SEMESTER – V

Applications of Electricity & Magnetism

UNIT - III: Alternating & Direct Currents

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UNIT-III Alternating & Direct Currents

Part-A

* (1) AC Generator.

An electrical machine used to convert mechanical energy into electrical energy is known as A.C generator/ alternator.

Principle :

It works on the principle of electromagnetic induction. i.e, when a coil is rotated in uniform magnetic field an induced emf is produced in it.

Construction :

The main Components of a.c. generator are.

i, **Armature :**

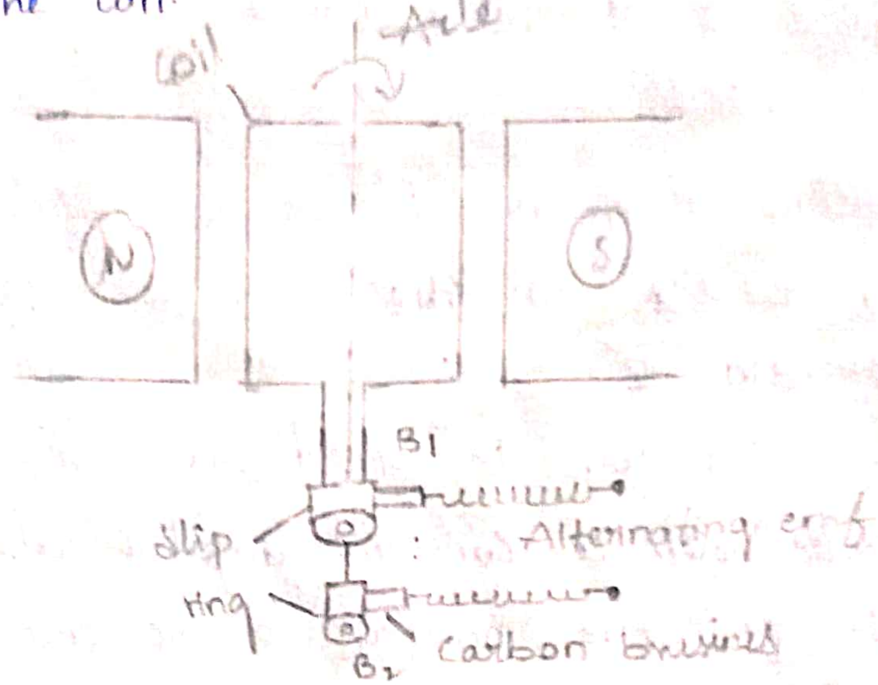
Armature coil (ABCD) Consists of large number of turns, of insulated copper wire wound over a soft iron core.

ii, **Slip Rings :**

Two ends of the armature coil are connected to two brass slips rings R_1 and R_2. These rings rotate along with the armature coil.

iii, **Strong field magnet :**

A strong permanent magnet or an electro magnet whose poles are cylindrical in shape used as a field magnet. The armature coil rotates b/w the pole pieces of the field magnet. The uniform magnetic field Provided by the field magnet is ⊥^{r} to the axis of rotating of the coil.



iv) Brushes :

iv, Brushes :

Two Carbon brushes, are pressed against the slip rings. The brushes remain fixed while slip rings rotate along with the armatore. These brushes are connected to the load through which the output is obtained.

Working :

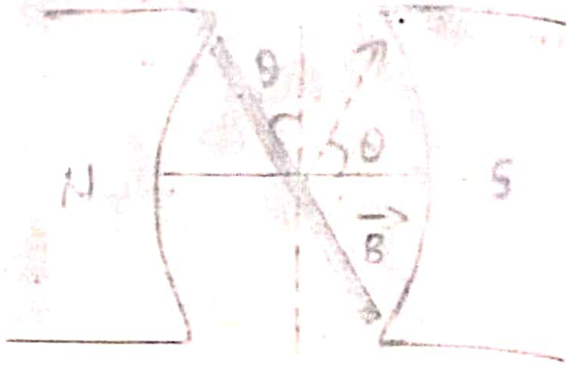
when the armature coil ABCD rotates in the magnetic field provided by the strong field magnet, it cuts the magnetic lines of force. The magnetic flux linked with the coil changes due to the rotation of the armature and hence induced e.m.f. is set up in the coil. The direction of the induced e.m.f or the current in the coil is determined by the fleming's right hand rule.

The current flows out through the brush B_1 in one direction of half of the revolution and through the

the brush B_2 in the next half revolution in the reverse direction. this process is repeated. Therefore e.m.f produced is of alternating nature.

Theory :

Consider the plane of the coil to be $\perp^r$ to the magnetic field $\vec{B}$.



Let the coil be rotated anti-clockwise with a constant angular velocity ω. then the angle b/w the normal to the coil and $\vec{B}$ at any instant t is given by $\theta = \omega t$.

∴ The component of magnetic field normal to the plane of the coil = $B\cos\theta = B\cos\omega t$.

Magnetic flux linked with a single turn of the coil = $(B\cos\omega t)A$ where A is the area of the coil.

If the coil has n turns, then the total magnetic flux linked with the coil is given by.

$$\phi = n(B\cos\omega t)A = nBA\cos\phi$$

According to faraday's law of electromagnetic induction, the induced e.m.f produced in the coil is given by

$$\varepsilon = \frac{-d\phi}{dt} = -\frac{d}{dt}(nBA\cos\omega t)$$

$$= -nBA(-\omega\sin\omega t)$$

$$\varepsilon = nBA\omega\sin\omega t$$

This is the expression for the induced emf produced in the coil at any instant t.

Induced emf will be maximum (i.e, $\mathcal{E} = \mathcal{E}_0$) if $\sin \omega t = 1$ then maximum value of emf $\mathcal{E}_0 = nBA\omega$.

Sub the value of above eq, we get:

$$\mathcal{E} = \mathcal{E}_0 \sin \omega t.$$

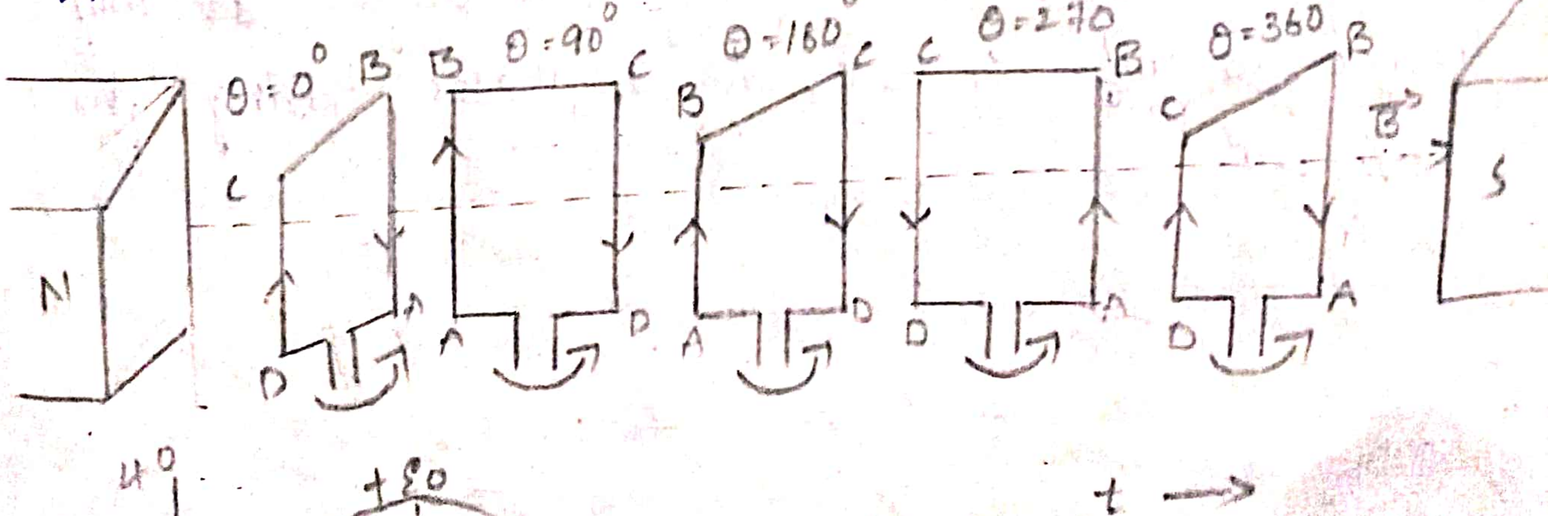
The direction of the current changes periodically and therefore the current is called "alternating current".

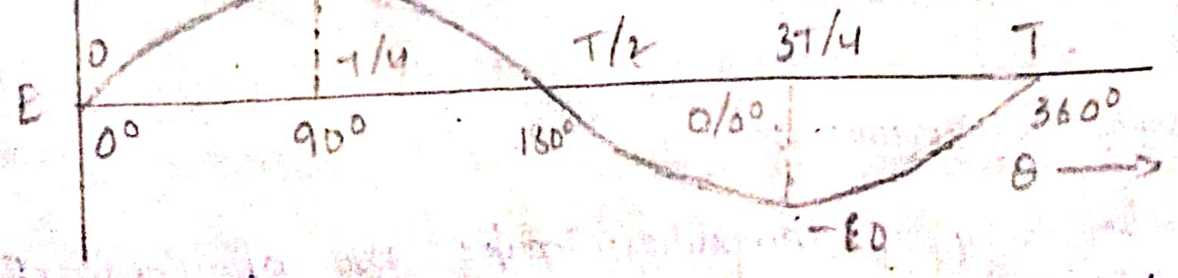
$$\mathcal{E} = \mathcal{E}_0 \sin 2\pi \omega t.$$

Instantaneous current in the circuit.

$$I = \frac{E}{R} = \frac{\mathcal{E}_0 \sin \omega t}{R}$$

Current supplied by an a.c generator is sinusoidal like its e.m.f $\boxed{I = I_0 \sin \omega t}$





... the coil is ⊥ to

2) Types of AC Generator :

AC Generators, also known as alternators, can be broadly classified into two main types based on their output : Single-phase and three-phase. Additionally they can be categorized by their construction and principle of operation, such as synchronous, asynchronous (induction), and permanent magnet generators.

1. Single-phase AC Generators :

* Produce a single alternating voltage waveform.
* Typically used in smaller applications where the load requirements are relatively low.

* Utilize a single armature winding to generate the AC voltage.

2. Three-phase AC generators :

* Produce three alternating voltage waveforms that are out of phase with each other.
* widely used in large-scale power generation and distribution systems due to their higher power capacity and efficiency.
* Employ three separate armature windings, often configured in either a wye (Y) or delta (Δ) connection.

3. Synchronous Generators :

* Rotate at a constant speed that is synchronized with the frequency of the generated AC power.
* widely used in power plants and other applications requiring a stable and reliable power supply.
* Features a rotor with field windings that are supplied with DC current to create a magnetic field.

4. Asynchronous (Induction) Generators :

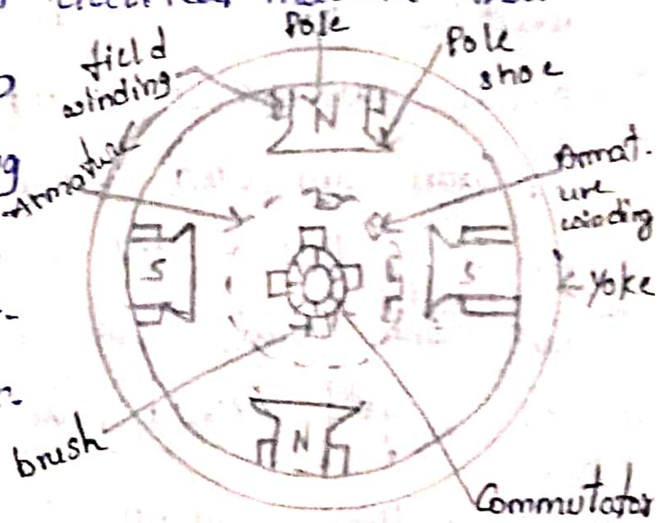
* Rely on slip (the difference between rotor speed and synchronous speed) for operation.
* Can be used in application where variable speed operation is acceptable.
* Do not require a separate DC excitation source for the rotor.

5. Permanent Magnet Generators :

* Utilize permanent magnets on the rotor to create the magnetic field, eliminating the need for field windings and DC excitation.
* Often found in smaller applications like wind turbines and some specialized industrial equipment.

(2) DC Generator :

A DC generator is an electrical machine that converts mechanical energy into direct current (DC) electricity using the principle of electromagnetic induction. It produces a unidirectional current through a commutator.



Construction :

The main components of D.C Generators are,

1. Yoke : The outer frame of a dc machine is called as Yoke. It is made up of cast iron or steel. It produces mechanical strength to the whole assembly but also carries the magnetic flux produced by field winding.
2. Poles and pole shoes : Poles are joined to the yoke with the help of bolts or welding. They carry field winding and pole shoes are fastened to them. Pole shoes serve two purposes; i, they support field coils and (ii) spread out the flux in air gap uniformly.
3. shaft : It produces torque, which causes rotation. It is constructed of mild steel and has the highest breaking strength. The shaft is a component of a DC generator

that influences the generator's ability to transport mechanical energy.

4. Field winding : They are usually made of Copper. Field coils are insulated conductors and placed on each pole and are connected in Series. They are wound in such a way that, they form alternate North and South poles when they are energized.

5. Armature Core : Armature Coil is the rotor of a dc machine. It is cylindrical in shape with slots to carry armature winding. The armature is built up of thin laminated circular steel disks for reducing eddy current losses. It may be provided with air ducts for the axial air flow for cooling purposes. Armature is keyed (fixed to the shaft).

6. Armature winding : It is usually a former wound copper Coil which rests in armature slots. The armature conductors are insulated from each other and also from the armature core. Armature winding can be wound by one of the two methods; lap winding or wave winding. Double layer lap or wave windings are generally used. A double layer winding means the each armature slot will carry two different coils.

7. Commutator and brushes : Physical connection to the armature winding is made through a Commutator - brush generated arrangement. The function of a Commutator in a dc generator is to collect the current generated in armature conductors. Whereas, in a dc generator is to ~~collect~~ Commutator helps in providing current to the

armature Conductors. A commutator Consists of a set of copper Segments which are insulated from each other. The number of Segments is equal to the number of armature coils. Each Segment is Connected to an armature coil and the Commutator is keyed (or fixed) to the shaft. Brushes are usually made from carbon or graphite. They rest on commutator Segments and slide on the Segments when the Commutator rotates keeping the physical contact to collect or supply the current.

working :

According to 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.

The field windings create a magnetic field between the poles. when the armature rotates, the Conductors cut through the magnetic field lines, inducing an EMF (voltage) in them. The induced EMF in the armature is alternating (AC) in nature. The Commutator and brushes work together to convert the alternating current in the armature to direct current (DC) in the external circuit. The DC output is then available for use in external circuits and devices.

Advantages :

* The design and Construction of a DC generator are simple.
* They are used to operate big ~~mistake~~ machines.
* These generators are useful in supplying electricity to large motors.
* Heavy electric devices are supplied electricity by using DC generators.
* A DC generator significantly reduces the electric fluctuations in the armature and gives a continuous supply.

Disadvantages :

* It cannot be used with a transformer.
* The efficiency of a DC generator is very low.
* The current flowing in the generator experiences various losses such as Eddy current losses, copper losses, mechanical losses, and others.
* DC generators placed at a long distance may experience major voltage drops.

(4) Types DC Generator :

A magnetic flux is produced while passing a circulating current in the field windings, which is called circulation excitation. The classification of DC Generators on the Method of Excitation :

→ Separately Exited

→ Self-Exited

1. Shunt wound
2. Series wound
3. Compound wound.

→ Separately Excited DC Generator : Here, the field windings are energized by a Separate DC source. The flux generated on the poles depends upon field current, and the saturated region remains constant.

→ Self-Excited DC Generator : The generator provides the current to the field winding, when the electric generator is off, a small is developed in the rotor which induces an electromotive force in the armature and producing current in the field windings.

The self-excited DC generator is further classified into shunt wound Generator, Series wound Generator and Compound wound Generator.

1. Shunt wound Generator : Here, the field winding is connected across the armature windings in a parallel also known as a shunt circuit, which helps to apply a full terminal voltage across it.

2. Series wound Generator : Here, the field coils are connected in series with the armature windings. The armature current is carried in the series field windings.

3. Compound wound 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. This type of DC generators may be of two types - short

shunt compound - wound generator and long shunt compound - wound generator.

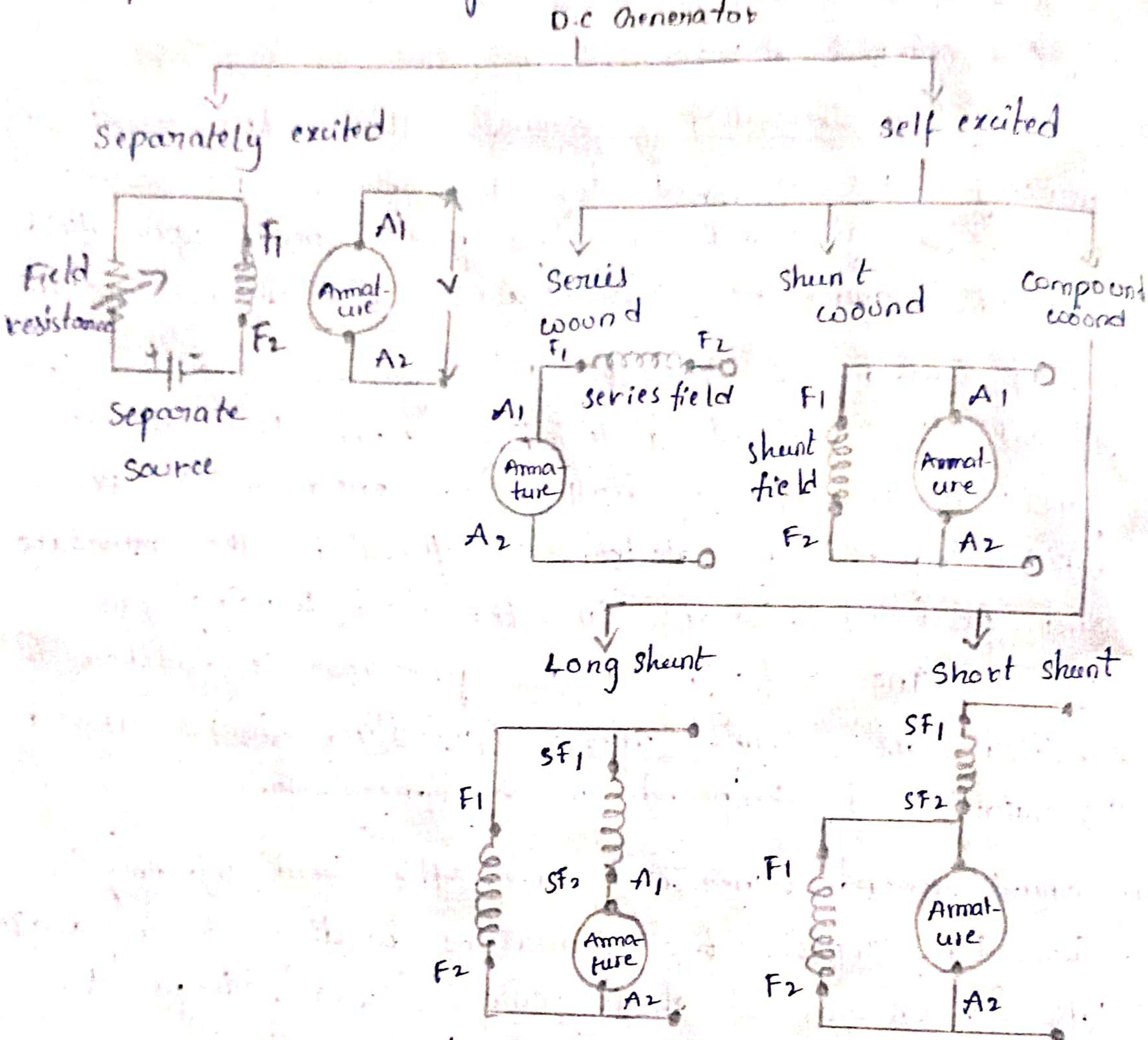


Fig. (17) classification of DC generators

(5)

* **Losses associated with DC generators:**

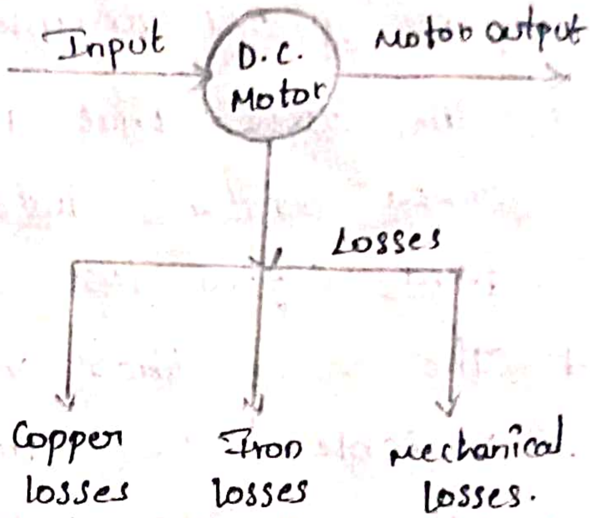
Losses in DC generators can be categerized into Copper losses, iron losses, mechanical losses, and stray losses. These losses are a result of the generator's operation and contribute to reduced efficiency and increased temperature.

1. **Copper Losses (known as I^2R losses):**

* These losses occur due to the resistance of the

windings (armature and field windings).

* The losses are directly proportional to the square of the current flowing through the winding.
* In a DC generator, copper losses are present in the armature winding and the field winding.



* $PC = I^2R$.
* Brush contact resistance also contributes to copper losses.

2. Iron or Core Losses :

* These losses occur in the iron core of the armature due to the rotating magnetic field.
* They are caused by hysteresis and eddy currents within the core.
* Hysteresis loss is due to the repeated magnetization and demagnetization of the core as the armature ~~field~~ rotates.
* Eddy current loss is due to circulating currents induced in the core by the changing magnetic field.

3. Mechanical Losses :

* These losses are due to friction and windage.
* Friction losses occur at the bearings, brushes and the commutator as well as air resistance.
* Windage losses are caused by the friction between the rotating armature and the surrounding air.

4. Stray Losses :

* Stray losses are a combination of iron and mechanical

losses.

* They are generally considered constant losses.
* stray losses can be difficult to measure directly.

5. Constant & Variable losses :

* The losses that remain constant all loads are called constant losses. it includes - Iron losses, shunt field copper loss, and mechanical losses.
* The losses that vary with load are known as variable losses. the variable losses in a DC machine are - armature copper loss and series field copper loss.

(6)

* Differences between AC & DC generators :

S/No	AC Generator	DC Generator.
1.	AC generator is a mechanical device that converts mechanical energy into AC electrical power.	DC generator is a mechanical device that converts mechanical energy into DC electrical power.
2.	In an AC generator, the electrical current reverses direction periodically.	In a DC generator, the electrical current flows only in one direction.
3.	AC generator does not have commutators.	DC generators have commutators to make the current flow in on direction. ~~and~~ only

4.	AC generators have slip-rings.	DC generators have Commutators.
5.	AC generators produce a high voltage which varies in amplitude and time. The output frequency varies (mostly 50HZ to 60HZ).	DC generators produce a low voltage when compared to AC generator which is Constant in amplitude and time i.e. output frequency is zero.
6.	AC generators require very little maintenance and are highly reliable.	DC generators require frequent maintenance and ~~also~~ are less reliable.
7.	The output from AC generators is easy to distribute using a transformer.	The output from DC generators is difficult to distribute as transformers cannot be used.
8.	AC generators are very efficient as the energy losses are less.	DC generators are less efficient due to sparking and other losses like copper, eddy current, mechanical, and hysteresis losses.
9.	It is used to power smaller motors and electrical appliance at homes (mixers, vacuum cleaners, etc)	DC generators power very large electric motors like those needed for Subway Systems.

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Part-B

* Transformers - construction and its working principle.

Transformer:-

A transformer is an electrical device used to increase or decrease AC voltage without changing the frequency.

Principle:-

It works on the principle of mutual induction and is widely used in power transmission, distribution, and electronic devices.

Construction:-

Transformer consists of:-

1. Core:-
   * Made of laminated soft iron or ferrite material.
   * It provides a path for magnetic flux.
   * Laminations reduce energy losses due to eddy currents.
2. primary coil:-
   * connected to the AC power supply.
   * It creates a changing magnetic field in the core.
3. Secondary coil:-
   * connected to the load.
   * It receives the induced voltage from the primary through the magnetic field.

Primary and secondary coils do not touch each other. They are magnetically linked, not electrically.

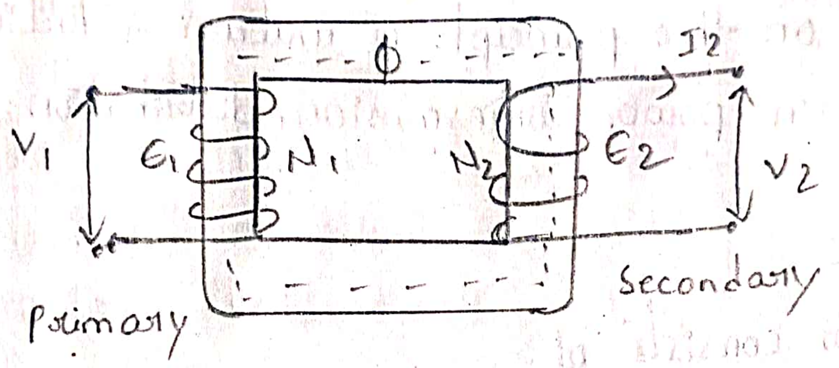
Working principle:-

Principle of transformer is mutual induction.

* when AC current flows through the primary coil, it produces a changing magnetic field.

* This changing magnetic field passes through the core and links to the secondary coil.
* According to faraday's law, induced emf is produced in the secondary coil due to this changing magnetic flux.
* The amount of voltage depends on the number of turns in each coil and the rate of change of magnetic flux.

EMF equation of a Transformer:-



Consider a transformer as shown in figure. Let N_1 and N_2 be the number of primary and secondary turns. Let an alternating voltage V_1 of frequency f is applied to the primary winding. Let ϕ be the alternating magnetic flux produced in the primary coil.

Then the flux at any time t is given by

$$\phi = \phi_m \sin(2\pi f t)$$

According to faraday's law, emf induced in a coil is given by;

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

$$e = -N\frac{d}{dt}\left[\phi_m \sin(2\pi f t)\right]$$

$$e = -2\pi f N \phi_m \cos(2\pi f t)$$

We know that

$$\sin(90^\circ - 2\pi f t) = \cos(2\pi f t)$$

(or)

$$\sin(2\pi f t - 90^\circ) = -\cos(2\pi f t)$$

substituting this in the above eqn. we get

$$e = 2\pi f N \phi_m \sin(2\pi f t - 90^\circ)$$

It is clear from the above eqn. that induced emf is also sinusoidal.

Peak value of the induced emf is given by

$$E_{max} = 2\pi f N \phi_m$$

RMS value of the induced emf is given by

$$E = \frac{2\pi f N \phi_m}{\sqrt{2}} = 4.44 f N \phi_m$$

$$E = 4.44 f N \phi_m$$

This equation is known as the emf equation of a transformer.

Induced emf in the primary, is given by

$$E_1 = 4.44 f N_1 \phi_m$$

Induced emf in the secondary is given by

$$E_2 = 4.44 f N_2 \phi_m$$

from the above two equations, we get

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

This is the relation between primary turns and secondary turns of the transformer with emf. Hence the ratio of secondary emf to primary emf is equal to the ratio of turns of secondary to primary.

(8)

* Types of Transformers.

A transformer works on the mutual induction principle, also known as Faraday's Law of Electromagnetic Induction, which states that the magnitude of voltage is directly proportional to the rate of change of magnetic flux.

Step-up Transformer :

A step-up transformer is an electrical device that increase the voltage of an alternating current (AC) power supply. It consists of a primary winding, a secondary winding, and an iron core.

A step-up transformer increases the voltage at the secondary windings relative to the primary side. From the equation for voltage transformation, for V_2 to be greater than V_1, the value of N_2 should be greater than N_1. Therefore, in a step-up transformer,

* $N_2 > N_1$

* $V_2 > V_1$

* $I_2 < I_1$

A step-up transformer always steps down the current (while stepping up the voltage) at the secondary side relative to that on the primary side. The thickness of a transformer coils depends upon the capacity of the current it is designed to carry. In a step-up transformer, the primary side carries more current; hence, thick insulated copper wire is used for the primary winding and thin insulated copper wire for the secondary side.

step-down Transformer :

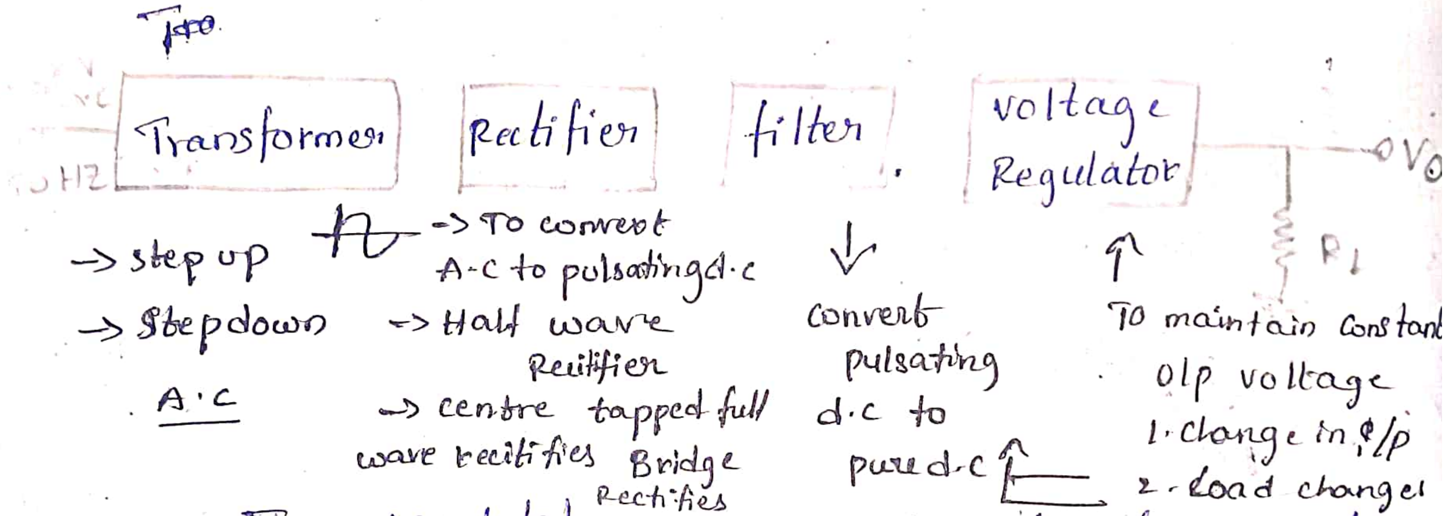
A step-down transformer is an electrical device that that reduces the voltage of an alternating current (AC) power supply. It consists of a primary winding, a secondary winding, and an iron core.

A step-down transformer decreases the voltage at the secondary windings relative to the primary side. From the equation for voltage transformation, for V_2 to be less than V_1, the value of N_2 should be less than N_1. Therefore, in a step-down transformer,

* $N_2 < N_1$
* $V_2 < V_1$
* $I_2 > I_1$

A step-down transformer always step up the current while stepping down the voltage) at the secondary side relative to that on the primary side. In a step-down transformer, the secondary side carries more current; hence, thick insulated copper wire is used for the seconding winding, thin insulated copper wire for the primary side. Step-down transformers are commonly used in low voltage transformers for landscape lighting applications.

(9) * Use of a Transformer in a regulated Power Supply.



In regulated power supplies, transformers play a crucial role in stepping down high AC mains voltage to a lower, more mangeable level before it's converted to DC. This voltage transformation is essential for ensuring the safety and efficient operation of electronic devices, as it allows the power supply to deliver the appropriate voltage for the specific components. The transformer also provides electrical isolation, preventing high voltage shock from reaching the device.

Voltage Regulation :

→ Transformers are used to reduce the high AC voltage from the mains (e.g., 120V or 240V) to a lower AC voltage suitable for the electronic device.

→ The reduced AC voltage is then passed through a rectifier, which converts it to pulsating DC.

→ A filter (often a capacitor) smooths out the pulsating DC, reducting the ripple and creating a more stable DC voltage.

→ The regulator circuit maintains a constant DC output voltage, even with variations in the input voltage or load current, ensuring stable power delivery to the device.

Electrical Isolation :

→ Transformer provide galvanic isolation between the primary (input) and secondary (output) windings, preventing direct electrical contact between the mains and the device's circuitry.

→ This isolation significantly reduces the risk of electrical shock and protects the device from voltage surges or fluctuations on the mains.

(10) * Single phase motor :

working Principle :

A Single-phase current cannot produce a rotating magnetic field by itself, an auxiliary method (like a capacitor) is used to start the motor. Once started, the rotor continues to turn under the influence of the magnetic field.

Construction :

→ stator : The stationary part of the motor, containing the main winding (also called running winding) and often a starting winding (or auxiliary winding).

→ Rotor : The rotating part, typically a squirrel cage rotor with conductors short-circuited at both ends.

→ Lamination : The stator and rotor are laminated (made of thin sheets) to reduce eddy current losses.

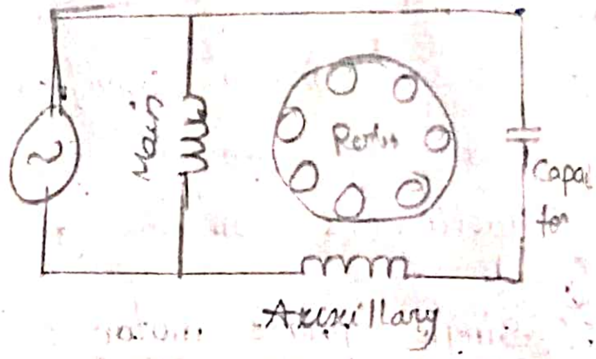
→ Windings : The main winding is directly connected to the AC power supply. The starting winding is often

Connected in series with a capacitor to create a phase difference with the main winding.

working :

-> when single-phase AC current flows through the main winding, it produces a pulsating magnetic field.

-> This pulsating field alone is not sufficient to produce a pulsating magnetic field.



-> To overcome this, the starting winding, often with a capacitor in series, is used to create a phase difference with the main winding. This phase difference generates a rotating magnetic field, allowing the motor to start.

-> Once rotating, the motor operates on the principle of electromagnetic induction, where the rotating magnetic field induces currents in the rotor, producing torque and continuous rotation.

Applications of Motors :

-> Domestic Applicances : Motors are fundamental in applicances like washing machines, refrigerators, mixers, blenders, fans, hair dryers, and vacuum cleaners.

-> Industrial Machinery : Motors are crucial for powering various industrial equipment, including pumps, compressors, conveyors, rolling mills, and automated machinery.

-> Transporation : Electric Vehicles, trains, trams, and elevators rely on electric motors for propulsion and control.

→ Robotics : Motors are essential components in robots, enabling movement, manipulation, and precision tasks in various applications.

→ power Tools : Cordless drills, saws, and other power tools use electric motors to provide the necessary torque and speed for cutting, drilling, and other tasks.

→ HVAC Systems : Motors play a vital role in heating, ventilation, and air conditioning systems, driving fans and blowers for air circulation.

→ Process Control : Motors are used in various process control applications in industries like chemical, pharmaceutical, and food processing, powering pumps, mixers, and other equipment.

→ Wearable Technology : Small DC motors are used in wearable devices like fitness ~~cd~~ trackers and smartwatches to provide haptic feedback.

→ Other Applications : Motors are also found in loudspeakers microphones, and even in some medical devices.