3^{rd} Semester, Electrical Engineering

DC Machines and Transformers (Th-4)

UNIT-1- DC GENERATOR

2 MARKS QUESTIONS

1. What is the function of pole shoes?
   The pole shoes in a DC generator spread the magnetic flux of the pole over a larger area of the armature. They reduce the flux density at the pole tip and avoid saturation of the pole tip. They also help to reduce the reluctance of the magnetic path from the pole core to the armature.
2. Differentiate between lap winding and wave winding?
    Lap winding: Each end of a coil is connected to an adjacent parallel path; thus the number of parallel paths A=P (number of poles). It is used in machines with heavy current and low voltage (many paths).
    Wave winding: The winding progresses in a “wave” around the armature so that there are only two parallel paths A=2, irrespective of number of poles. It is used in machines for higher voltage and lower current.

3. What are the effects of armature reaction in a dc generator?
   The armature reaction causes:

- Distortion of main field flux (cross-magnetising effect) which shifts the magnetic neutral axis.
- Demagnetisation of the main field (reducing flux per pole) which lowers the induced emf.
- Interference with commutation (because the neutral plane shifts) and may cause sparking at brushes.

4. State Fleming’s right-hand rule.

For a generator: If you stretch the thumb, forefinger and middle finger of your right hand mutually perpendicular:

- Thumb → direction of motion of conductor (relative to magnetic field)
- Forefinger → direction of magnetic flux (from N to S)
- Middle-finger → direction of induced current in the conductor.

5. What is commutation?

The reversal of current in a coil when it passes through the brush axis is called commutation.

6. List two applications of DC generators.

    i. Charging of batteries (for example for backup power).
    ii. Supply of DC power for electroplating, electro-refining, and DC motors where stable DC supply is needed.

7. Define armature reaction in a DC generator.
   Armature reaction is the effect of the magnetic field (mmf) produced by the armature current on the distribution of the main field flux under the pole-faces of the machine. This effect distorts and/or weakens the main flux.
8. What are the different types of losses in a DC machine?

    i. Copper losses (in armature winding and field winding)
    ii. Iron (core) losses (hysteresis + eddy currents in the iron parts)
    iii. Mechanical losses (windage and friction)

9. State the function of interpole.
   Interpoles (also called commutating poles) are small poles placed between the main poles, connected in series with the armature winding. They produce a flux that opposes the armature reaction's cross-magnetising flux and assist in improving commutation (reduce sparking at brushes).
10. What is the basic working principle of a DC Generator?
    A DC generator works on the principle of electromagnetic induction: when a conductor rotates in a magnetic field (or a magnetic field rotates relative to a conductor), the conductor cuts magnetic flux lines and an emf is induced in the conductor according to Faraday's law. The direction of induced emf is given by Fleming's right-hand rule. The induced AC in the armature is converted to DC by the commutator and brushes.

5 MARKS QUESTION

1. Derive the EMF Equation of DC Generator.
   For one revolution of the conductor,
   Let,Φ = Flux produced by each pole in weber (Wb)
   P = number of poles in the DC generator.
   therefore, Total flux produced by all the poles $= \phi \times P$
   And,Time taken to complete one revolution $= \frac{60}{N}$

Consider N as the speed of the armature conductor, measured in revolutions per minute (rpm).

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.

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

Therefore,

Induced emf of one conductor is

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

Let us suppose there are Z total numbers of conductor in a generator, and arranged in such a manner that all parallel paths are always in series.

Here,Z = total numbers of conductor

A = number of parallel paths

Then,Z/A = number of conductors connected in series

It is important to know that the induced EMF is consistent across each path in the generator.

Therefore,The induced EMF of the DC generator, denoted as E, is calculated as the EMF of one conductor multiplied by the number of conductors connected in series.

Induced emf of DC generator is

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

Simple wave wound generator

Numbers of parallel paths are only 2 = A

Therefore,Induced emf for wave type of winding generator is

$$\frac{\phi PN}{60} X \frac{Z}{2} = \frac{\phi ZPN}{120} \ volts$$

Simple lap-wound generator

Here, number of parallel paths is equal to number of conductors in one pathi.e. P = A

Therefore,Induced emf for lap-wound generator is

$$E_g = \frac{\phi ZN}{60} X \frac{P}{A} \ volt$$

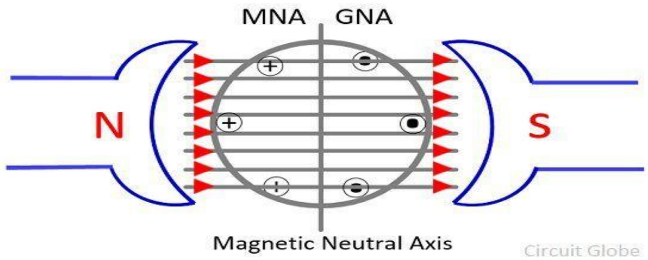
2. Define and Explain armature reaction and its effects.

The effect of armature flux on the main lux is known as Armature reaction.

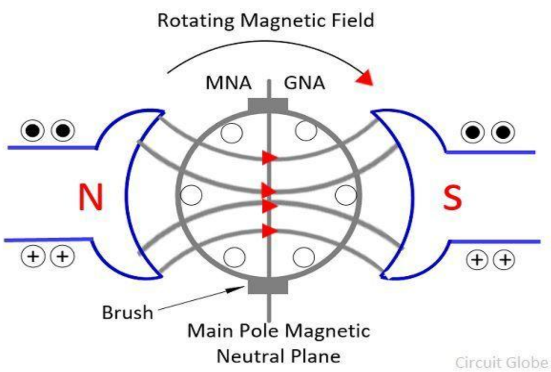
Geometric Neutral Axis & Magnetic Neutral Axis

GNA-Axis of symmetry between two adjacent poles.

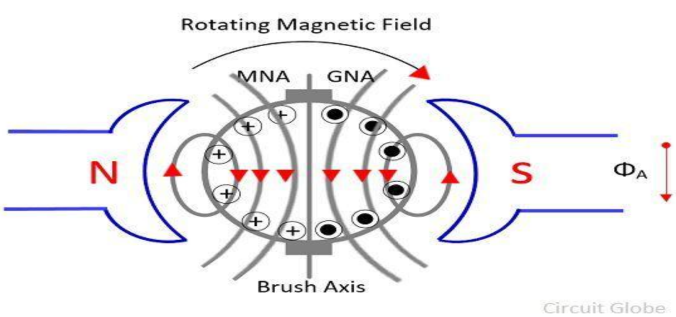
MNA- It is the axis drawn perpendicular to the mean direction of flux passing through the centre of the armature. No emt is induced in the armature conductor along the axis. So to achieve sparkless commutation, the brushes must lie along M.N.A.



Consider the figure below shows the two poles dc generator. When no load connected to the generator, the armature current becomes zero. In this condition, only the MMF of the main poles exists in the generator. The MMF flux is uniformly distributed along the magnetic axis. The magnetic axis means the centre line between the north and south pole. The arrow in the below-given image shows the direction of the magnetic flux Φ_M. The magnetic neutral axis or plane is perpendicular to the axis of the magnetic flux.



The MNA coincides with the geometrical neutral axis (GNA). The brushes of the DC machines are always placed in this axis, and hence this axis is called the axis of commutation.

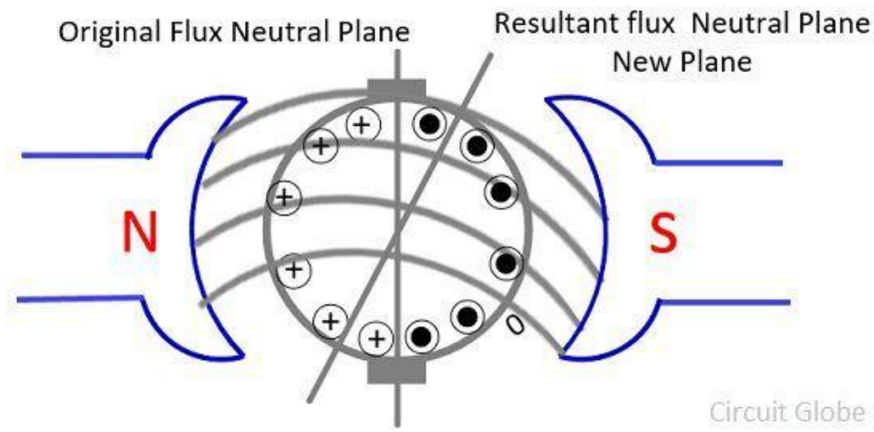


Consider the condition in which only the armature conductors carrying current and no current flows through their main poles. The direction of the current remains the same in all the conductors lying under one pole. The direction of current induces in the conductor is given by the Fleming right-hand rule. And the direction of flux generates in the conductors is given by the corkscrew rule.

The direction of current on the left sides of the armature conductor goes into the paper (represented by the cross inside the circle). The armature conductors combine their MMF for generating the fluxes through the armature in the downward direction.

Similarly, the right-hand side conductors carry current, and their direction goes out of the paper (shown by dots inside the circle). The conductor on the right-hand sides is also combining their MMF for producing the flux in the downwards direction. Hence, the conductor on both sides combines their MMF in such a way so that their flux goes downward direction. The flux induces in the armature conductor Φ_A is given by the arrow shown above.

The figure below shows the condition in which the field current and the armature current are simultaneously acting on the conductor.



This happens when machines running at no-load condition. Now the machine has two fluxes, i.e., the armature flux and the field pole flux. The armature flux is produced by the current induced in the armature conductors while the field pole flux is induced because of the main field poles. These two flux combines and gives the resultant flux Φ_R as shown in the figure above.

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 the 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 the 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.

Effects of Armature Reaction

1. **Flux Distortion (Magnetic Field Distortion)**
   - The main field is no longer symmetrical.

- The flux density increases under one pole tip and decreases under the other.
- This causes a shift in the **Magnetic Neutral Axis (MNA)** — the axis where no emf is induced.

2. **Shift of the Magnetic Neutral Axis (MNA)**
   - The MNA shifts in the direction of rotation in a generator.
   - Brushes are usually placed along the MNA; hence, the shift causes **sparking at the brushes** because the commutation is no longer perfect.
3. **Reduction of Effective Flux (Demagnetizing Effect)**
   - Some of the armature magnetomotive force (MMF) opposes the main field flux.
   - As a result, the **effective flux per pole decreases**, leading to:
     - Lower generated emf ($E \propto \Phi$)
     - Reduced terminal voltage under load
4. **Sparking at Brushes**
   - Due to the shift in the neutral plane, the current reversal in coils occurs when they are still cutting magnetic flux.
   - This results in sparking and poor commutation.

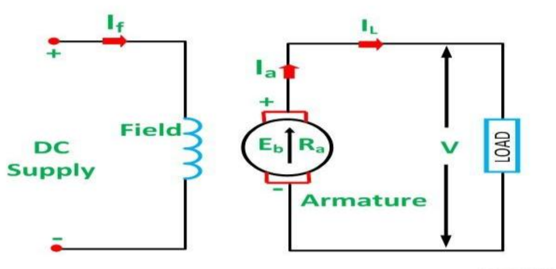
3. Classify different types of dc generator with schematic diagram and write its application.

DC generators are classified **based on the method of field excitation**

1. Separately Excited DC Generator

- The field winding is supplied from an *external* DC source (not from the generator itself).

Application:
Used where wide and independent voltage control is required — e.g. electroplating, laboratory testing, excitation of AC alternators.



2. Self-Excited DC Generator

- The field winding gets current from the *armature output* of the same machine.
  These are further divided based on how the field is connected:

(a) Shunt Generator

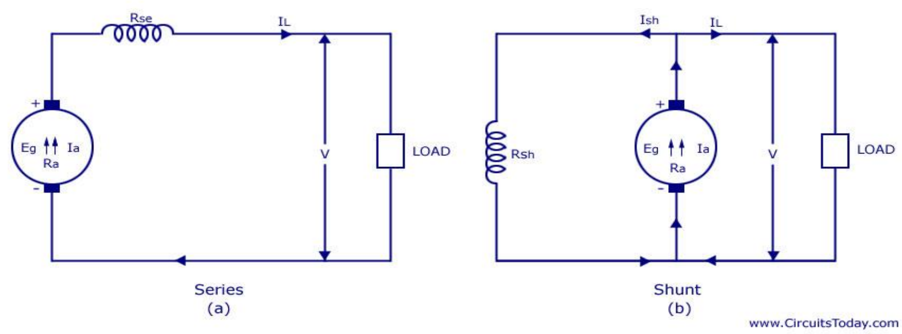
- Field winding connected **in parallel** (shunt) with the armature.
- Field current is small and almost constant.

Applications:
Battery charging, lighting, and constant-voltage supply systems.

(b) Series Generator

- Field winding connected **in series** with the armature.
- Field current = armature current → varies with load.

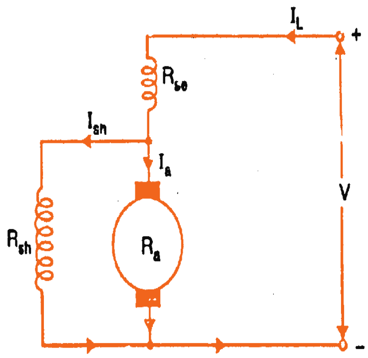
Applications:
Used for arc welding, boosters, and as current regulators (rare today).



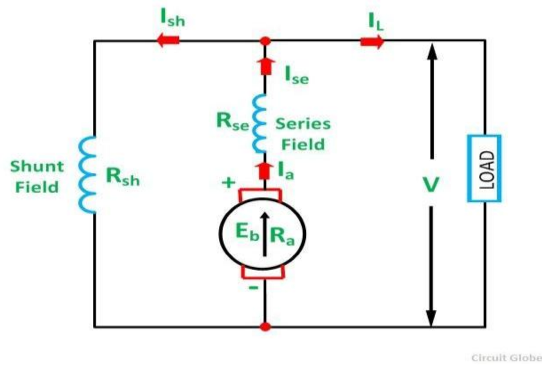
(c) Compound Generator

- Has both **shunt** and **series** field windings.
- Can be:
  - **Long-shunt:** shunt field in parallel with both armature and series field.
  - **Short-shunt:** shunt field in parallel with armature only.

Applications:
Used in lighting, power supply, and traction where voltage must remain nearly constant.



Short-shunt connection



4. Explain different parts of dc machine with its function.

A **DC machine** mainly consists of **two parts**:

1. **Stator (Stationary part)** → produces the magnetic field
2. **Rotor (Rotating part)** → where emf is induced or torque is developed

Yoke (Frame)-The outer cover of the DC machine made of cast iron or steel.

- **Function:**
    - Provides **mechanical support** for poles and other parts.
    - Acts as the **protective cover** for internal components.
    - Forms the **magnetic path** for the magnetic flux.

Poles-Projecting structures bolted to the yoke.

- **Function:**
    - Carry **field windings** that produce magnetic flux.
    - Distribute flux uniformly around the armature.
    - Help in fixing the field coils in position.

Pole Core and Pole Shoe-Each pole has a **core** and a **pole shoe** attached.

- **Function:**
    - The **pole core** carries the magnetic flux.
    - The **pole shoe** spreads the flux uniformly over the armature surface.
    - The pole shoe also provides mechanical support for field coils.

Field Winding (Field Coils)-Copper coils wound around each pole core.

- **Function:**

- When DC current passes through them, they **magnetize the poles** to produce magnetic flux.
- Controls the **strength of the magnetic field** (and hence voltage in generators or speed in motors).

Armature Core-Laminated soft iron core mounted on the shaft with slots on its outer surface.

- **Function:**
  - Provides a **low-reluctance path** for magnetic flux.
  - Slots house the armature conductors.
  - The lamination reduces **eddy current losses**.

Armature Winding-Copper conductors placed in the slots of the armature core.

- **Function:**
  - In a **generator**, emf is **induced** in these windings.
  - In a **motor**, current flows through these windings to produce **torque**.

Commutator- Cylindrical structure made up of copper segments insulated by mica, mounted on the shaft.

- **Function:**
  - Converts the **alternating emf** induced in the armature conductors into **direct current (DC)** at the output terminals (in generator mode).
  - Ensures **unidirectional torque** (in motor mode).
  - Acts as a **mechanical rectifier**.

Brushes-Made of carbon or graphite, kept in contact with the commutator.

- **Function:**
  - Conduct **current between the rotating commutator and external circuit**.
  - Usually held in **brush holders** with springs to maintain firm contact.

Shaft-Steel shaft that holds and supports the rotating parts (armature core, commutator, etc.).

- **Function:**
  - Transmits **mechanical power** (in generator mode) or **mechanical load torque** (in motor mode).

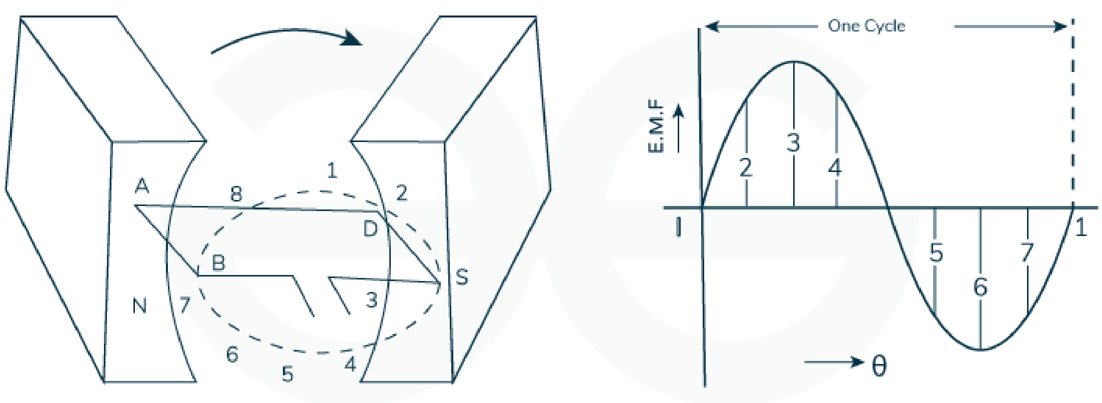
Bearings- Placed between the shaft and end housings.

- **Function:**
  - Reduce **friction** between moving and stationary parts.
  - Ensure smooth rotation of the armature.

5. Describe the working principle of dc generator.

A DC generator works on the principle of **Faraday's law of electromagnetic induction**, where a mechanical force rotates conductors (armature) within a magnetic field, inducing a voltage (EMF). The commutator, a split-ring system connected to the armature windings, reverses the connections to the external circuit every half-rotation, which rectifies the alternating current (AC) generated in the armature into a direct current (DC) output.

Consider a single loop DC generator (as seen in the diagram), in which a single turn loop 'ABCD' rotates clockwise in a uniform magnetic field at constant speed. As the loop rotates, the magnetic flux between the coil sides 'AB' and 'CD' changes continually. This change in flux linkage causes an EMF to be induced in both coil sides, and the induced EMF on one coil side is added to the induced EMF on the other.



Construction And Working of a DC Generator

The EMF produced by a DC generator may be explained as follows:

- When the loop is at position 1, no EMF is produced since the coil sides move in parallel with the magnetic flux.
- When the loop is in position 2, the loop sides move in the direction of the attracting motion, generating a tiny EMF.
- When the loop is at place 3, the coil sides move at the right point to the attractive transition, resulting in the highest EMF.
- When the loop is in position 4, the coil sides cut the attractive transition at a point, resulting in a lower EMF in the coil sides.

- When the loop is at place 5, there is no motion coupling with the coil side, and the movement is aligned with the attractive transition. Consequently, no EMF is produced in the coil.
- At position 6, the coil sides move beneath an inverse extremity post, switching the extremity of the generated EMF. The most intense EMF will be produced toward this route at position-7, and zero at position-1. This cycle repeats for each coil turn.

It is evident that the produced EMF is a spinning one. It is because any coil side (for example, AB) has EMF in one direction when impacted by an N-pole and in the opposite direction when affected by an S-pole. As a result, when a load is attached to the generator's terminals, alternating current flows through it. Currently, using a commutator, the alternating emf created in the loop may be converted into direct voltage.

10 MARKS QUESTION

1. Explain commutation. What are the methods to improve commutation?

   The currents induced in the armature conductors of a DC generator are alternating in nature. The change from a generated alternating current to the direct current applied involves the process of **Commutation**. When the conductors of the armature are under the north pole, the current which is induced flows in one direction. While the current flows in the opposite direction when they are under the south pole.

As the conductor passes through the influence of the north pole and enters the south pole, the current in them is reversed. The reversal of current takes place along the MNA or brush axis. When the brush span has two commutator segments, the winding element connected to those segments is short-circuited.

The term **Commutation** means the change that takes place in a winding element during the period of a short circuit by a brush.

Let us understand Commutation more clearly by considering a simple ring winding shown below in Figure A.

In the position shown in Figure A, the current I flowing towards the brush from the left-hand side passes around the coil in a clockwise direction.

Now consider the other figure B shown below:

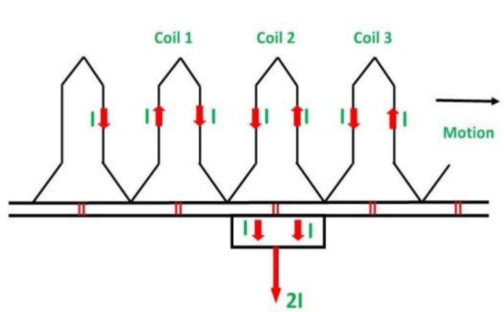


Figure B

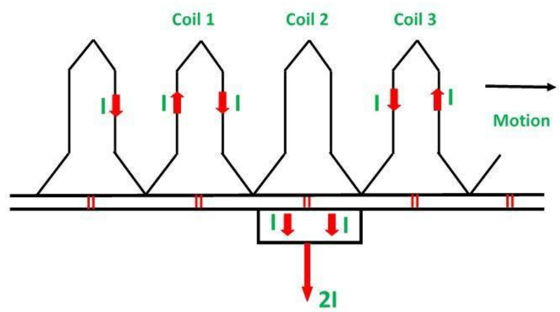


Figure A

In the above figure, the position of the coil shows that the same amount of current is carried by all the coils, and the direction of the current is also similar, but the coil is too short-circuited by the brush.

In Figure C shown below the brush makes contact with bars a and b, thereby short-circuiting coil 1. The current is still I from the left-hand side and I from the right-hand side. It is seen that these two currents can reach the brush without passing through coil 1.

In figure D shown below, the bar (b) has just left the brush, and the short circuit of coil one has ended. It is now necessary for the current I reaching the brush from the right-hand side in the anticlockwise direction.

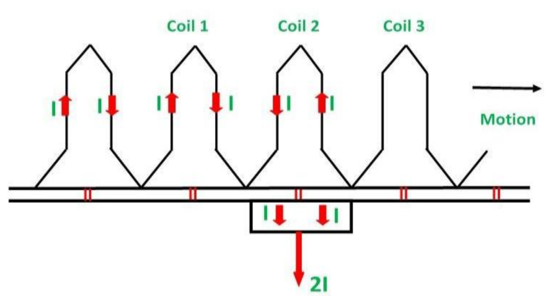


Figure D

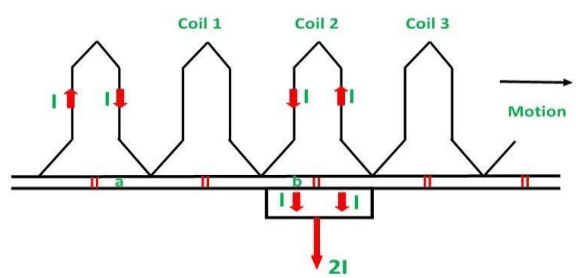
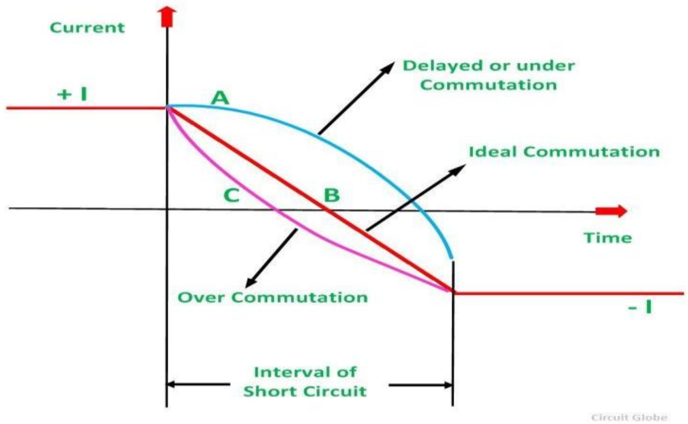


Figure C

From all the above discussion, it is seen that during the period of the short circuit of an armature coil by a brush the current in the coil must be reversed and also brought up to its full value in the reverse direction. The time of the short circuit is called the **period of commutation**.

The figure shown below shows how the current in the short-circuited coil varies during the brief interval of the short circuit. The curve b shows that the current changes from +I to –I linearly in the commutation period. Such a commutation is called **Ideal Commutation** or **Straight-line Commutation.**



If the current through the coil 1 has not reached its full value in the position in figure D, then, since the coil 2 carrying full current, the difference between the currents through elements 2 and 1 has to jump from commutator bar to the brush in the form of a spark.

Thus, the cause of sparking at the commutator is the failure of the current in the short-circuited elements to reach the full value in the reverse direction by the end of the short circuit. This is known as **under commutation** or **delayed commutation.**

The curve of current against time in such a case is shown in figure E by the curve A. In ideal commutation curve B, the current of the commutating coils changes linearly from +I to –I during the commutation period.

In actual practice, the current in the short-circuited coil after the commutation period does not reach its full value. This is due to the fact that the short-circuited coil offers self-inductance in addition to the resistance. The rate of change of current is so high that the self-inductance of the coil sets up a back EMF, which opposes the reversal.

Since the current in the coil has to change from +I to –I, the total change is 2I. If t_c is the time of short circuit and L is the inductance of the coil (= self-inductance of the short-circuited coil + mutual inductances of the neighbouring coils), then the average value of the self-induced voltage is:

$$L\frac{di}{dt} = \frac{L \times 2I}{t_c} = \frac{2LI}{t_c}$$

This is called the **reactance voltage.**

The large voltage appearing between commutator segments to which the coil is connected causes sparking at the brushes of the machine. The sparking of the commutator is much harmful, and it will damage both commutator surface and brushes. Its effect is cumulative which may lead to a short circuit of the machine with an arc around the commutator from brush to brush.

There are three main **methods of improving commutation**. These are

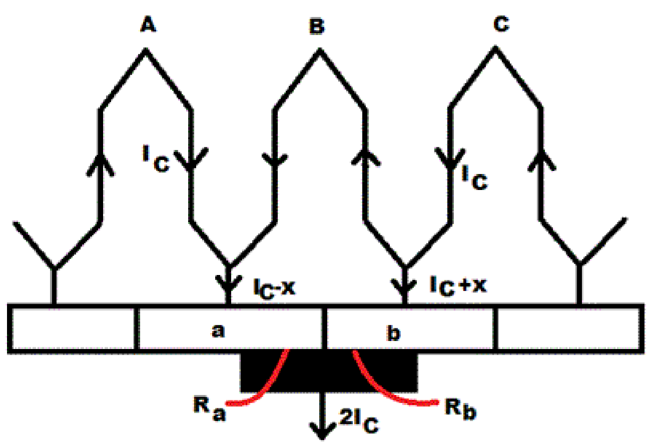
1. Resistance commutation
2. E.M.F. commutation
3. Compensating windings

Resistance Commutation

In this method of commutation we use high electrical resistance brushes for getting spark less commutation. This can be obtained by replacing low resistance copper brushes with high resistance carbon brushes.

We can clearly see from the picture that the current I_C from the coil C may reach to the brush in two ways in the commutation period. One path is direct through the commutator segment b and to the brush and the 2nd path is first through the short-circuit coil B and then through the commutator segment a and to the brush. When the brush resistance is low, then the current I_C from coil C will follow the shortest path, i.e. the 1st path as its electrical resistance is comparatively low because it is shorter than the 2nd path.

When high resistance brushes are used, then as the brush moves towards the commutator segments, the contact area of the brush and the segment b decreases and contact area with the segment a increases. Now, as the electrical resistance is inversely proportional to the contact area of then resistance R_b will increase and R_a will decrease as the brush moves. Then the current will prefer the 2nd path to reach to the brush.



This method ensures the quick reversal of current in the desired direction, improving commutation.

$$Resistance: \quad R = \rho\frac{l}{A}$$

ρ is the resistivity of the conductor.

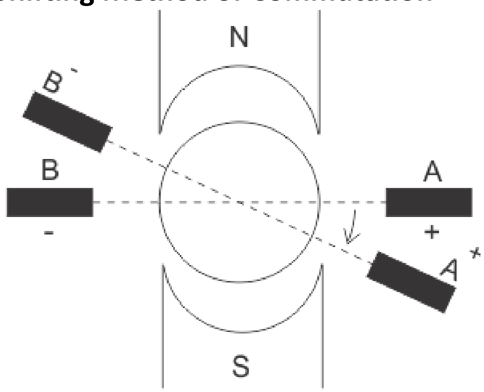
l is the length of the conductor.
A is the cross-section of the conductor (here is this description it is used as contact area).

E.M.F. Commutation

The main reason of the delay of the current reversing time in the short circuit coil during commutation period is the inductive property of the coil. In this type of commutation, the reactance voltage produced by the coil due to its inductive property, is neutralized by producing a reversing emf in the short circuit coil during commutation period.

1. By brush shifting.
2. By using inter-poles or commutating poles.

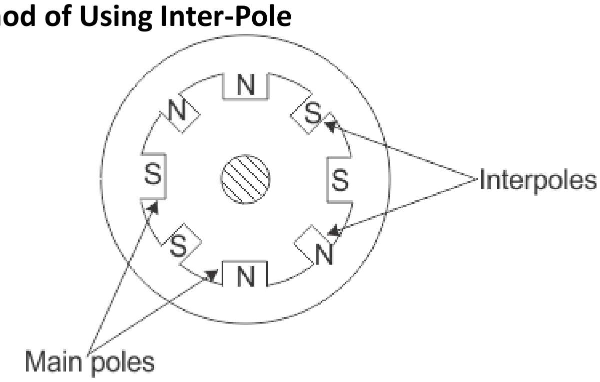
Brush Shifting Method of Commutation



Generator Brush Shift

In this method of improving commutation the brushes are shifted forward direction for the DC generator and in backward direction for the motor for producing the sufficient reversing emf for eliminating the reactance voltage. When the brushes are given the forward or backward lead then it brings the short circuit coil under the influence of the next pole which is of the opposite polarity. Then the sides of the coil will cut the necessary flux form the main poles of opposite polarity for producing the sufficient reversing emf. This method is rarely used because for best result, with every variation of load, the brushes have to be shifted.

Method of Using Inter-Pole



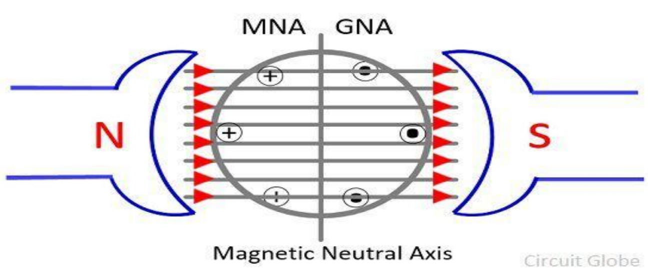
Interpole Commutation

In this method, small poles called inter-poles are fixed to the yoke and placed between the main poles. For generators, their polarity matches the adjacent main poles, and for motors, it matches the preceding main poles. The inter-poles induce an emf in the short circuit coil during the commutation period, opposing the reactance voltage and ensuring spark-less commutation.

Compensating Windings
This is the most effective mean of eliminating the problem of armature reaction and flash over by balancing the armature mmf. Compensating windings are placed in slots provided in pole faces parallel to the rotor (armature) conductors.
The major drawback of compensating windings is their high cost. They are mainly used in large machines subject to heavy overloads or plugging and in small motors requiring sudden reversal and high acceleration.

2. Describe armature reaction and its effect. Write the methods to improve armature reaction.

   The effect of armature flux on the main lux is known as Armature reaction.
   Geometric Neutral Axis & Magnetic Neutral Axis
   GNA-Axis of symmetry between two adjacent poles.
   MNA- It is the axis drawn perpendicular to the mean direction of flux passing through the centre of the armature. No emt is induced in the armature conductor along the axis. So to achieve sparkless commutation, the brushes must lie along M.N.A.



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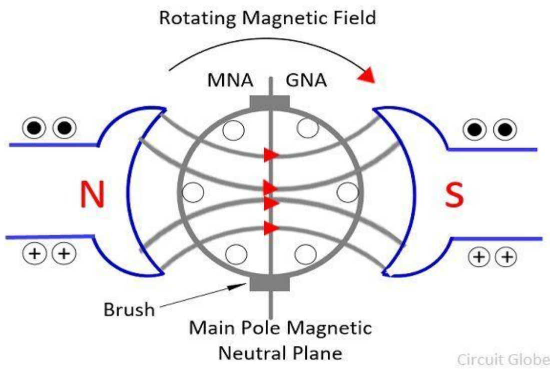
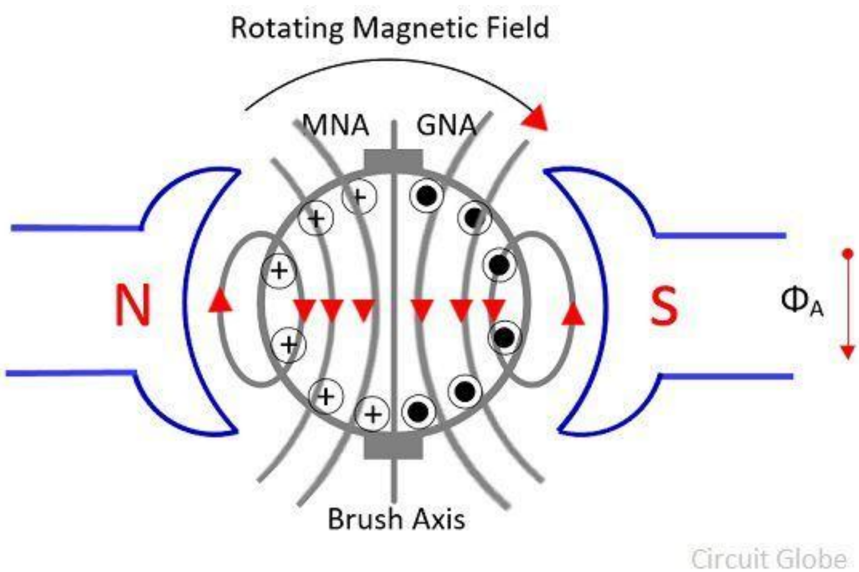


The MNA coincides with the geometrical neutral axis (GNA). The brushes of the DC machines are always placed in this axis, and hence this axis is called the axis of commutation.

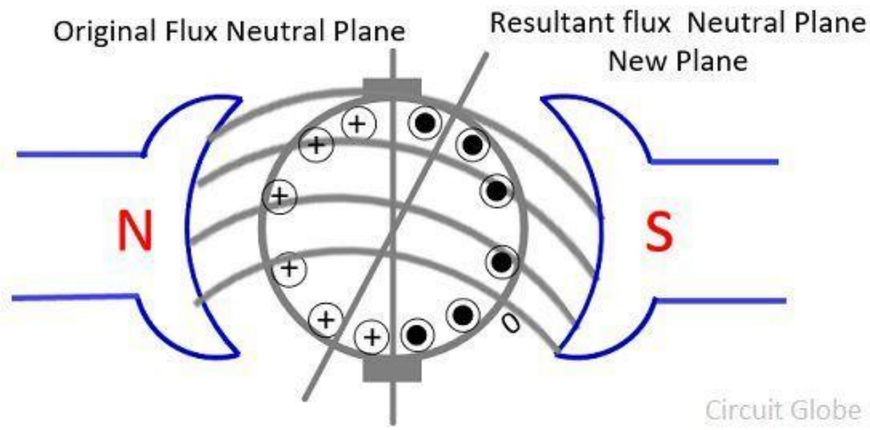


Consider the condition in which only the armature conductors carrying current and no current flows through their main poles. The direction of the current remains the same in all the conductors lying under one pole. The direction of current induces in the conductor is given by the Fleming right-hand rule. And the direction of flux generates in the conductors is given by the corkscrew rule.

The direction of current on the left sides of the armature conductor goes into the paper (represented by the cross inside the circle). The armature conductors combine their MMF for generating the fluxes through the armature in the downward direction.

Similarly, the right-hand side conductors carry current, and their direction goes out of the paper (shown by dots inside the circle). The conductor on the right-hand sides is also combining their MMF for producing the flux in the downwards direction. Hence, the conductor on both sides combines their MMF in such a way so that their flux goes downward direction. The flux induces in the armature conductor Φ_A is given by the arrow shown above.

The figure below shows the condition in which the field current and the armature current are simultaneously acting on the conductor.



This happens when machines running at no-load condition. Now the machine has two fluxes, i.e., the armature flux and the field pole flux. The armature flux is produced by the current induced in the armature conductors while the field pole flux is induced because of the main field poles. These two flux combines and gives the resultant flux Φ_R as shown in the figure above.

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 the 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 the 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.

Effects of Armature Reaction

1. **Flux Distortion (Magnetic Field Distortion)**
   - The main field is no longer symmetrical.
   - The flux density increases under one pole tip and decreases under the other.
   - This causes a shift in the **Magnetic Neutral Axis (MNA)** — the axis where no emf is induced.
2. **Shift of the Magnetic Neutral Axis (MNA)**
   - The MNA shifts in the direction of rotation in a generator.
   - Brushes are usually placed along the MNA; hence, the shift causes **sparking at the brushes** because the commutation is no longer perfect.
3. **Reduction of Effective Flux (Demagnetizing Effect)**
   - Some of the armature magnetomotive force (MMF) opposes the main field flux.
   - As a result, the **effective flux per pole decreases**, leading to:

        - Lower generated emf ($E \propto \Phi$)
        - Reduced terminal voltage under load

4. **Sparking at Brushes**
    - Due to the shift in the neutral plane, the current reversal in coils occurs when they are still cutting magnetic flux.
    - This results in sparking and poor commutation.

Methods to Improve Armature Reaction

1. Use of Interpoles (Commutating Poles)

- Small auxiliary poles placed **between main poles**, connected **in series with the armature**.
- **It**
    - Produces a magnetic flux proportional to the armature current.
    - The flux **opposes the armature reaction flux** in the commutating zone.
    - Reduces sparking at brushes and improves commutation.

2. Use of Compensating Windings

- Windings embedded in the **pole faces**, connected in series with the armature.
- **How it helps:**
    - Produces an MMF that **cancels the cross-magnetizing effect** of the armature.
    - Neutralizes flux distortion under the poles.
    - Keeps the **neutral plane nearly stationary** under varying load.

3. Proper Brush Shifting

- Shifting the brushes to the **new neutral plane** which moves due to armature reaction.
- **How it helps:**
    - The coil under the brush is in a **flux-free zone**, minimizing induced EMF during commutation.
    - Reduces sparking without altering the machine physically.

4. Series-Parallel Field Adjustment (Load Adjustment)

- Properly designing **shunt and series windings** in compound generators.
- **How it helps:**
    - Maintains main flux relatively constant under load.
    - Reduces the effect of demagnetizing component of armature reaction.

UNIT-2- DC MOTOR

2 MARKS QUESTIONS

1. How does Fleming's Left-Hand Rule apply to a DC motor?
   A: It determines the direction of force on a current-carrying conductor in a magnetic field. The thumb shows the force (motion), the first finger shows the magnetic field, and the second finger shows the current direction.
2. What is back e.m.f. in a DC motor?
   A: Back e.m.f. is a voltage induced in the rotating armature windings as they cut through the magnetic field, which opposes the supply voltage.
3. What is the significance of back e.m.f.?
   A: It regulates the armature current; as speed increases, back e.m.f. increases, and this limits the armature current to a value just sufficient to produce the required torque for the load.
4. Write the voltage equation for a DC motor.
   A: The voltage equation is
   V=Eb+IaRa V =supply voltage,
   Eb= back emf Ia= armature current R= armature resistance$a$
5. Define armature torque.
   A: Armature torque is the total torque developed by the current-carrying conductors in the armature windings due to the electromagnetic forces.
6. What is the necessity of using a DC motor starter?
   A: A starter is necessary to limit the high initial armature current at startup when the back e.m.f. is zero. It protects the motor from damage due to excessive current.
7. What is the principle behind the speed control of a DC motor?
   A: The speed of a DC motor can be controlled by changing either the magnetic flux per pole or the armature voltage. Decreasing flux increases speed, and increasing flux decreases speed.
8. How can the speed of a DC shunt motor be controlled?
   A: Speed can be controlled by both armature and flux control. Flux control is achieved by placing a variable resistance (rheostat) in series with the shunt field winding, while armature control is done by adding a variable resistance in series with the armature.
9. Explain the function of the "No-Volt Release" (NVR) coil in a three-point DC motor starter.
   A: The NVR coil is a safety feature that holds the starter's operating handle in the "RUN" position against spring tension. If the main voltage supply fails or drops significantly, the NVR coil de-energizes, releasing the handle, which then returns to the "OFF" position automatically. This prevents the motor from restarting unexpectedly when the voltage returns, which would be an unsafe high-current start condition.

10. How does a brushless DC motor work?
    A: An electronic controller, based on sensor feedback or a back e.m.f. sensing method, energizes the stator windings in a specific sequence, creating a rotating magnetic field that interacts with the permanent magnet rotor, causing it to rotate.

5 MARK QUESTIONS

1. Derive the condition for maximum efficiency in a dc motor?

CONDITION FOR MAXIMUM EFFICIENCY

Generator output = VI_L --------------where V is the terminal voltage and I_L is load current.

Generator input = VI_L + losses = $VI_a + I_a^2 r + P_c$

Where $I_a^2 r$ = Cu loss also called as variable loss; P_c= Iron loss also called as constant loss

If the shunt field current is negligible, then $I_a = I_L$

Hence Generator input = $V I_L + I_L^2 r + P_c$

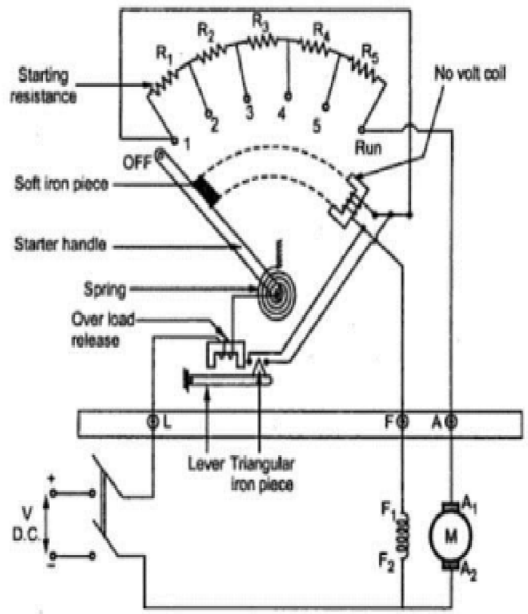
Generator Efficiency: $\eta = \frac{Output}{Input} = \frac{VI_L}{VI_L + I_L^2 R_a + P_C}$

Efficiency will be maximum when $\frac{d}{dI_L}\eta = 0$ OR $I_L^2 R_a = P_C$

Hence efficiency is maximum when variable loss is equal to constant loss.

The load current corresponding to maximum efficiency is $I_L = \sqrt{\frac{P_c}{r_a}}$

2. Explain the working of 3 point starter.



Internal view of three point starter

It consists of resistances arranged in steps, R_1 to R_5 connected in series with the armature of the shunt motor. Field winding is connected across the supply through a protective device called 'NO – Volt Coil'. Another protection given to the motor in this starter is 'over load release coil'. To start the motor the starter handle is moved from OFF position to Run position gradually against the tension of a hinged spring. An iron piece is attached to the starter handle which is kept hold by the No-volt coil at Run position. The function of No volt coil is to get de-energized and release the handle when there is failure or disconnection or a break in the field circuit so that on restoration of supply, armature of the motor will not be connected across the lines without starter resistance. If the motor is over loaded beyond a certain predetermined value, then the electromagnet of overload release will exert a force enough to attract the lever which short circuits the electromagnet of No volt coil. Short circuiting of No volt coil results in de-energisation of it and hence the starter handle will be released and return to its off position due to the tension of the spring.

If it is desire to control the speed of the motor in addition, then a field rheostat is connected in the field circuit. The motor speed can be increased by weakening the flux ($N \propto 1/\phi$). But there is one difficulty for control speed with this arrangement. If too much resistance is cut in by the field rheostat, then field current is reduced too much so that it is enable to create enough electromagnetic pull to overcome the spring tension. Hence the arm is pulled back to OFF position. It is this undesirable feature of a three-point starter which makes it unsuitable for use with variable-sped motor. This can be overcome with four-point starter.

3. Derive the equation for armature torque of a DC motor.

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

T=F*r

In a d.c. motor, each conductor is acted upon by a circumferential force F at a distance r, the radius of the armature (Fig. 4·11). Therefore, each conductor exerts a torque, tending to rotate the armature. The sum of the torques due to all armature conductors is known as *gross or armature torque* (T_a).

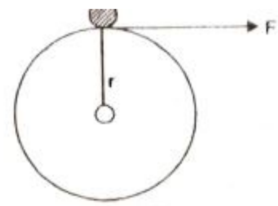


Fig. 4.11

Let in a d.c. motor

r = average radius of armature in m
l = effective length of each conductor in m
Z = total number of armature conductors
A = number of parallel paths
i = current in each conductor = I_a/A
B = average flux density in Wb/m^2
ϕ = flux per pole in Wb
P = number of poles

Force on each conductor, $F = B\,i\,l$ newtons

Torque due to one conductor $= F \times r$ newton- metre

Total armature torque, $T_a = Z F r$ newton-metre $= Z B i l r$

Now $i = I_a/A$, $B = \phi/a$ where a is the x-sectional area of flux path per pole at radius r. Clearly, $a = 2\pi r l/P$.

$$\therefore \quad T_a = Z \times (\phi/a) \times (I_a/A) \times l \times r$$

$$= Z \times \frac{\phi}{2\pi r\, l/P} \times \frac{I_a}{A} \times l \times r$$

$$= \frac{Z \phi I_a P}{2\pi A} \text{ N-m}$$

or $$T_a = 0{\cdot}159\, Z \phi I_a (P/A) \text{ N-m} \qquad ...(i)$$

Since Z, P and A are fixed for a given machine,

$$\therefore \quad T_a \propto \phi I_a$$

Hence *torque in a d.c. motor is directly proportional to flux per pole and armature current.*

(*i*) For a *shunt motor,* flux ϕ is practically constant.

$$\therefore \quad T_a \propto I_a$$

(*ii*) For a *series motor,* flux ϕ is directly proportional to armature current I_a provided magnetic saturation does not take place.

$$\therefore \quad T_a \propto I_a^2 \qquad \text{...upto magnetic saturation}$$

Alternative expression for T_a

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

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

From eq. (*i*), we get the expression of T_a as :

$$T_a = 0{\cdot}159 \times \left(\frac{60 \times E_b}{N}\right) \times I_a$$

or $$T_a = 9.55 \times \frac{E_b I_a}{N} \text{ N-m}$$

4. Explain construction and working of Brushless DC motor.

Construction of BLDC Motor

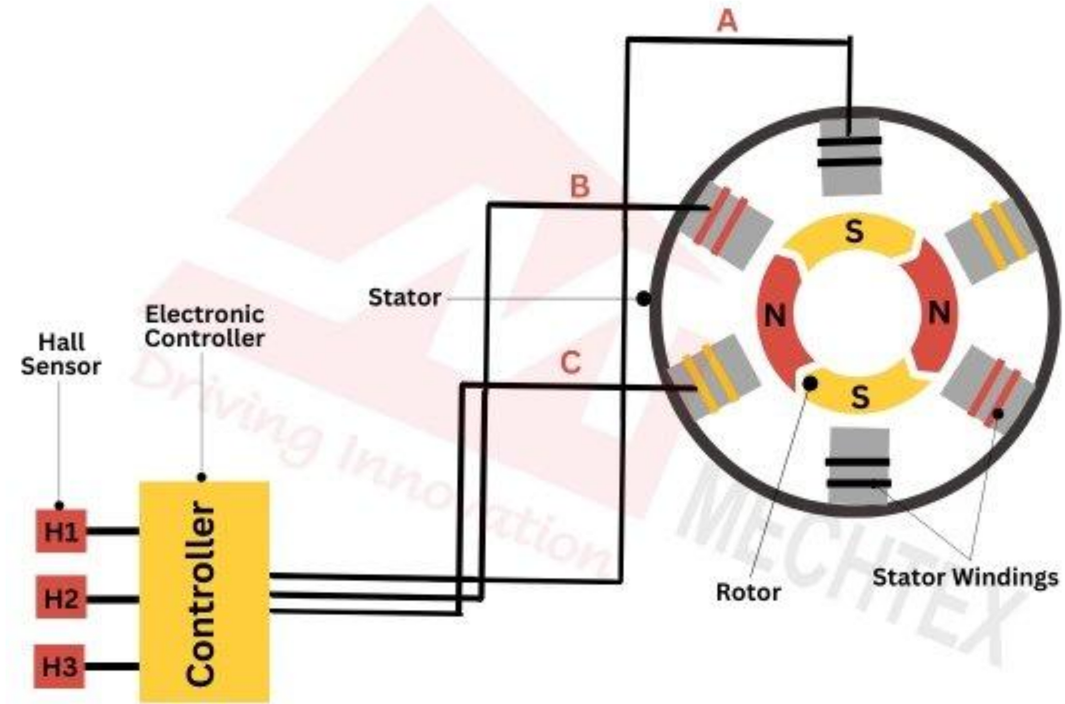
A BLDC motor consists of the following main parts:

1. **Stator (Stationary Part):**
    - Made of laminated steel with **slots for windings**.
    - Usually has **three-phase windings** connected in star or delta configuration.
    - When energized, these windings produce a **rotating magnetic field**.
2. **Rotor (Rotating Part):**
    - Contains **permanent magnets** (usually NdFeB) attached to the rotor core.
    - The rotor rotates due to the interaction of its magnetic field with the stator field.
    - No windings are on the rotor, unlike a brushed DC motor.
3. **Electronic Controller (Drive):**
    - Replaces mechanical brushes and commutator.
    - Switches the current in stator windings in a specific sequence to produce continuous rotation.
4. **Position Sensors (Optional, Hall sensors or Encoders):**
    - Detect rotor position to ensure correct timing for energizing stator windings.

Advantage of Construction: No brushes or commutator → less maintenance, no sparking, higher efficiency.

Working of BLDC Motor

1. The **controller monitors the rotor position** using sensors or by detecting back EMF.
2. Based on rotor position, the controller **energizes the appropriate stator windings** in sequence.
3. The energized stator winding produces a **magnetic field**, which interacts with the permanent magnets on the rotor.
4. The rotor **aligns with the stator's magnetic field** and begins to rotate.
5. The controller **continuously switches the stator windings** so the magnetic field "rotates," causing the rotor to keep spinning.
6. **Speed and torque control** is achieved by adjusting:
    - Magnitude of current
    - Switching frequency
    - Applied voltage



5. Explain the armature resistance of speed control of a DC shunt motor.

The **speed** of DC Motor is given by the relation shown below:

Here equation (1) shows the speed is dependent upon the supply voltage V, the armature circuit resistance Ra and the field flux ϕ, which is produced by the field current.

$$N = \frac{V - I_a R_a}{k\varphi} \quad \dots\dots\dots\dots (1)$$

The connection diagram of a shunt motor of the armature resistance control method is shown below. In this method, a variable resistor Re is put in the armature circuit. The variation in the variable resistance does not affect the flux as the field is directly connected to the supply mains.

If a **variable external resistance** Rext is added in series with the armature, the effective voltage across the armature decreases:

Veffective=Va−Ia(Ra+Rext)

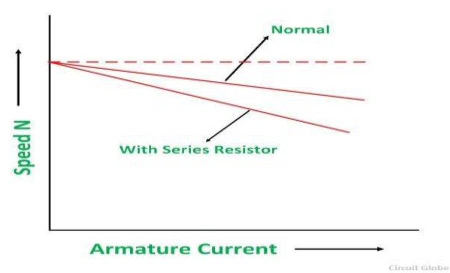
This reduces the back EMF and therefore the speed decreases. The field current is kept constant, so the flux Φ remains unchanged.

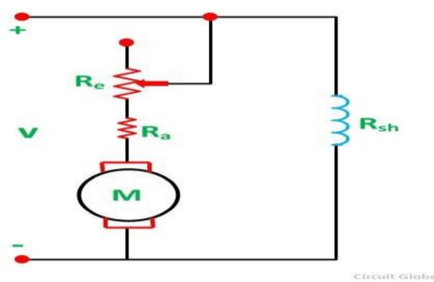
Advantages:

- Simple to implement.
- Provides smooth speed control below rated speed.

Disadvantages:

- Power is wasted in the external resistor → poor efficiency.
- Speed regulation is not very good, as it depends on load current.
- Cannot increase speed above rated value.





10 MARK QUESTION

A 4-pole, 240 V, wave connected shunt motor gives 1119 kW when running at 1000 r.p.m. and drawing armature and field currents of 50 A and 1.0 A respectively. It has 540 conductors. Its resistance is 0.1 Ω. Assuming a drop of 1 volt per brush, find (a) total torque (b) useful torque (c) useful flux / pole (d) rotational losses and (e) efficiency.

Solution. $E_b = V - I_a R_a - \text{brush drop} = 240 - (50 \times 0.1) - 2 = 233 \text{ V}$

Also $I_a = 50 \text{ A}$

(a) Armature torque $T_a = 9.55 \dfrac{E_b I_a}{N} \text{ N-m} = 9.55 \times \dfrac{233 \times 50}{1000} = 111 \text{ N-m}$

(b) $T_{sh} = 9.55 \dfrac{\text{output}}{N} = 9.55 \times \dfrac{11{,}190}{1000} = 106.9 \text{ N-m}$

(c) $E_b = \dfrac{\Phi Z N}{60} \times \left(\dfrac{P}{A}\right) \text{ volt}$

∴ $233 = \dfrac{\Phi \times 540 \times 1000}{60} \times \left(\dfrac{4}{2}\right) \quad \therefore \quad \Phi = 12.9 \text{ mWb}$

(d) Armature input $= V I_a = 240 \times 50 = 12{,}000 \text{ W}$

Armature Cu loss $= I_a^2 R_a = 50^2 \times 0.1 = 250 \text{ W}$; Brush contact loss $= 50 \times 2 = 100 \text{ W}$

∴ Power developed $= 12{,}000 - 350 = 11{,}650 \text{ W}$; Output $= 11.19 \text{ kW} = 11{,}190 \text{ W}$

∴ Rotational losses $= 11{,}650 - 11{,}190 = 460 \text{ W}$

(e) Total motor input $= VI = 240 \times 51 = 12{,}340 \text{ W}$; Motor output $= 11{,}190 \text{ W}$

∴ Efficiency $= \dfrac{11{,}190}{12{,}240} \times 100 = 91.4 \%$

2.a.Classify different types of DC Motor with schematic diagram.

On the basis of excitation dc motor classified in to 2 types

i. separately excited dc motor
ii. self excited dc motor

Separately Excited DC Motor

A DC motor whose magnetic field winding is excited from an independent source of DC electric supply like a battery is called a **separately excited DC motor**. Figure-1 shows the connection diagram of a separately excited DC motor.

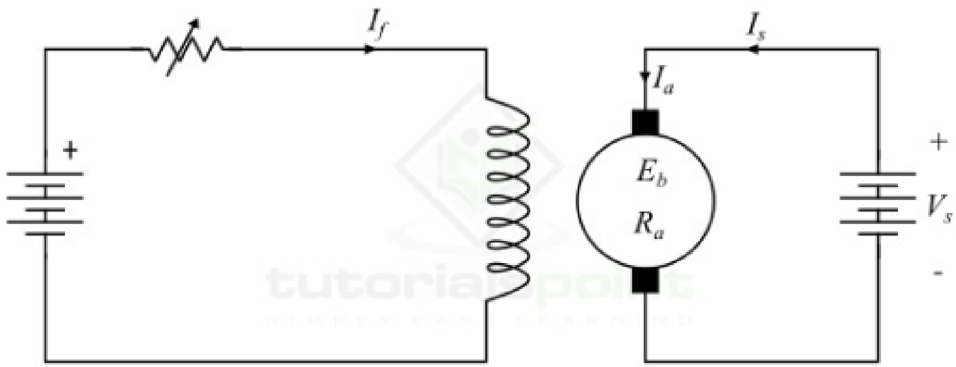


Figure 1 - Separately Excited DC Motor

The speed of a separately excited DC motor depends upon the supply voltage and field current, i.e. magnetic flux in the machine. However, the separately excited DC motors are rarely used in practical applications because these require an external source of DC power for field excitation.

Self-Excited DC Motors

The type of DC motor whose magnetic field winding is excited from the same power supply from which the armature is supplied, is known as a **self-excited DC motor**.

Depending upon the manner in which the field winding is connected with the armature winding, self-excited DC motors are classified in the following three types –

- Series DC motor
- Shunt DC motor
- Compound DC motor

Series DC Motor

A DC motor whose field winding is connected in series with the armature winding so that whole armature current passes through the field winding is called a **series DC motor**. Figure-2 shows the connection diagram of a series DC motor.

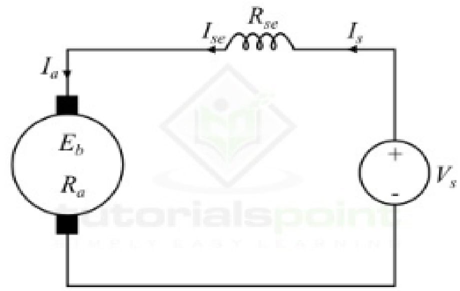


Figure 2 - Series DC Motor

In case of a series DC motor, the field winding carries the whole armature current, thus it is made up of thick wire with less number of turns so that it possesses minimum resistance.

The following are some important expressions for the series DC motor −

$$\text{Armature current}, I_a = I_{se} = I_s$$

Where, I_{se} is the series field current and I_s is the supply current.

$$\text{Supply voltage}, V_s = E_b + I_a (R_a + R_{se})$$

Where, E_b is the back EMF, R_a is the armature circuit resistance, R_{se} is the series field resistance.

Shunt DC Motor

A DC motor whose field winding is connected in parallel with the armature winding so that total supply voltage is applied across it, is known as a **shunt DC motor.** Figure-3 shows the connection diagram of a shunt DC motor.

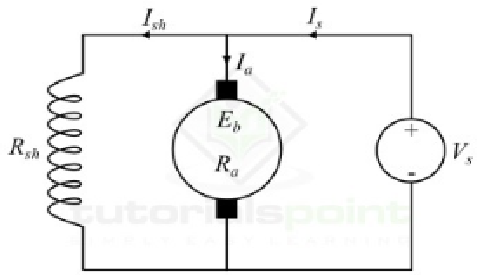


Figure 3 - Shunt DC Motor

In a shunt DC motor, the shunt field winding has a large number of turns of thin wire so that it has high resistance, and therefore only a part of supply current flows through it and the rest flows through the armature winding.

Following are the important expressions of a shunt DC motor −

$$\textbf{Armature current}, I_a = I_s - I_{sh}$$

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

$$\textbf{Supply Voltage}, V_s = E_b + I_a R_a$$

Compound DC Motor

A **compound DC motor** is one which has two sets of field windings on each magnetic pole one is in series and the other is in parallel with the armature winding.

Compound DC motors are sub-divided into the following two types −

- Short-shunt compound DC motor
- Long-shunt compound DC motor

A **short-shunt compound DC motor** is one in which only shunt field winding is in parallel with the armature winding as shown in Figure-4.

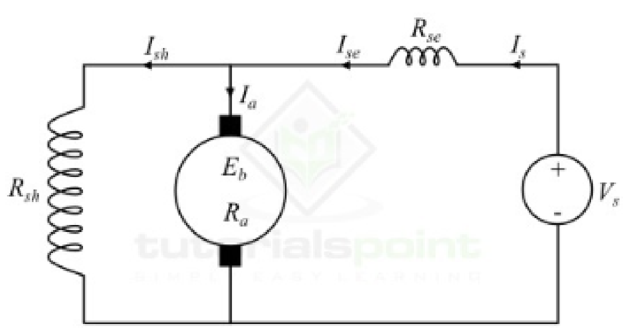


Figure 4 - Short Shunt DC Motor

A **long-shunt compound DC motor** is one in which shunt field winding is in parallel with both series field winding and armature winding as shown in Figure-5.

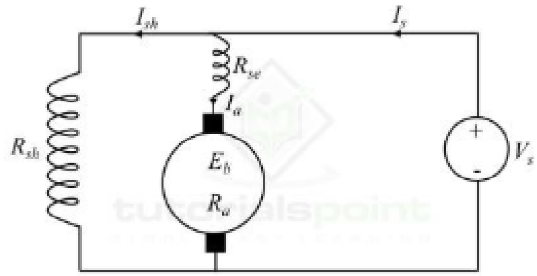


Figure 5 - Long Shunt DC Motor

The following are the important expressions for compound DC motors –

For short-shunt motor,

$$\text{Armature current}, I_a = I_s - I_{sh}$$

$$\text{Series field current}, I_{se} = I_a$$

$$\text{Shunt field current}, I_{sh} = \frac{V_s - I_{se}R_{se}}{\mathrm{R_{sh}}}$$

$$\text{Supply voltage}, V_s = E_b + I_a R_a + I_{se} R_{se}$$

For long-shunt motor,

$$\text{Armature current}, I_a = I_s - I_{sh}$$

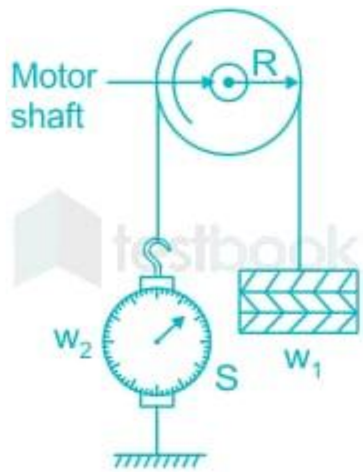
$$\text{Series field current}, I_{se} = I_s$$

$$\text{Shunt field current}, I_{sh} = \frac{V_s}{\mathrm{R_{sh}}}$$

$$\text{Supply voltage}, V_s = E_b + I_a (R_a + R_{se})$$

b.Explain Brake test.

It is a direct method to determine the efficiency of DC motor
It consists of applying a brake to a water-cooled pulley mounted on the motor shaft as shown in fig.
The brake band is fixed with the help of wooden blocks gripping the pulley.
One end of the band is fixed to earth via a spring balance S and the other is connected to a suspended weight W1.
The motor is running and the load on the motor is adjusted till it carries its full load current."



"Let   W1 = suspended weight in kg

W2 = reading on spring balance in kg-wt

The net pull on the band due to friction at the pulley is

= (W1 − W2) kg-wt = 9.81(W1 − W2) N.

If R = radius of the pulley in meter

Then, shaft torque Tsh developed by the motor

= R(W1 − W2) kg-m = 9.81R(W1 − W2) N-m

Motor output power = (Tsh × 2π N) watt

N = motor or pulley speed in r.p.s.

Therefore, η = P0/Pin

Where,

P0 = Motor Output or shaft power

Pin = Input power of motor"

UNIT-III

SINGLE PHASE TRANSFORMERS

2MARKS

1.State the working principle of transformer.

Answer

i)The working principle of a transformer is based on the principle of electromagnetic induction specifically, mutual induction between two coils. When an alternating current (AC) flows through the primary coil, it produces a time-varying magnetic flux in the transformer's core.

ii)This changing magnetic flux links with the secondary coil and induces an electromotive force (emf) in it according to Faraday's Law of Electromagnetic Induction.

2.What are the two main types of single-phase transformers?

Answer:
The two main types are:

1. **Core-type transformer** – windings surround the core.
2. **Shell-type transformer** – core surrounds the windings.

3.what do you means by ideal transformer?

Answer.

1.No copper losses:
The windings have zero resistance, so there is no I^2R loss.

2.No core losses:
There are no hysteresis or eddy current losses in the magnetic core.

3.No leakage flux:
All magnetic flux produced by the primary winding links completely with the secondary winding.

4. Perfect magnetic coupling:
The coupling coefficient $k = 1$.

5. No magnetizing current needed:

4. Write the EMF equation of a transformer.

Answer

EMF Equation of a Transformer

When an alternating current flows through the primary winding of a transformer, a sinusoidal magnetic flux (Φ) is produced in the core.
This changing flux links both the primary and secondary windings, inducing electromotive forces (emfs) in them according to Faraday's law of electromagnetic induction.

Let:

Φ_m= maximum value of flux in the core (in Weber, Wb)

f= frequency of the AC supply (in Hz)

N_1= number of turns in the primary winding

N_2= number of turns in the secondary winding

Instantaneous flux:$\Phi = \Phi_m \sin(\omega t)$
where $\omega = 2\pi f$

Induced emf per turn:$e = -\frac{d\Phi}{dt}$

The average value of the induced emf per turn over one-half cycle is:$E_{\text{per turn}} = 4.44 f \Phi_m$

Therefore:

EMF in primary winding:$E_1 = 4.44 f N_1 \Phi_m$
EMF in secondary winding:$E_2 = 4.44 f N_2 \Phi_m$

5. Name the main parts of a single-phase transformer.

Answer:
Main parts are:

- Magnetic core
- Primary winding
- Secondary winding
- Tank (enclosure)
- Insulation
- Cooling system (oil/radiators)
- Bushings

6. What are CRGO and CRNGO materials used for?

ANSWER

1. CRGO (Cold Rolled Grain Oriented) and CRNGO (Cold Rolled Non-Grain Oriented) steels are used for transformer core laminations.

2.They reduce eddy current and hysteresis losses in the core.

7. What is the voltage transformation ratio?

Answer:

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

where K= transformation ratio = voltage ratio = turns ratio.

8. Define transformer efficiency.

Answer:
Efficiency (η) is the ratio of output power to input power.

$$\eta = \frac{\text{Output Power}}{\text{Input Power}} \times 100 = \frac{V_2 I_2 \cos\ \phi_2}{V_2 I_2 \cos\ \phi_2 + \text{Losses}} \times 100$$

9. What is all-day efficiency?

Answer:
All-day efficiency is the ratio of total energy output to total energy input in 24 hours, considering variable load conditions.

$$\text{All-day efficiency} = \frac{\text{Energy output in kWh}}{\text{Energy input in kWh}} \times 100$$

10. What is leakage reactance in a transformer?

Answer:
Leakage reactance is the reactance due to leakage flux that does not link both windings but links only one winding, causing voltage drops and reduced voltage regulation.

5MARKS

1. **Explain the construction and working of a single-phase transformer with a neat diagram.**

Answer:

A single-phase transformer consists of the following main parts:

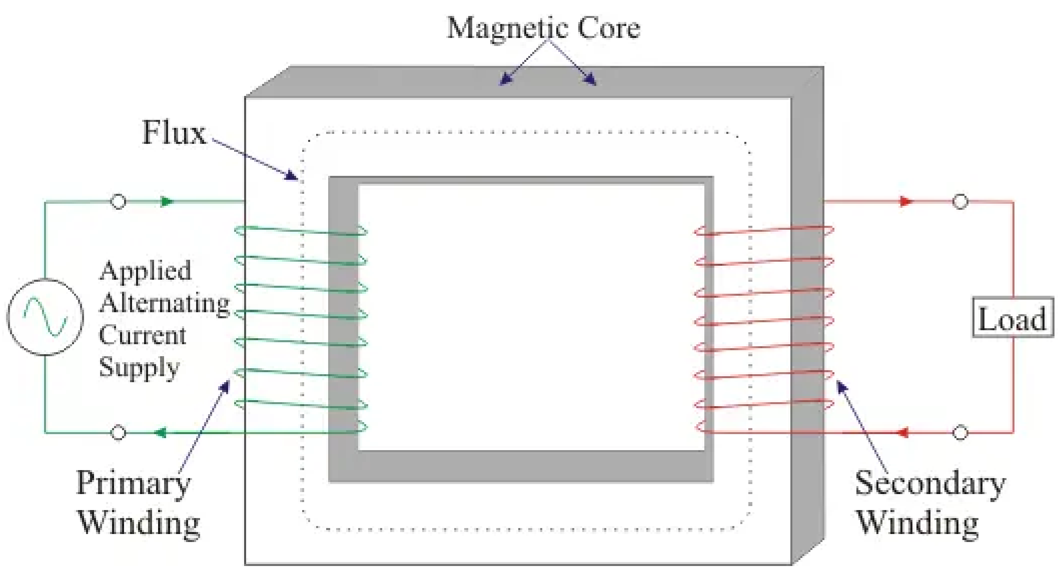
Core: Made of laminated silicon steel to provide a low reluctance path for magnetic flux.

Windings: Primary and secondary coils wound on the core limbs.

Tank: Contains transformer oil for insulation and cooling.

Bushings: Provide terminals for external connections.

Cooling System: Radiators or fans to remove heat.



Single Phase Transformer

working of a single-phase transformer

i)The working principle of a transformer is based on the principle of electromagnetic induction specifically, mutual induction between two coils. When an alternating current (AC) flows through the primary coil, it produces a time-varying magnetic flux in the transformer's core.

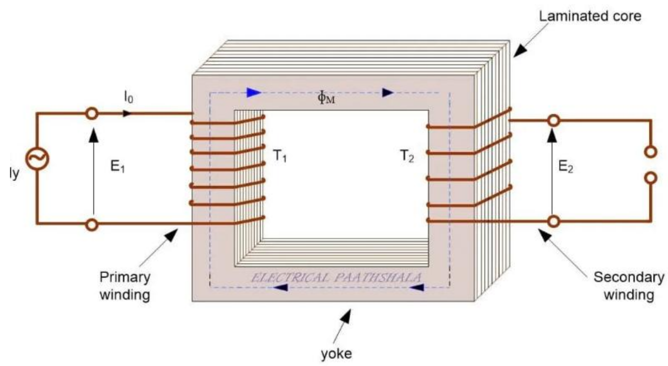
ii)This changing magnetic flux links with the secondary coil and induces an electromotive force (emf) in it according to Faraday's Law of Electromagnetic Induction.

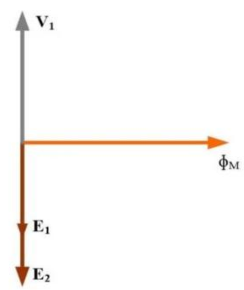
2. Draw and explain the phasor diagram of a transformer on no-load.

In a single phase transformer, there is a primary winding and a secondary winding. The winding to which AC voltage source is connected is known as Primary winding, and the winding to which Load is connected is known as Secondary winding. Then wha

If there is **no load** connected with the secondary winding then, it is called as a no-load transformer. We will discuss no load transformer with its phasor diagram in this post.

In a no load transformer, the secondary side is open circuited. Hence, there will be no current flowing in the secondary circuit.





A small current will flow in the primary side, which is known as the no load current and it is denoted as "I_o". This no-load current I_o has two components, **magnetizing component (I_μ)** and **working component (I_w).**

Magnetizing component (I_μ) :

This component is known as magnetizing component, because it is actually use to magnetize the core of the transformer. We can also say that, **I_μ** is used to set up flux(ϕ_M) in the core. Now, as the flux ϕ_M is developed by the **I_μ,** so they both will be in phase to each other as shown in the phasor diagram below.

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*.

I_W is in phase with the applied voltage V_1.

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 transformer on no-load

We will draw the phasor diagram of transformer under no load condition in few steps, then by combining all the steps together, we will draw a final figure.

3.Distinguish between core and shell type transformers

ANSWER

Feature	Core-Type Transformer	Shell-Type Transformer
1. Construction	The windings surround the laminated magnetic core.	The core surrounds the windings.
2. Core Structure	Has two limbs (legs) — each limb carries part of the windings (primary and secondary).	Has three limbs — the central limb carries both windings, and the outer limbs provide the return path for magnetic flux.
3. Magnetic Flux Path	The flux has two parallel paths.	The flux has one central path (main limb) with two side limbs for return.
4. Winding Arrangement	Cylindrical or concentric type windings are placed on both limbs.	Sandwich (interleaved) type windings are placed on the central limb.
5. Cooling	Easier to cool because windings are more exposed.	Cooling is comparatively difficult due to windings being enclosed.
6. Mechanical Strength	Lower mechanical strength — windings are more exposed to mechanical stresses.	Higher mechanical strength — windings are well supported and better protected.
7. Common Applications	Commonly used for high-voltage, low-current applications.	Commonly used for low-voltage, high-current applications (e.g., power transformers).

4. A single-phase transformer working at unity power factor has an efficiency of 90% at both half load and at the full-load of 500W.Determine the efficiency at 75%full load and the maximum efficiency.

Answer

Given Data:

- Full-load output power $P_{out,FL} = 500$ W
- Efficiency at full-load $\eta_{FL} = 90\% = 0.9$
- Efficiency at half-load $\eta_{HL} = 90\% = 0.9$
- Power factor = 1 (unity)

We need to find: i) Efficiency at 75% full-load

ii)Maximum efficiency and the load at which it occurs

Let:

- P_i =iron (core) loss = constant
- P_{cu} =full-load copper loss

At load fraction x:

$$P_{cu,x} = x^2 P_{cu}$$

Use efficiency formula

$$\eta = \frac{\text{Output Power}}{\text{Output Power} + \text{Losses}}$$

At full-load $(\text{x} = 1)$:

$$0.9 = \frac{500}{500 + \text{P}_\text{i} + \text{P}_\text{cu}} (1)$$

At half-load $(\text{x} = 0.5)$:

$$0.9 = \frac{250}{250 + \text{P}_\text{i} + 0.25\text{P}_\text{cu}} (2)$$

$$500 + P_i + P_{cu} = \frac{500}{0.9} = 555.56$$
$$P_i + P_{cu} = 55.56 (\text{A})$$

$$250 + P_i + 0.25P_{cu} = \frac{250}{0.9} = 277.78$$
$$P_i + 0.25P_{cu} = 27.78 (\text{B})$$

$$(P_i + P_{cu}) - (P_i + 0.25P_{cu}) = 55.56 - 27.78$$
$$0.75P_{cu} = 27.78$$
$$P_{cu} = 37.04\text{ W}$$

Substitute in (A):

$$P_i = 55.56 - 37.04 = 18.52\text{ W}$$

Iron loss = 18.52 W, Full-load copper loss = 37.04 W

Efficiency at 75% load (x = 0.75)

Output power = $0.75 \times 500 = 375$ W
Copper loss = $(0.75)^2 \times 37.04 = 20.84$ W

$$\eta_{0.75} = \frac{375}{375 + 18.52 + 20.84} = \frac{375}{414.36} = 0.904$$

Efficiency at 75% load = 90.4%

Condition for maximum efficiency

Maximum efficiency occurs when:

$$P_{cu} = P_i$$
$$x^2 P_{cu} = P_i$$
$$x = \sqrt{\frac{P_i}{P_{cu}}} = \sqrt{\frac{18.52}{37.04}} = 0.707$$

Thus, maximum efficiency occurs at 70.7% of full-load.

Calculate maximum efficiency

Output = $0.707 \times 500 = 353.5$ W
Losses = $P_i + x^2 P_{cu} = 18.52 + 18.52 = 37.04$ W

$$\eta_{max} = \frac{353.5}{353.5 + 37.04} = 0.905 = 90.5\%$$

5. Derive the EMF equation of a transformer.

Answer:
Let maximum flux = Φ_m, frequency = f, turns = N_1, N_2.

$$\Phi = \Phi_m \sin(\omega t)$$

Induced emf per turn = rate of change of flux = $4.44 f \Phi_m$ volts.

Hence,

- Primary induced emf: $E_1 = 4.44fN_1\Phi_m$
- Secondary induced emf: $E_2 = 4.44fN_2\Phi_m$

Voltage ratio:

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

10 marks

1. A single-phase 500 kVA, 11 kV/0.4 kV transformer has the following test data:

Open-circuit (OC) test on LV side:

- **Voltage = 400 V**
- **Current = 10 A**
- **Power = 2 kW**

Short-circuit (SC) test on HV side:

- **Voltage = 120 V**
- **Current = 22.7 A**
- **Power = 1.5 kW**

Tasks:

a)Draw the equivalent circuit of the transformer referred to HV side.

b)Determine the equivalent resistance and reactance referred to HV side.

c)Calculate the voltage regulation at full load, 0.8 lagging power factor.

d)Find the efficiency at full load if the transformer is supplying rated load at unity power factor.

Solution:

Step 1: Calculate core (iron) loss and magnetizing parameters from OC test

- OC test applied on LV side (0.4 kV)
- $V_{OC} = 400$ V, $I_{OC} = 10$ A, $P_{OC} = 2$ kW

Core (iron) resistance:

$$R_0 = \frac{V_{OC}^2}{P_{OC}} = \frac{400^2}{2000} = 80\ \Omega$$

Magnetizing reactance:

$$I_m = \sqrt{I_{OC}^2 - (V_{OC}/R_0)^2} = \sqrt{10^2 - (400/80)^2} = \sqrt{100 - 25} = \sqrt{75} = 8.66 \text{ A}$$

$$X_m = \frac{V_{OC}}{I_m} = \frac{400}{8.66} \approx 46.2\ \Omega$$

Step 2: Equivalent series parameters from SC test

- SC test applied on HV side (11 kV side)
- $V_{SC} = 120$ V, $I_{SC} = 22.7$ A, $P_{SC} = 1.5$ kW

Equivalent resistance (referred to HV side):

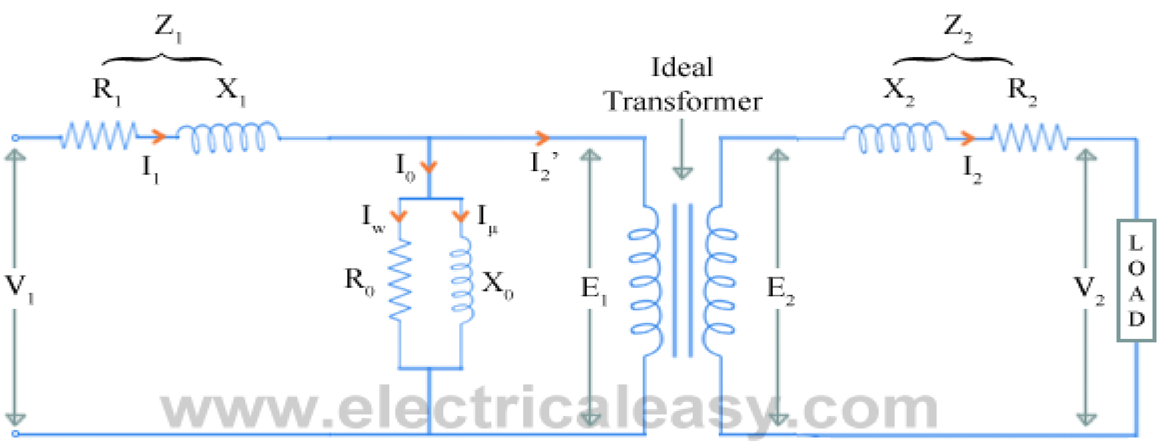
$$R_{eq} = \frac{P_{SC}}{I_{SC}^2} = \frac{1500}{22.7^2} = \frac{1500}{515.3} \approx 2.91\ \Omega$$

Equivalent impedance:

$$Z_{eq} = \frac{V_{SC}}{I_{SC}} = \frac{120}{22.7} \approx 5.29\ \Omega$$

Equivalent reactance:

$$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2} = \sqrt{5.29^2 - 2.91^2} = \sqrt{27.98 - 8.47} = \sqrt{19.51} \approx 4.42\ \Omega$$



step 3: Voltage regulation at full load

Voltage regulation formula:

$$\%VR = \frac{I_2(R\cos\ \phi + X\sin\ \phi)}{V_2} \times 100$$

- Full load current on HV side:

$$I_2 = \frac{S}{V_{HV}} = \frac{500 \times 10^3}{11 \times 10^3} \approx 45.45 \text{ A}$$

- Power factor: $\cos\ \phi = 0.8, \sin\ \phi = 0.6$

$$\%VR = \frac{45.45(2.91 \cdot 0.8 + 4.42 \cdot 0.6)}{11000} \times 100$$
$$= \frac{45.45(2.328 + 2.652)}{11000} \times 100 = \frac{45.45 \cdot 4.98}{11000} \cdot 100$$

Voltage regulation = 2.06%

Step 4: Efficiency at full load (unity p.f.)

$$\eta = \frac{\text{Output}}{\text{Output + Losses}}$$

- Full load copper loss: $P_{cu} = I_2^2 R_{eq} = 45.45^2 \cdot 2.91 \approx 6020$ W
- Core loss: $P_i = 2000$ W

$$\eta = \frac{500000}{500000 + 6020 + 2000} = \frac{500000}{508020} \approx 0.984 = 98.4\%$$

2.A)A 230/115 V transformer takes 0.8 A and 60 W on no-load. Find:

1. **No-load current**
2. **Power factor**

Solution:

$$I_0 = 0.8 \text{ A}, P = 60 \text{ W}, V = 230 \text{ V}$$
$$\cos\ \phi_0 = \frac{P}{VI_0} = \frac{60}{230 \times 0.8} = 0.326$$
$$I_0 = 0.8 \text{ A}, \cos\ \phi_0 = 0.326$$

B)A 10 kVA, 2500/250 V transformer has an efficiency of 96% at full-load and unity power factor. Find full-load copper losses if iron losses are 150 W.

Solution:

$$\eta = \frac{\text{Output}}{\text{Output} + P_i + P_c}$$

$$0.96 = \frac{10{,}000}{10{,}000 + 150 + P_c}$$

$$10{,}000 + 150 + P_c = \frac{10{,}000}{0.96} = 10{,}416.7$$

$$P_c = 10{,}416.7 - 10{,}150 = 266.7\ \text{W}$$

Full-load copper loss = 267 W

Unit 4-Three phase Transformer

2 mark questions

1.What is the need for parallel operation of three-phase transformers?

Answer: To increase the total capacity for carrying load, to provide for maintenance by taking one transformer offline, or to improve reliability by having a backup .

2.State the conditions for the parallel operation of two three-phase transformers.

Answer: The transformers must have the same voltage ratio, same polarity, same per-unit impedance, and same phase displacement.

3.What is a "bank of three single-phase transformers"?

Answer: It is when three separate single-phase transformers are connected together (either on the primary or secondary side) to function as a three-phase transformer.

4.List two advantages of a single-unit three-phase transformer over a bank of single-phase transformers.

Answer: A single-unit transformer is cheaper, requires less space, and is lighter.

5.State two criteria for selecting a distribution transformer.

Answer: Voltage regulation, efficiency, and mechanical strength are key considerations for distribution transformers.

6.What is the purpose of a Y-Δ connection?

Answer: A Y-Δ (wye-delta) connection is often used for stepping down voltage and is common in power distribution applications, such as providing the three-phase and single-phase power required for most industrial and residential loads.

7.What is a "phasing out" test?

Answer: A phasing out test is a method to identify the correct phase sequence and connections of a three-phase transformer, often using a low-voltage source to ensure the correct high-voltage winding polarities are connected together.

8.Explain the significance of polarity in parallel operation.

Answer: Polarity is crucial for parallel operation to prevent a short circuit. If polarity is reversed, the voltages from the two transformers would oppose each other, leading to a very large current flow and potential damage.

9.State any two applications of a Δ-Δ connection.

Answer: A Δ-Δ connection is used for large low-voltage applications or when a higher level of reliability is required, as one transformer can be removed and the other two can continue to operate in an open-delta configuration.

10.What is the difference between a distribution transformer and a power transformer?

Answer: Distribution transformers operate at full load for long periods, are used to step down voltage for end-users, and have efficiencies ranging from 98.5%to 99.5%. Power transformers are used in transmission networks to step up or step down voltage and are often more efficient, with efficiencies around 99.5% to 99.9%.

5 mark question

1.**State the criteria for selection of a distribution transformer.**

Answer:

1. **Voltage rating:** Matches supply and consumer voltage levels (e.g., 11 kV / 433 V).
2. **kVA rating:** Depends on expected load demand.
3. **Cooling method:** ONAN for small/medium; ONAF for higher capacity.
4. **Efficiency:** High efficiency at light load (since load varies).
5. **Voltage regulation:** Should be good to maintain constant output.
6. **Installation site:** Outdoor or pole-mounted, depending on requirement.
7. **Cost and maintenance:** Should be low for distribution purposes.

2.**What are the main conditions for parallel operation of three-phase transformers?**

Answer:

For successful parallel operation:

1. **Same voltage ratio (turns ratio).**
2. **Same polarity.**
3. **Same phase sequence.**
4. **Same vector group (phase displacement).**
5. **Equal percentage (per-unit) impedance.**
6. **Similar voltage regulation and efficiency.**

3. Differentiate between distribution and power transformers.

Parameter	**Distribution Transformer**	**Power Transformer**
Rating	Up to 200 kVA	Above 200 kVA
Voltage	11/0.4 kV, etc.	132/33, 220/132 kV
Load	Variable	Constant
Efficiency	High at light load	High at full load
Cooling	ONAN	ONAF/OFAF
Location	Near consumers	In substations
Regulation	Better	Moderate

4. **What are the advantages and disadvantages of using a bank of three single-phase transformers instead of one three-phase transformer?**

Answer:

Advantages of Bank of Single-Phase Transformers:

1. Easy transportation and installation.
2. One unit can be replaced if faulty — continuity of supply.
3. Flexibility — can operate in open-delta (V–V) if one transformer fails.
4. Useful when units of different ratings are available.

Disadvantages:

1. Occupies more space.
2. More cost for same total rating.
3. Higher losses and lower efficiency.
4. Requires more maintenance and connections.

5.Describe the procedure for performing a polarity and phasing-out test on a three-phase transformer.

Answer:
1. Polarity Test:

- Performed similarly to the single-phase method but on each pair of windings (R–r, Y–y, B–b).
- Apply a small single-phase voltage to one winding pair.
- Measure voltage across primary and secondary terminals to determine additive or subtractive polarity.
- Ensures correct polarity for interconnection of windings.

2. Phasing-Out Test (Phase Sequence Test):
Purpose: To check whether the phase sequence on both primary and secondary sides is the same.

Procedure:

1. Apply a 3-phase supply to the primary.
2. Measure voltages between corresponding terminals of primary and secondary (e.g., between R and r, Y and y, etc.).
3. If voltages are **small**, phase sequence is **same**.
   If **large (≈ line voltage)**, the phase sequence is **opposite**.

Importance:

- Ensures correct phase relation before connecting transformers in parallel or into a power system.
- Prevents short-circuits and system faults.

<u>10 mark question</u>

Q1. Explain the different connections of a bank of three single-phase transformers (Y–Y, Δ–Δ, Δ–Y, Y–Δ) with neat diagrams.

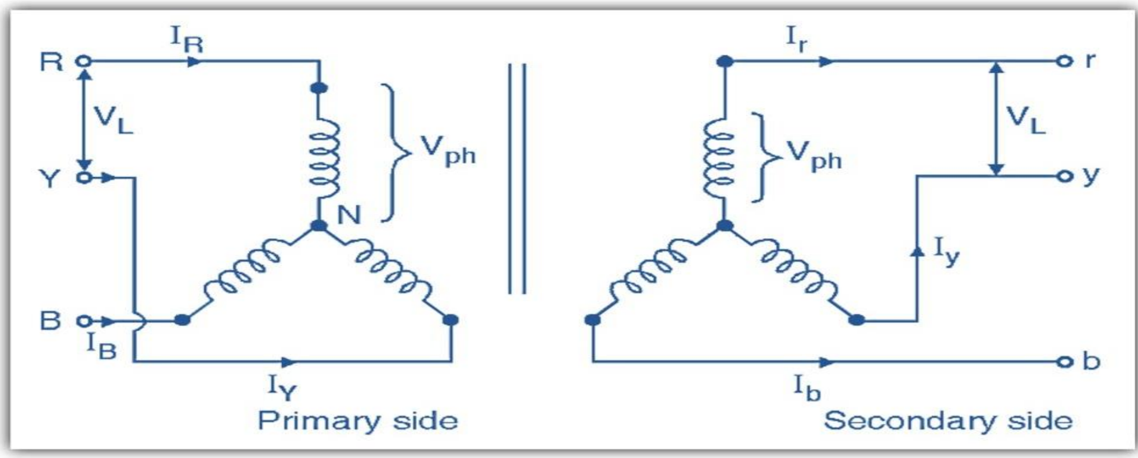
Answer:

A **three-phase transformer** can be obtained by connecting **three single-phase transformers** in a suitable manner.
The primary and secondary windings can be connected either in **star (Y)** or **delta (Δ)**.

There are **four possible combinations**:

1. Star–Star (Y–Y) Connection

Diagram:



Features:

-
- Both sides are star connected.
- Line voltage = √3 × Phase voltage.
- Line current = Phase current.

Advantages:

- Neutral point available for grounding.
- Economical — windings need less insulation (only phase voltage per winding).

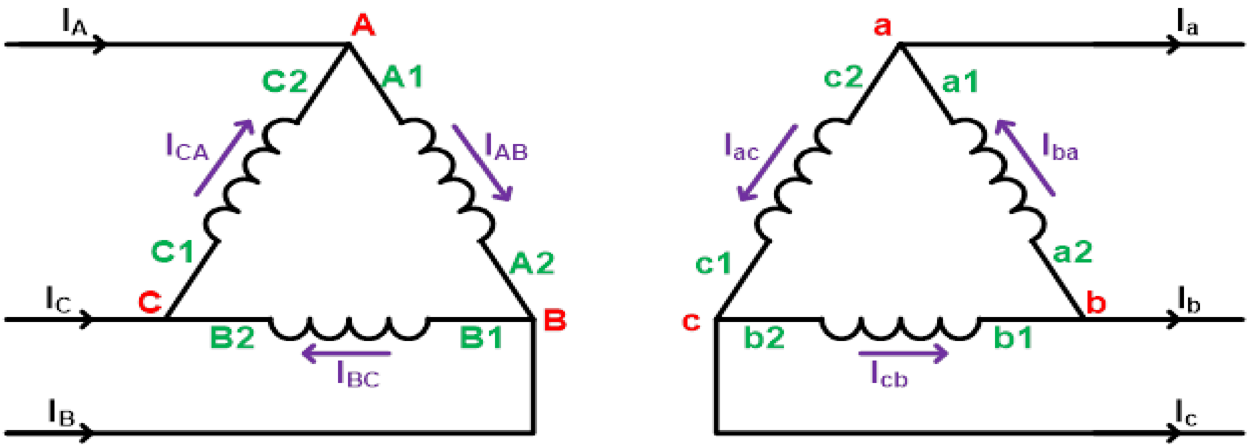
Disadvantages:

- Third harmonics cause neutral shift and distortion.
- Not suitable for unbalanced loads.

Applications: Step-up or step-down where neutral grounding is required and load is balanced.

2. Delta–Delta (Δ–Δ) Connection

Diagram:



Features:

- Line voltage = Phase voltage.
- Line current = √3 × Phase current.

Advantages:

- No neutral required.
- If one transformer fails, remaining two can run in **open-delta (V–V)** connection at 58% capacity.
- Handles unbalanced loads well.

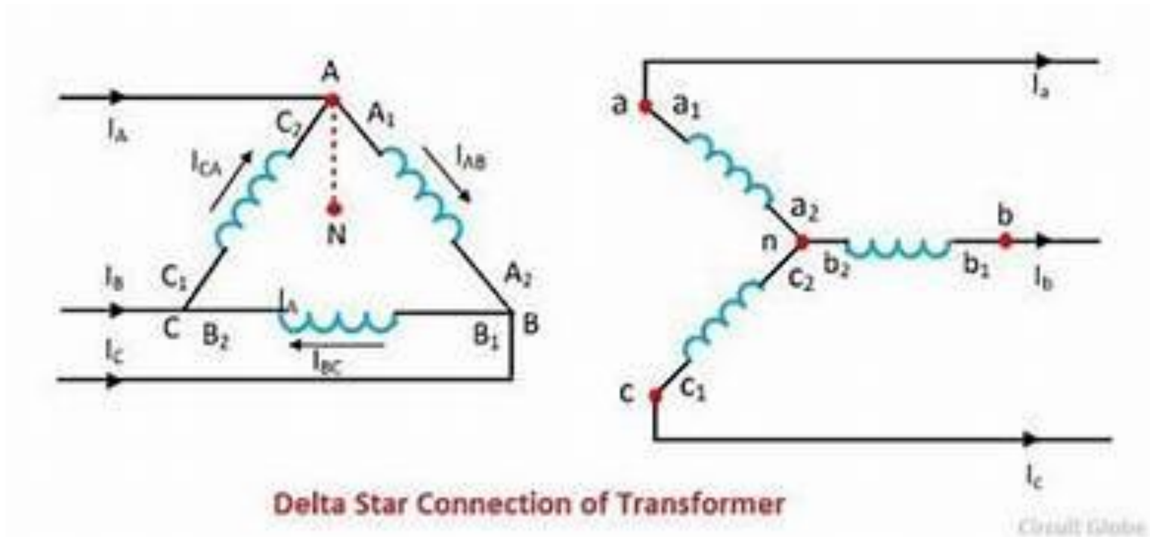
Disadvantages:

- No neutral for single-phase loads.

Applications: Common in industrial systems where balanced three-phase loads exist.

3. Delta–Star (Δ–Y) Connection

Diagram:



Features:

- Line-to-line voltage on primary; line-to-neutral voltage on secondary.
- Voltage ratio = (√3 × turns ratio).

Advantages:

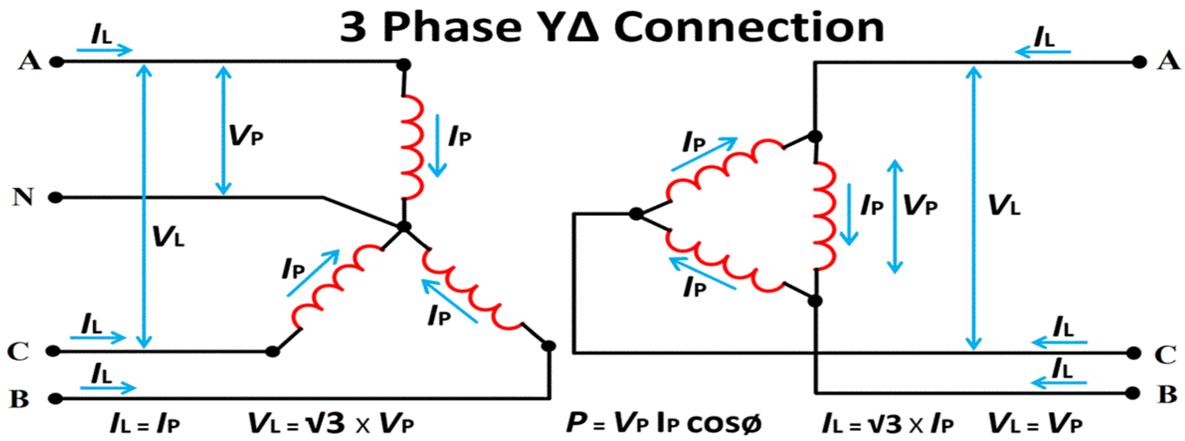
- Star side provides neutral for 3-phase, 4-wire system.
- Third harmonics confined within delta winding.
- Commonly used as **step-up** transformer in transmission systems.

Disadvantages:

- Phase shift of 30° between primary and secondary voltages (important for parallel operation).

Applications: Transmission networks (e.g., generator transformers).

4. Star–Delta (Y–Δ) ConnectionDiagram:



Features:

- Primary phase voltage = Line voltage / √3.
- Secondary line voltage = Phase voltage.

Advantages:

- Star connection on HV side reduces insulation cost.
- Delta side provides path for third harmonics and balanced load.
- Suitable for **step-down** applications.

Disadvantages:

- 30° phase shift between primary and secondary voltages.

Applications: Step-down transformers in substations.

Type	Phase Shift	Neutral Available	Common Use	Remarks
Y–Y	0°	Yes	Balanced systems	Harmonic issues
Δ–Δ	0°	No	Industrial loads	Works in open-delta
Δ–Y	+30°	Yes (secondary)	Step-up	Common in transmission
Y–Δ	−30°	No	Step-down	Common in distribution

2. Explain the need and conditions for parallel operation of three-phase transformers.

A. Need for Parallel Operation

Two or more transformers are said to operate **in parallel** when their **primary windings** are connected to the same supply bus bars and their **secondary windings** are connected to a common load.

The need arises due to the following reasons:

1. **Increased Load Demand:**
   - When the load on a substation increases beyond the capacity of a single transformer, two or more transformers are connected in parallel to share the load.
2. **Continuity of Supply (Reliability):**
   - During maintenance or fault of one transformer, the other(s) can continue supplying power, ensuring uninterrupted service.
3. **Flexibility in Operation:**
   - One transformer can be switched off during light load periods to improve efficiency.
4. **Future Expansion:**
   - Instead of replacing an existing transformer with a larger one, additional units can be added in parallel as demand grows.
5. **Ease of Transportation and Installation:**
   - Large single transformers are difficult to transport; using smaller ones in parallel is more convenient.

B. Conditions for Parallel Operation

For transformers to operate successfully in parallel **without circulating currents** and **with proper load sharing**, the following conditions must be satisfied:

1. Same Voltage Ratio (Turns Ratio)

- The voltage ratio of each transformer must be identical.
- Otherwise, unequal secondary voltages cause **circulating currents**, leading to losses and possible overloading.

$$\frac{N_1}{N_2} = \text{constant for all transformers}$$

2. Same Polarity

- The polarity of all transformers must be the same.
- If not, severe short-circuit currents will flow when secondaries are paralleled.

Test: Polarity test must be conducted before paralleling (connect secondary terminals and check voltage).

3. Same Phase Sequence

- The phase sequence (R–Y–B order) of all transformers must be identical.
- If the sequence differs, large circulating currents will occur due to phase opposition.

4. Same Phase Angle (Vector Group)

- The phase displacement between primary and secondary voltages must be the same.
- Transformers of different vector groups (e.g., Dyn11 and Dy5) cannot be paralleled.

5. Equal (or Proportional) Impedance

- Transformers should have the same per-unit (p.u.) impedance to ensure proper load sharing.

If impedances differ, the transformer with **lower impedance** carries **more load**, leading to overheating.

$$\frac{I_1}{I_2} = \frac{Z_2}{Z_1}$$

6. Similar Voltage Regulation and Efficiency

- Transformers should have similar performance characteristics so that voltage drop and efficiency remain balanced under varying load conditions.

UNIT-V

SPECIAL PURPOSE TRANSFORMERS

1.Define a single-phase autotransformer.

A single-phase autotransformer is a transformer with only one winding that acts as both primary and secondary, with a portion of the winding common to both.

2. **Mention two advantages of using a single-phase autotransformer over a two-winding transformer**.

1. Less copper is required. 2. Smaller and lighter for the same rating.

3. List two common applications of a three-phase autotransformer.

1. Voltage regulation in power systems. 2. Starting of induction motors (reduced voltage starting).

4.Explain the main difference between a three-phase autotransformer and a three-phase two-winding transformer.

In a three-phase autotransformer, the primary and secondary share part of the winding, whereas a two-winding transformer has completely separate primary and secondary windings.

5.Define an isolation transformer.

An isolation transformer is a transformer with primary and secondary windings electrically separated to provide electrical isolation while transferring power.

6.State two constructional features of an isolation transformer.

1. Primary and secondary windings are magnetically coupled but electrically isolated. 2. Often includes shielding to reduce noise and transients.

7. Why is an isolation transformer used in sensitive electronic equipment?

To prevent ground loops and protect equipment from voltage spikes or electrical noise from the main supply.

5 MARKS

1. Differentiate between autotransformer and isolation transformer.

Feature	Autotransformer	Isolation Transformer
Winding	Single winding with taps	Separate primary and secondary
Electrical Isolation	No	Yes
Cost	Low	High
Size	Smaller	Larger
Applications	Voltage regulation, motor starting	Safety, noise reduction, medical equipment

2.Describe Properties of Autotransformer.

- Auto Transformer is electrically and magnetically coupled device
- In Autotransformer, power is constant
- In autotransformer, overall flux is constant
- In autotransformer, frequency is constant
- Voltage and current vary based on a number of turns.
- Autotransformer is also called a phase-shifting device
- The losses are less in autotransformer as compared to two winding transformer due to single winding
- The efficiency of the autotransformer is more as compared to two winding transformers
- Both iron and copper losses are less an autotransformer.

3.Write the Advantages and Disadvantages of Autotransformer.

<u>The advantages are</u>

- Losses in Autotransformer are less
- The efficiency of the autotransformer is more
- Copper Requirement is less
- The core requirement is less

<u>The disadvantages are</u>

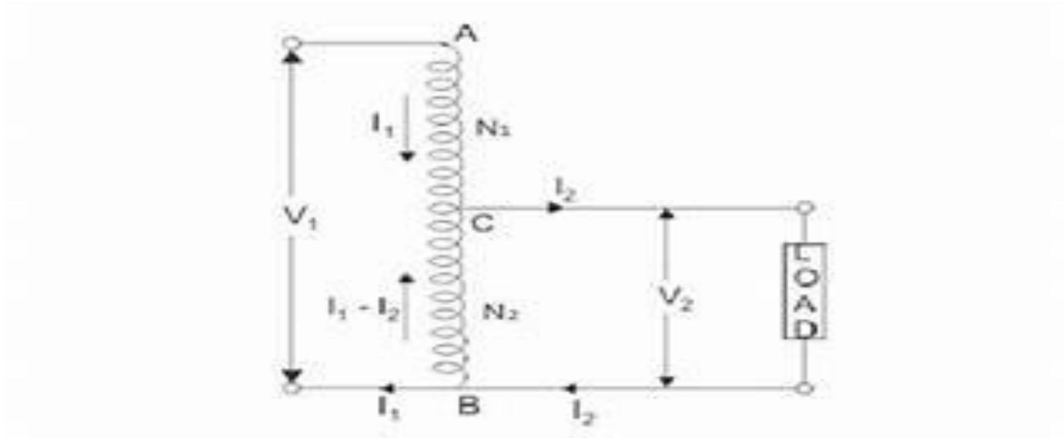
- Autotransformers cannot be used for high voltages. Since any discontinuity in the primary winding would result in complete primary voltage on the secondary side, therefore it cannot be used for high voltages
- The insulation requirement is more. Since autotransformer is both electrically and magnetically coupled, the requirement of insulation is more.
- Because of common winding, a neutral connection is difficult.

4.Explain Construction Auto Transformer.

A transformer basically consists of two parts

- Conductors
- Core

The conductors in the autotransformer are made up of copper. They are of low resistance. The copper conductors are insulated with each other. The material used for insulation is impregnated paper, mica, etc. The insulation also helps in reducing eddy current losses. The winding is wound around the core. For a single winding transformer, the requirement of copper is less as compared to two winding transformers.



auto-transformer-construction

To transfer flux from primary to the secondary, core is used. The core is made up of magnetic material like silicon steel, CRGO steel, etc. CRGO steel is the most efficient material for core, as it has the least hysteresis losses. The role core is to transfer flux from one part of winding to other parts.
Other important parts as shown in figure 3 are bearings, brushes, terminal boards, etc. The parts shown are used for dimmer stat basically used for laboratory purposes.

5. Explain Construction three phase Auto Transformer

A **three-phase auto transformer** is similar in principle to a single-phase auto transformer — it has a **common winding** for both the primary and secondary sides, instead of two separate windings (as in a two-winding transformer).
It can be used to step up or step down voltage in a three-phase system with better efficiency and lower cost, especially for small voltage changes.

There are **two main construction methods** for a three-phase auto transformer:

Three Single-Phase Auto Transformers Connected in Three-Phase Bank

- Three identical single-phase auto transformers are connected in **Star (Y)** or **Delta (Δ)** configuration.
- Each phase operates independently.
- Easier to transport and maintain (since one unit can be replaced if it fails).
- Commonly used in practice.

Integrated (Core-Type) Three-Phase Auto Transformer

- A single core with **three limbs** is used (similar to a three-phase transformer).
- Each limb carries one phase winding.

- The windings on each limb are tapped to provide both **primary** and **secondary** connections (common winding).
- This type is more compact and efficient for large power ratings.

Parts of a Three-Phase Auto Transformer

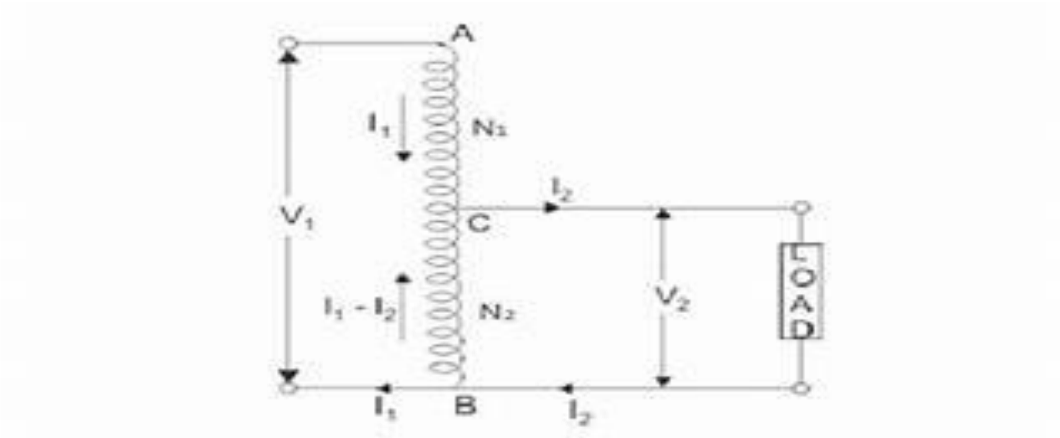
Let's look at the key components:

Part	Description
Core	Laminated silicon steel core with three limbs, each carrying one phase flux. Reduces eddy current and hysteresis losses.
Windings	Copper or aluminium conductors wound around each limb. Each winding has a tap to provide both primary and secondary connections.
Tap Changer	Used to vary the number of turns and adjust the output voltage. Can be off-load or on-load type.
Insulation	Electrical insulation between turns, layers, and core.
Tank and Oil (for oil-cooled type)	Contains transformer oil for insulation and cooling.
Cooling System	May include radiators, fans, or pumps depending on power rating.
Bushings	For bringing external connections to the windings.

10 marks

1.Explain the construction, working principle, and applications of a Single-Phase Autotransformer with neat diagram.

answer



Construction:
A single-phase autotransformer has only one winding on a laminated iron core, which serves as both the primary and secondary.

- A portion of the winding is common to both sides.
- The winding has tapping points to provide variable secondary voltage.
- The core is made of silicon steel laminations to reduce eddy current losses.

2. Working Principle:

- It works on the principle of electromagnetic induction.
- When an alternating voltage is applied to the primary winding, an alternating flux is produced in the core.
- This flux induces an emf in the entire winding as well as in the portion connected to the load (secondary).
- Since part of the winding is common, energy transfer takes place by both conduction and induction.

3. Equation:

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$$

where,
V_1, V_2= primary and secondary voltages
N_1, N_2= number of turns
I_1, I_2= primary and secondary currents

4. Advantages:

- Smaller size and weight
- Higher efficiency
- Economical for small voltage changes

5. Applications:

- Starting induction motors
- Variac (variable autotransformer) for laboratory use
- Interconnecting systems with small voltage differences
- Voltage regulation in power systems

2.What is an Isolation Transformer? Explain its constructional features and applications.

Answer

1.Definition:
An isolation transformer is a transformer that provides complete electrical isolation between its primary and secondary windings, usually with a 1:1 turns ratio.

2. Constructional Features:

- Core: Made of laminated silicon steel to minimize eddy current loss.
- Windings:
    - Primary and secondary windings are physically separated by insulation to ensure electrical isolation.
    - Both windings are wound on separate sections of the core.
- Insulation: High-grade insulation is provided between windings and between winding and core.
- Shielding: Often includes an electrostatic shield between windings to prevent capacitive coupling of noise.

3. Working Principle:

- Operates on the principle of mutual induction.
- Alternating current in the primary winding induces an emf in the secondary winding.
- Since the windings are isolated, there is no direct electrical connection between the two circuits.

4. Advantages:

- Provides electrical safety by isolating equipment from supply.

- Reduces electrical noise and ground loops.
- Protects sensitive electronic circuits.

5. Applications:

- Used in hospitals for patient safety (medical equipment).
- In laboratories and control circuits for protection.
- For noise suppression in communication and audio systems.
- In power electronic circuits for isolation between control and power circuits.

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