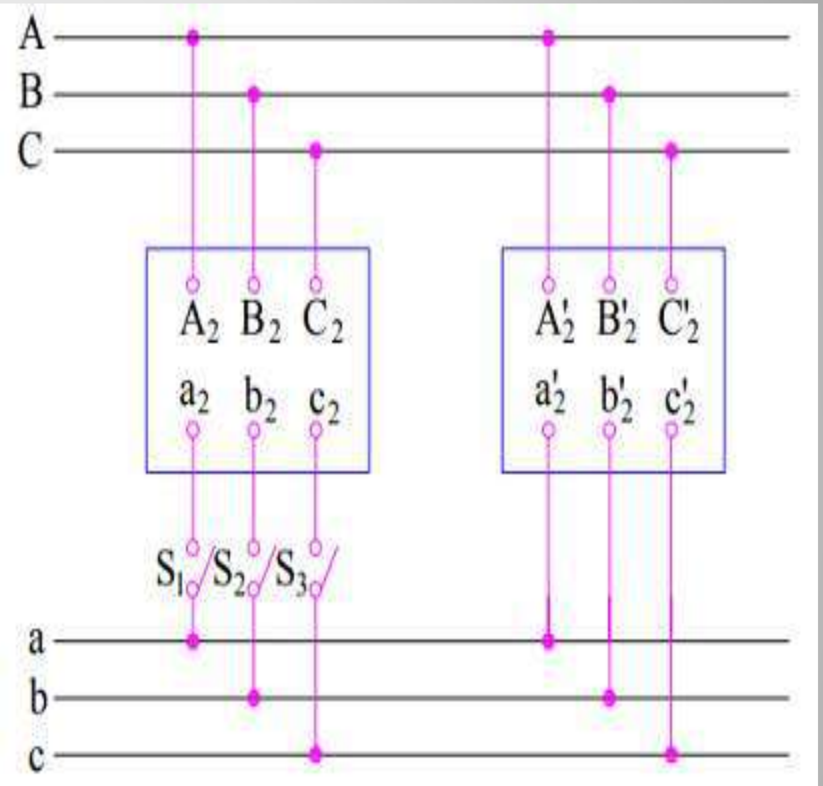
1. Same voltage ratio and turns ratio (both primary and secondary voltage rating is same)
2. Same percentage impedance and X/R ratio.
3. Identical position of tap changer
4. Same KVA ratings
5. Same phase angle shift (vector group are same)
6. Same frequency rating
7. Same polarity
8. Same phase sequence.



THREE PHASE TRANSFORMER

PARALLEL OPERATION OF TRANSFORMERS

Advantages of Transformer Parallel Operation



1. Maximize electrical system efficiency

Generally, electrical power transformer gives the maximum efficiency at full load. If one runs numbers of transformers in parallel, one can switch on only those transformers which will give the total demand by running nearer to its full load rating for that time.

When load increases, one can switch no one by one other transformer connected in parallel to fulfill the total demand. In this way one can run the system with maximum efficiency.

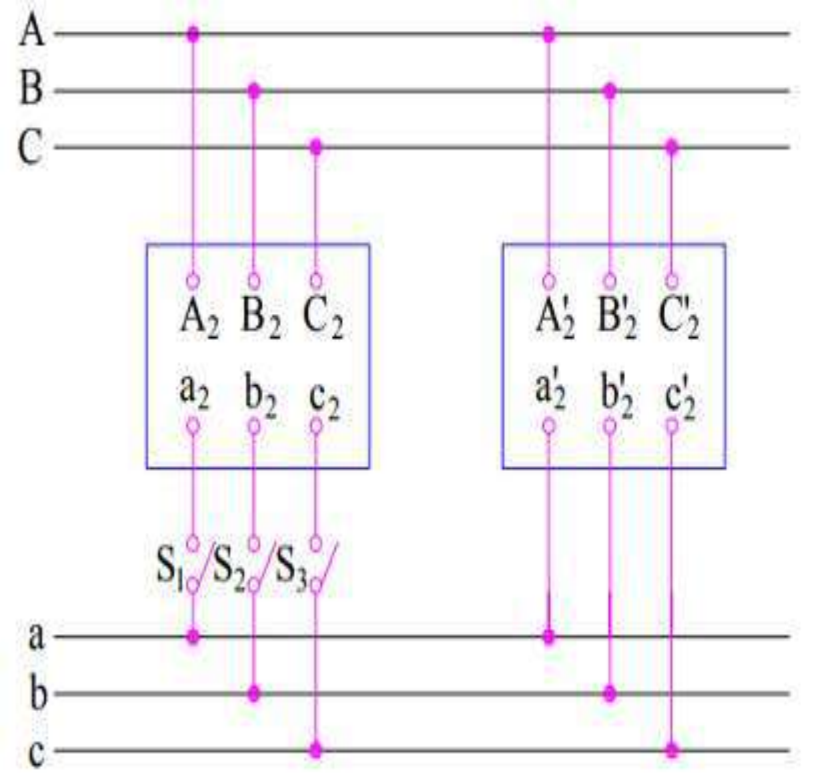
2. Maximize electrical system availability

If numbers of transformers run in parallel, one can take shutdown any one of them for maintenance purpose. Other parallel transformers in system will serve the load without total interruption of power.

THREE PHASE TRANSFORMER

PARALLEL OPERATION OF TRANSFORMERS

Advantages of Transformer Parallel Operation



3. Maximize power system reliability

If nay one of the transformers run in parallel is tripped due to fault, other parallel transformers in the system will share the load hence power supply may not be interrupted if the shared loads do not make other transformers over loaded.

4. Maximize electrical system flexibility

There is a chance of increasing or decreasing future demand of power system. If it is predicted that power demand will be increased in future, there must be a provision of connecting transformers in system in parallel to fulfill the extra demand, because it is not economical from business point of view to install a bigger rated single transformer by forecasting the increased future demand as it is unnecessary investment of money.

Again, in future demand is decreased, transformers running in parallel can be removed from system to balance the capital investment and its return.

PARALLEL OPERATION OF TRANSFORMERS

Disadvantages of Transformer Parallel Operation

1. Increasing short-circuit currents that increase necessary breaker capacity.

2. The risk of circulating currents running from one transformer to another transformer. Circulating currents that diminish load capability and increased losses.

3. The bus ratings could be too high.

4. Paralleling transformers reduce the transformer impedance significantly, i.e. the parallel transformers may have very low impedance, which creates the high short circuit currents. Therefore, some current limiters are needed, e.g. reactors, fuses, high impedance buses, etc

5. The control and protection of three units in parallel is more complex.

6. It is not a common practice in this industry.

Module:5

THREE PHASE TRANSFORMER

Topic:

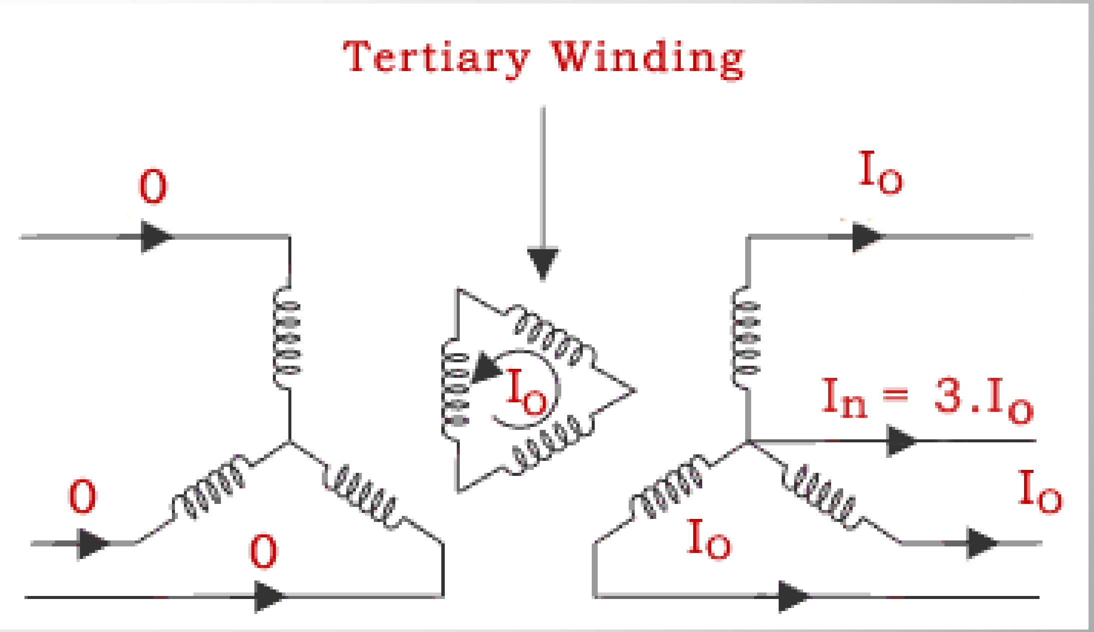
- TERTIARY WINDING OF TRANSFORMER
- OPEN DELTA CONNECTION
- SCOTT-T TRANSFORMER CONNECTION

THREE PHASE TRANSFORMER

TERTIARY WINDING OF TRANSFORMER

In some high rating transformer, one winding in addition to its primary and secondary winding is used. This additional winding, apart from primary and secondary windings, is known as Tertiary winding of transformer. Because of this third winding, the transformer is called three winding transformer or 3 winding transformer.

The voltage ratings of all the three windings of the transformer are usually un-equal. The primary winding has the highest voltage rating; the tertiary has the lowest voltage rating, and the secondary has the intermediate voltage rating. The chief advantages of the three winding transformers is an economy of construction and their great efficiency.



TERTIARY WINDING OF TRANSFORMER

Advantages of Using Tertiary Winding in Transformer

Tertiary winding is provided in electrical power transformer to meet one or more of the following requirements-

1. It reduces the unbalancing in the primary due to unbalancing in three phase load.

2. It redistributes the flow of fault current.

3. Sometime it is required to supply an auxiliary load in different voltage level in addition to its main secondary load. This secondary load can be taken from tertiary winding of three winding transformer.

4. As the tertiary winding is connected in delta formation in 3 winding transformer, it assists in limitation of fault current in the event of a short circuit from line to neutral.

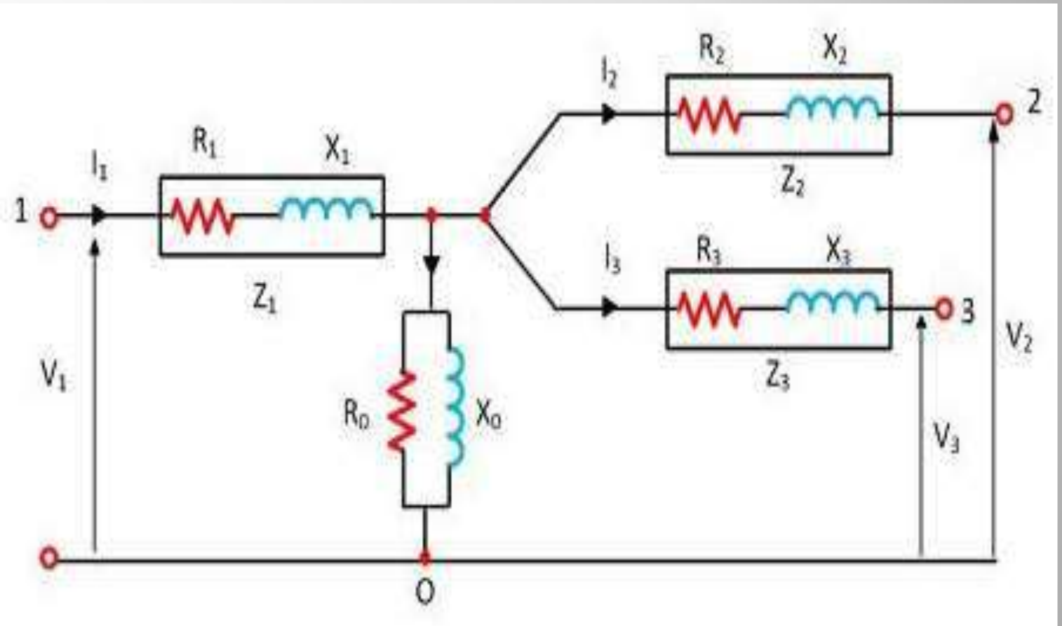
THREE PHASE TRANSFORMER

TERTIARY WINDING OF TRANSFORMER

Rating & Equivalent of Tertiary Winding of Transformer

Rating of **tertiary winding of transformer** depends upon its use. If it has to supply additional load, its winding cross – section and design philosophy is decided as per load, and three phase dead short circuit on its terminal with power flow from both sides of HV and MV.

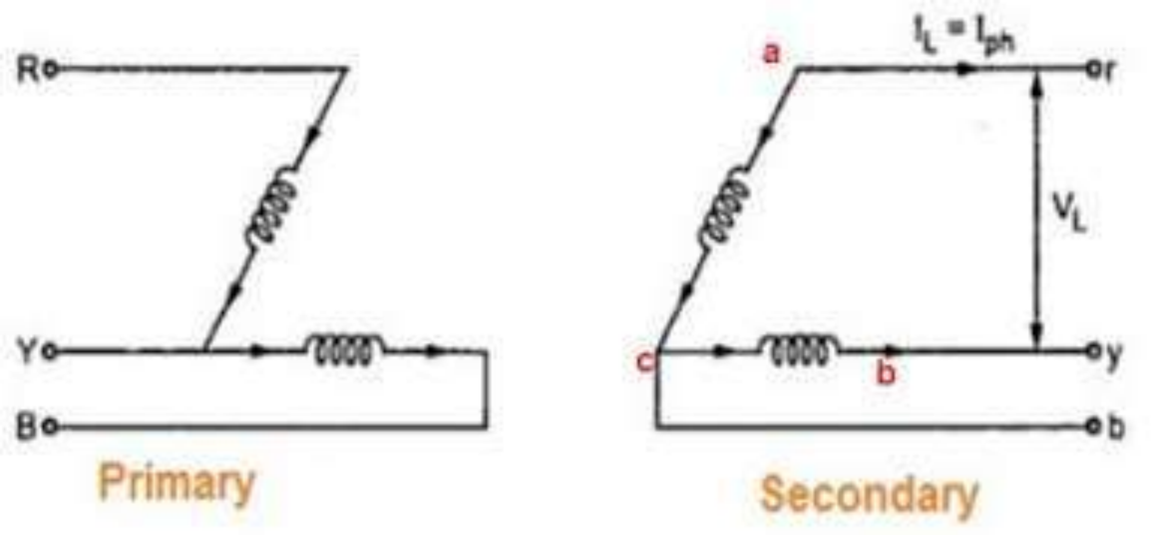
In case it is to be provided for stabilizing purpose only, its cross-section and design has to be decided from thermal and mechanical consideration for the short duration fault currents during various fault conditions single line to ground fault being the most onerous.



THREE PHASE TRANSFORMER

OPEN DELTA OR V-CONNECTION OF TRANSFORMER

As we know, a three phase Transformer bank connected in Delta-Delta when supplies a three phases balanced load then individual Transformers share 1/3 of the total load. But if there is some fault in any one of the Transformer and due this one Transformer is taken out of service, then also three phase power can be supplied though at a reduced power level. The resulting connection obtained after the removal of one of the Transformer from a three phase Transformer bank connected in Delta-Delta is known as an Open Delta or V-connection of Transformer. Figure below depicts this open Delta or V-connection.



OPEN DELTA OR V-CONNECTION OF TRANSFORMER

VA Delivered by Open Delta

Case1: When all the three transformers of three phase Transformer bank are in service.

Line Voltage $V_L = V_{ph}$ (because of Delta connection)

Line Current $I_L = 1.732 I_{ph}$

Thus,
VA Rating of Bank of three Transformers in Delta
$= 1.732 V_L I_L$

$= 1.732 x V_{ph} x 1.732 x I_{ph}$

$= 3 V_{ph} I_{ph}$

Case2: Open Delta Connection

As in Open Delta connection, only two Transformers are there in service so,
VA Rating of Open Delta

$= 1.732 x V_L x I_L$

$= 1.732\ V_{ph} I_{ph}$

Line Current in Open Delta $I_L = I_{ph}$ as there is no path to bifurcate the line current. Same current is flowing in line as well as in phases.

THREE PHASE TRANSFORMER

OPEN DELTA OR V-CONNECTION OF TRANSFORMER

VA Delivered by Open Delta

VA Rating of Open Delta / VA Rating of Close Delta

$= 1.732V_{ph}I_{ph}/ 3V_{ph}I_{ph}$

$=1 / 1.732$

=0.577

Thus the VA delivering capacity of Open Delta becomes 57% of that of the full capacity when all the three Transformers are in service. It shall also be noted that, though the total capacity of Transformers in Open Delta is $2V_{ph}I_{ph}$ but still Open Delta can only deliver $1.732V_{ph}I_{ph}$.

The Ratio of actual available kVA rating to the sum of the kVA rating of installed Transformer is called Utilization Factor and given by

U.F = Ratio of actual available kVA / Sum of the kVA rating of installed Transformer

For Open Delta connection,

$U.F = 1.732V_{ph}I_{ph}/ 2V_{ph}I_{ph}$

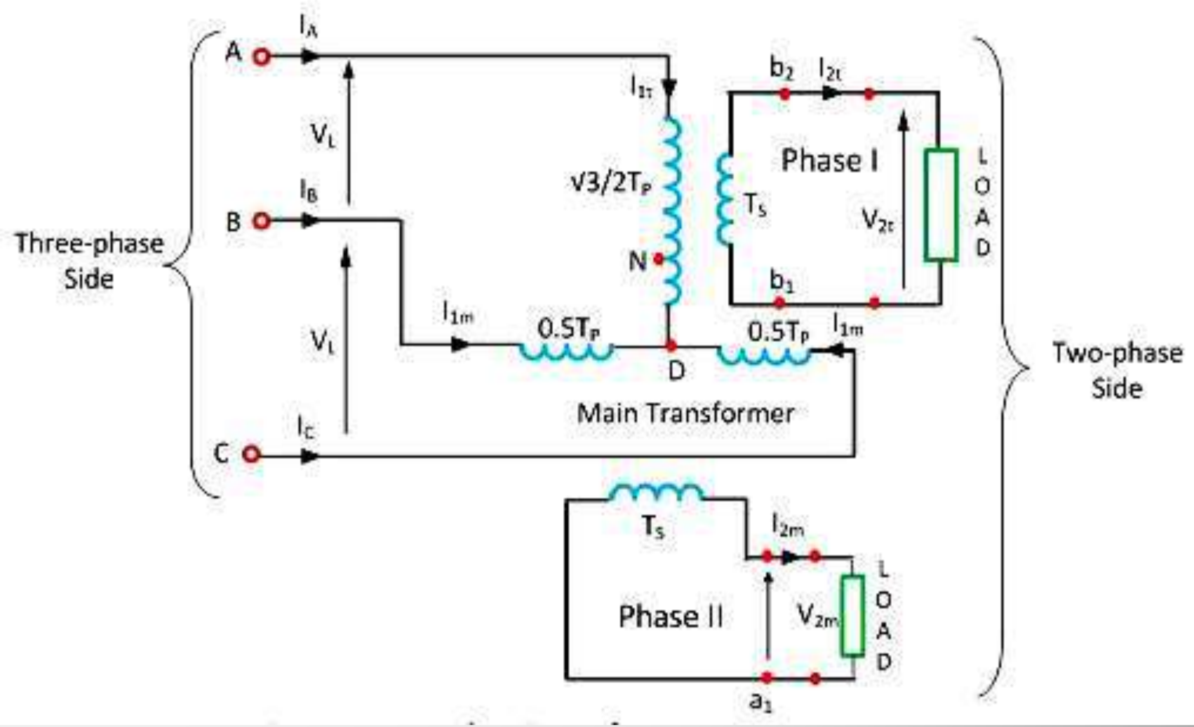
$= 0.866$

Thus it is beneficial to operate the bank of Transformer in Open Delta at 86% of rated capacity while the faulty Transformer is under maintenance.

THREE PHASE TRANSFORMER

SCOTT-T TRANSFORMER CONNECTION

The Scott-T Connection is the method of connecting two single phase transformer to perform the 3-phase to 2-phase conversion and vice-versa. The two transformers are connected electrically but not magnetically. One of the transformers is called the main transformer, and the other is called the auxiliary or teaser transformer.



The main transformer is centre tapped at D and is connected to the line B and C of the 3-phase side. It has primary BC and secondary a_1a_2. The teaser transformer is connected to the line terminal A and the centre tapping D. It has primary AD and the secondary b_1b_2

The identical, interchangeable transformers are used for Scott-T connection in which each transformer has a primary winding of T_p turns and is provided with tapping at $0.289T_p$, $0.5T_p$and $0.866\ T_p$.

SCOTT-T TRANSFORMER CONNECTION

Applications of Scott Connection

1. The Scott-T connection is used in an electric furnace installation where it is desired to operate two single-phase together and draw the balanced load from the three-phase supply.

2. It is used to supply the single phase loads such as electric train which are so scheduled as to keep the load on the three phase system as nearly as possible.

3. The Scott-T connection is used to link a 3-phase system with a two–phase system with the flow of power in either direction.

4. The Scott-T connection permits conversions of a 3-phase system to a two-phase system and vice versa. But since 2-phase generators are not available, the converters from two phases to three phases are not used in practice.