Electrical machines — An electrical m/c is an electro-mechanical energy conversion device. The device which converts electrical energy into mech. energy → motor. The device which converts mech. energy to electrical energy → Generator

Classification of Electrical machines

- Electrical machines
  - Direct Current m/C
    - DC Generator
    - DC motor
  - Alternating current m/C
    - Transformers
    - Induction m/C
    - Synchronous m/C
    - Fractional KW m/C

CHAPTER 26

D.C. GENERATORS

26.1 Introduction

D.C. generator is a machine which converts mechanical energy into electrical energy. Direct-current generators are used to supply power for radio equipment, for battery charging, for electrolytic cells etc. A disadvantage common to all d.c machines is the complexity of design, mainly due to the use of brush gear. Apart from its complex design, brush gear is subject to sparking. A d.c. machine consists essentially a stationary part, called, the field structure and a rotating part called the armature.

26.2 Principle of Operation

D.C. generator is based on the principle that whenever magnetic flux is cut by a moving conductor, an emf is induced in the conductor as per Faraday's laws of electromagnetic induction. The emf so induced is an alternating emf. It is made unidirectional with the help of commutator and brushes. This emf causes flow of current in the external circuit if the circuit is closed.

re direction of ← duced emf is ven by Fleming's ght hand rule. Sketch out ght hand with rst finger, middle nger and thumb re mutually perpendicular each other. If rst finger points n direction of ux, thumb in rection of motion f conductor, then iddle finger will oint in direction of induced emf.

26.3 Constructional Details

The main parts of a d.c. machine (a generator or a motor) are described below.

(i) Yoke. It is the outermost cylindrical part of the machine. The yoke is made of cast iron or cast steel or forged steel. The yoke acts as the supporting frame for the machine and also completes the path for the main magnetic flux. In small dc machines, yoke is made of cast iron. In large d.c. generators, yoke is usually made of cast steel from consideration of better magnetic properties.

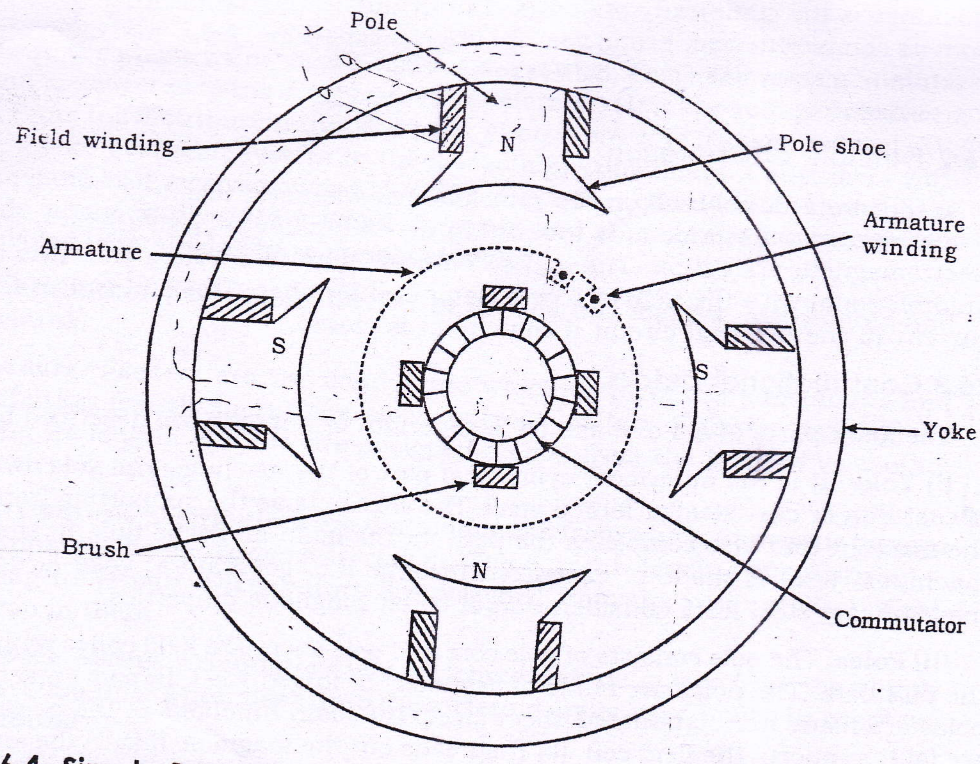
(ii) Poles. The pole consists of pole core and pole shoe. The field coil is wound on the pole core. The poles are made of cast steel or forged steel. In some machines, poles are made from laminated sheet steel. The main functions of the poles shoe are (a) It supports the field coil. (b) It spreads out the magnetic flux in the air gap. (c) Since pole shoe is of large cross-section, it reduces the reluctance of the magnetic path.

(iii) Field coils. The fields coils are wound on pole cores. They are connected in series and the connections are arranged so that due to the flow of current in these coils alternate N and S poles are made. The field coils are made from enameled copper wire.

(iv) Armature. The armature is that part of d.c. machine where an emf is induced as it rotates relative to the main field. The armature consists of the toothed core, a winding dropped in the core slots, and a commutator mounted on the armature shaft. The armature core is composed of electrical-sheet steel lamination. The armature winding consists of lap connected or wave connected coils.

(v) Commutator. The commutator, which is a typical component of d.c. machines, is a hollow cylinder. The commutator is made up of wedge shaped segments of high conductivity hard drawn or drop forged copper. The segments are insulated from each other by thin layer of mica. The function of the commutator is to convert the alternating emf induced in the armature conductors into unidirectional voltage across the load impédance.

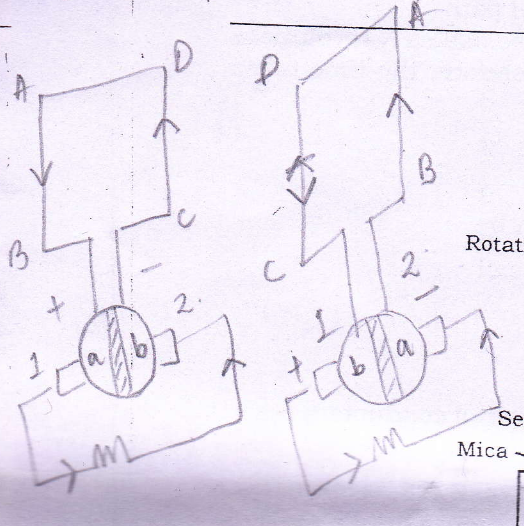
(vi) Brushes. The function of the brush is to collect current from the rotating commutator and deliver it to the external load impedance. The brushes are made of carbon. The brushes are mounted in a box typed brush holder and are held on the commutator by a spring.

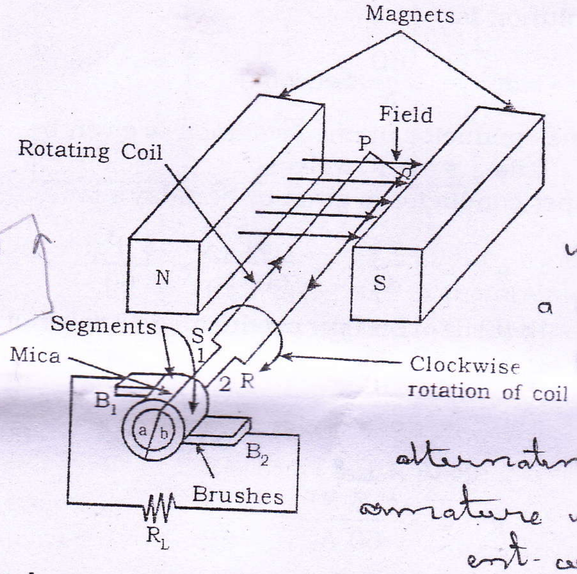


26.4 Simple DC Generator

The Fig. gives the basic structure. When a coil is rotated in a uniform magnetic field, an alternating emf is generated across the terminals 1 and 2 of the coil.

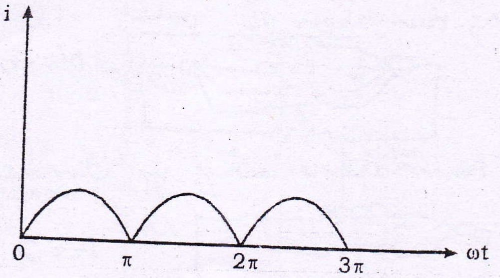
Consider a single turn rotating about its own axis in a M.F. Consider that coil is rotating in clockwise direction. An emf is induced in coil which is prop. to rate of change of flux linkage. When plane of coil is at right angles to direction of flux, flux linked with coil is max. whereas rate of change of flux linkage is min. Hence there is no induced emf. When plane of coil is in direction of field during its rotation, flux linked with coil is min. whereas rate of change of flux linkage is max. Hence max. emf induced in coil is max. Thus emf induced in coil is alternating.





Inorder to get a unidirectional current in ext. load resistance, a split ring (commutator) is provided. The fun. of converter is to convert alternating current produced in armature into direct current in ext. circuit

If a unidirectional current is desired in the external circuit, the two ends of the coil PQRS are connected to the two segments a and b are insulated from each other. When b is positive, the brush B_2 makes contact with it. But for the other half rotation of the coil, the segment a becomes positive and now this makes contact with the brush B_2. Thus we see that the brush B_2 remains positive all the time, and hence a unidirectional current results in the external circuit as shown in the figure.



The current in the external circuit is unidirectional. But its strength varies considerably. It rises and falls between zero and maximum for each half rotation of the coil. This defect of having large variations in the unidirectional emf (or the current) can be overcome by using more coils on the rotor.

26.5 EMF equation of a DC Generator

Let

ϕ = Flux per pole in the dc generator

P = Number of poles

Z = Total number of armature conductors

N = Speed of armature in R.P.M.

A = Number of parallel paths

$$E = \text{EMF generated per parallel path}$$

Consider one revolution of the armature. As the armature makes N revolutions per minute, it makes N/60 revolutions in one second. Therefore, the time taken to complete one revolution is

$$dt = \frac{60}{N} \text{ Second}$$

The flux cut by one conductor in one revolution is given by

$$d\phi = \phi P \text{ webers.}$$

The induced emf per conductor is given by Faraday's law.

$$e = \frac{d\phi}{dt} = \frac{\phi P}{60/N} = \frac{\phi PN}{60}$$

$$\text{EMF per parallel path (E)} = \text{Emf per conductor} \times \text{Number of conductors per parallel path}$$

$$= e \times \frac{Z}{A} = \frac{\phi PN}{60} \times \frac{Z}{A} = \frac{\phi ZNP}{60A}$$

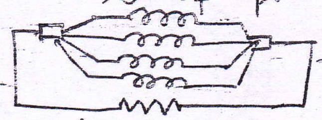
$$E = \frac{\phi ZNP}{60A}$$

$$A = P \text{ for lap winding}$$
$$A = 2 \text{ for wave winding}$$

26.6 Armature winding

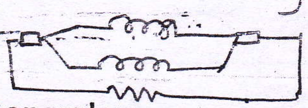
There are two types of d.c. armature winding (i) Lap winding (ii) Wave winding

Lap winding. – Armature wdg is divided into as many parallel paths as number of poles



No. of parallel paths, A = no: of poles, P.

Wave Winding. – Armature wdg is divided into 2 parallel paths



A = 2.

26.7 Types of D.C. Generators

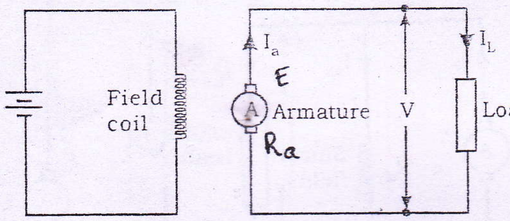
D.C. generators are generally classified according to the method used for field excitation. Thus D.C. generators are classified as

(i) Separately excited generator

(ii) Self excited generator

Separately excited generator. When the field coils are excited from a storage battery or from a separate dc source the generator is called a separately excited generator.

$+BD$
$-E + I_a R_a + V = 0$
$V = E - I_a R_a$ - Brush Drop



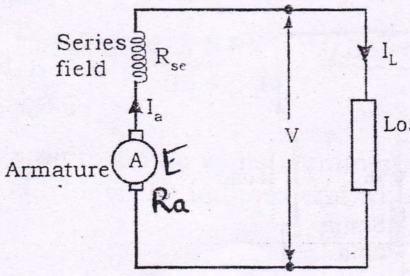
Let	I_a	=	Armature current
	R_a	=	Resistance of armature winding
	E	=	EMF generated in the armature winding
	I_L	=	Current applied to the load
	V	=	Terminal voltage across the load

The various relations for a separately excited dc generator are as follows.

Here	I_a	=	$I_L = I$ (Say)
Then	V	=	$E - I R_a$ - Brush drop
	Power developed	=	$E I_a$
	Power delivered	=	VI_L

Self excited generator. If the field coils are excited by generator itself, it is called self excited generator. Such generators are further subdivided into three categories.

(i) Series wound generator. In this type of generator the field winding is connected in series with the armature winding as shown in figure. The field winding consists of a few turns of thick wire or strip as the whole of the armature current passes through it.

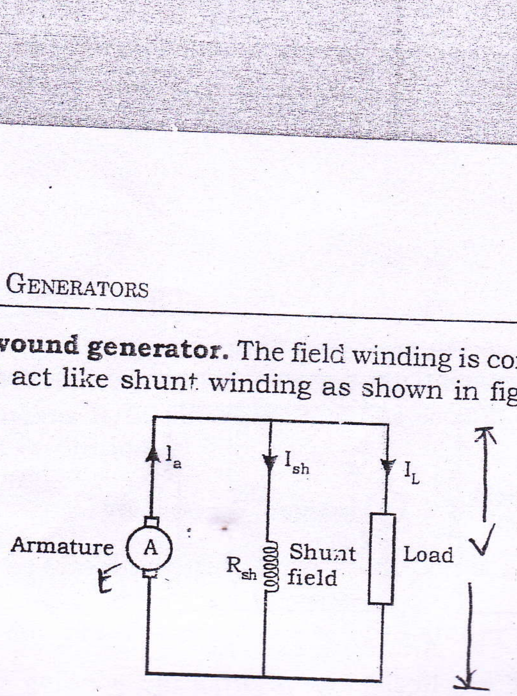


Let	R_{se}	=	Resistance of the series field.
	I_{se}	=	Current through series field.

The various relations for a series wound generator are as follows.

Here	I_a	=	$I_{se} = I_L = I$ (Say)
	V	=	$E - I(R_a + R_{se})$ - Brush drop
	Power developed	=	EI_a
	Power developed	=	VI_L

(ii) Shunt wound generator. The field winding is connected across the armature terminals and act like shunt winding as shown in figure.



Let $\quad R_{sh}$ = Resistance of shunt field

I_{sh} = Current through shunt field

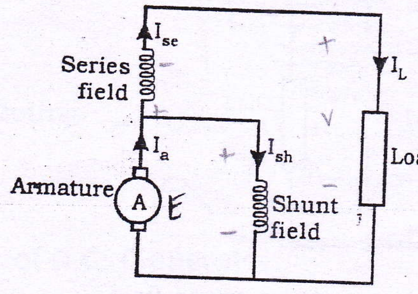
The various relations for a shunt wound generator are as follows.

Here
$$I_{sh} = \frac{V}{R_{sh}}$$
$$I_a = I_{sh} + I_L$$
$$V = E - I_a R_a \text{ - Brush drop}$$
Power developed $= EI_a$

Power delivered $= VI_L$

(iii) Compound wound generator. In this generator, there are two sets of field winding. One in series with the armature and the other in parallel with the armature. Compound wound generators are of two types.

(a) Short shunt compound wound generator. The shunt coil is placed directly across the armature while series coil is placed in series with the load as shown in figure.



$-I_{sh}R_{sh} + I_{se}R_{se} + V = 0$

$I_{se}R_{se} + V = I_{sh}R_{sh}$

$I_{sh} = \dfrac{V + I_{se}R_{se}}{R_{sh}}$

Here
$$I_{se} = I_L \quad \text{and} \quad I_{sh} = \frac{V + I_{se} R_{se}}{R_{sh}}$$
$$I_a = I_{sh} + I_L$$
$$V = E - I_a R_a - I_{se} R_{se} \text{ - Brush drop}$$
Power developed $= EI_a$

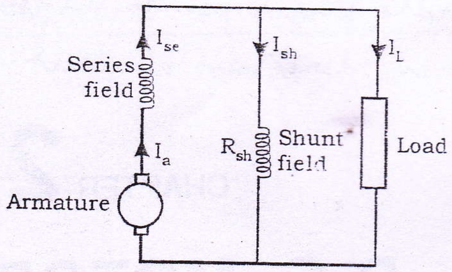
Power delivered $= VI_L$

Compound generator

Cumulatively compound generator
- If fluxes produced by series and shunt field wdg aid each other

Differentially compound generator
- Fluxes produced by series and shunt field wdg oppose each other

(b) long shunt compound wound generator. The shunt coil is placed in parallel with both armature and the series coil as shown in figure.



Here

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

$$I_{sh} = \frac{V}{R_{sh}}$$

$$V = E - I_a R_a - I_a R_{se} \quad \text{- Brush drop}$$

$$V = E - I_a (R_a + R_{se}) \quad \text{- Brush drop}$$

Power developed $= EI_a$

Power delivered $= VI_L$

Example 1

A 4 pole 1000 rpm dc generator has a lap-wound armature having 60 slots and 10 conductors per slot. If the flux per pole is 0.03 wb., determine the emf induced in the armature.?

Solution :

$$P = 4, \ N = 1000 \text{ r p m}, \ \phi = 0.03 \text{ wb}$$

$$Z = \text{No. of slots} \times \text{conductors per slot}$$

$$= 60 \times 10 = 600$$

For lap winding, $A = p = 4$

$$\text{EMF induced, } E = \frac{\phi \ Z \ NP}{60 \ A} = \frac{0.03 \times 600 \times 1000 \times 4}{60 \times 4} = \textbf{300 Volt}$$

Example 2

The induced emf in a dc machine while running 600 rpm is 190V. Assuming constant flux per pole, calculate the induced emf when the machine runs at 800 rpm.?

Solution :

The equation for the induced emf is given by

ϕ, Z, N, P and A are constant for all condition. $E \propto N$

$$E = \frac{\phi \ Z \ NP}{60 \ A} = KN$$

where K is a constant for the machine.

Then

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

The direction of this force is given by Fleming's left hand rule.
Fleming's left Hand Rule → Stretch out left hand with first finger, middle finger and thumb at right angles to one another. If the first finger points in direction of mag. field, middle finger points in direction of current, then thumb will point in direction of mech. force o the conductor.

CHAPTER **27**

D.C. MOTORS

27.1 Introduction

D.C Motor is a device which converts electrical power into mechanical power. It receives electrical power from the supply mains, and delivers mechanical power to any load coupled to it. Thus a motor can be used to drive a generator. D.C motor operates on the principle that a mechanical force acts on a current carrying conductor situated in a magnetic field. If the conductor is free to move, it does move in the direction of the force. The magnitude of the force is given by

F = BIl Newton. Where

B = flux density of the magnetic field in which the conductor is placed

I = Current carried by the conductor

l = Active length of the conductor

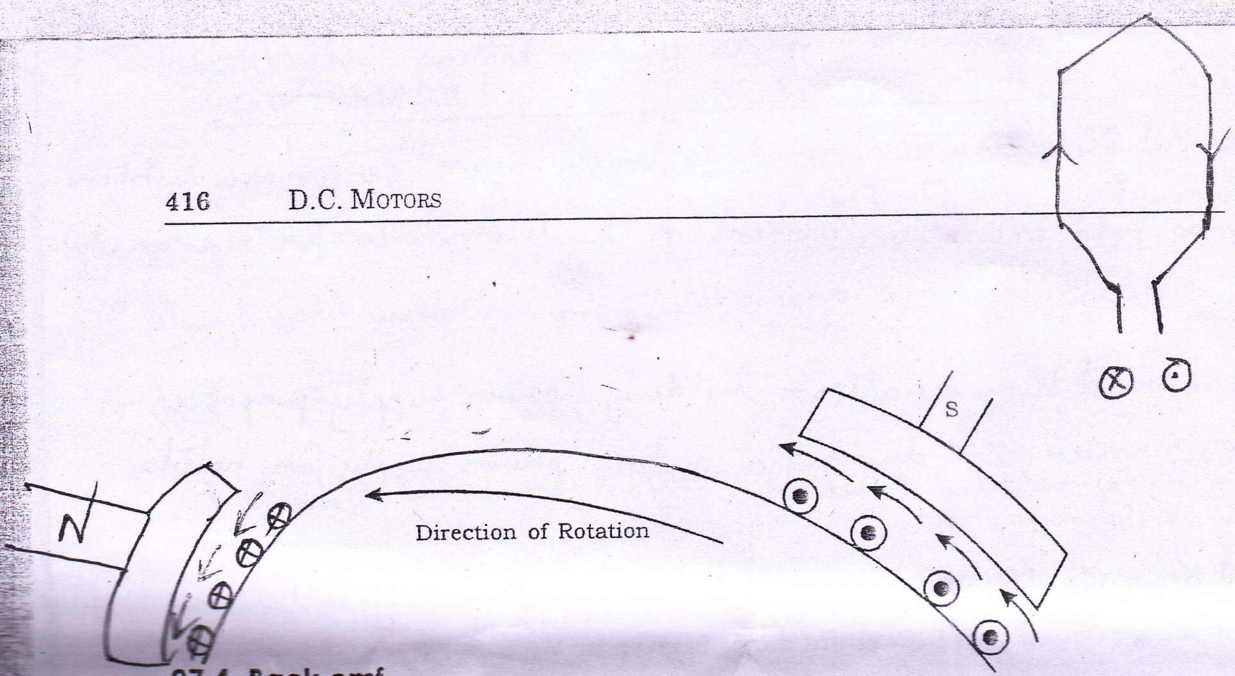
The direction of this force is given by Fleming's left hand rule.

27.2 Parts of a DC Motor

Armature (the rotating part of the machine) and field magnets (the stationary parts of the machine).

27.3 Production of Torque in a DC Motor

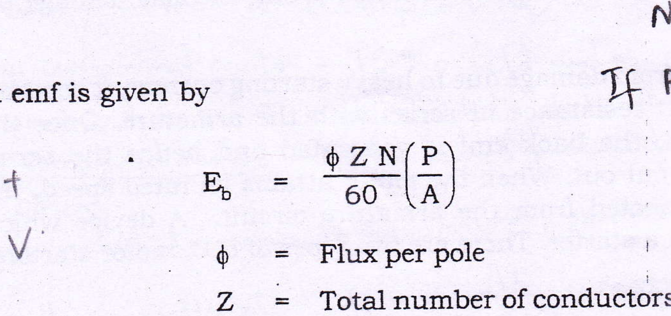
The figure shows a part of a multipolar dc motor. When the field magnets are excited and current is sent through the armature conductors, then the conductors experience a force tending to rotate the armature. Let the armature conductors under north pole carry current in the direction normal to the surface of paper in Fig. and pointing into the paper as shown by the crosses. Similarly let the conductors under south pole carry current in the direction normal to the surface of paper and pointing out as shown by the dots. Application of Fleming's left hand rule gives the direction of the force exerted on each conductor. This force exerted on armature conductor tends to rotate in the anti-clockwise direction. These forces on conductor add up to produce the driving torque which causes rotation of he armature.



27.4 Back emf

In a d.c motor, as the armature rotates, its conductors also rotate and cut the flux of the poles. Hence as per the law of electromagnetic induction, emf is induced in the conductors. As per Fleming's right hand rule, the direction of this emf is opposite to the applied voltage. Hence this emf is called counter emf or back emf (E_b). The applied V has to force current thru arm. against E_b. The electrical work done in overcoming & causing current to flow against E_b is converted into mech. energy dev. in arm.

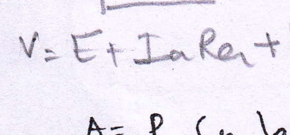
Back emf, E_b is always less than applied V.



Net V across arm. = $V - E_b$

If R_a = arm resistance, $I_a = \dfrac{V - E_b}{R_a}$

Back emf is given by



$V = E + I_a R_a + BD$

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

ϕ = Flux per pole

Z = Total number of conductors

N = speed of the armature in rpm

P = Number of poles

A = Number of parallel paths

A = P for lap wound m/c and A = 2 for wave wound m/c.

Application of DC Generator

a) Separately excited DC generator - testing purpose in labs, Ward Leonard systems of speed control

(b) Shunt wound DC generator - general lighting, used for small power supply, giving excitation to alternators, to charge battery

(c) Series wound DC generator - used as boosters, in series arc lightening, for supplying field excitation current in DC locomotives for regenerative braking

(d) Compound wound DC generator - lighting, power supply purposes, heavy power services, for driving a motor, power supply for hotels, offices, arc welding.

27.10 Necessity of Starter

The voltage equation of D.C. shunt motor is given by $V = E_b + I_a R_a$

The armature current is given by

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

When the motor is at rest, there is no back e.m.f. generated. i.e., $E_b = 0$.

If $V = 250$ V and $R_a = 0.1$, then I_a is given by

$$I_a = \frac{250}{0.1}$$

$$= 2500 \text{ A}$$

If the motor is connected directly across the supply mains, a heavy current flows through the armature conductors. Such a heavy current may damage the armature.

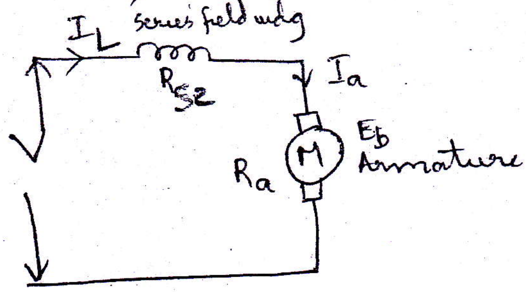
To protect the d.c. motor from damage due to heavy starting current, it becomes necessary to include a high resistance in series with the armature. Once the motor starts gaining speed, the back emf is generated and hence the series resistance can be gradually cut out. When the motor attains its rated speed, the entire resistance is disconnected from the armature circuit. A device which provides this facility is called a starter. There are two types of D.C. motor starters.

1. The three point starter and
2. The four point starter.

Different types of DC motors

I Self Excited DC Motor

① **Series Motor** – A series motor is one in which field wdg is connected in series with armature

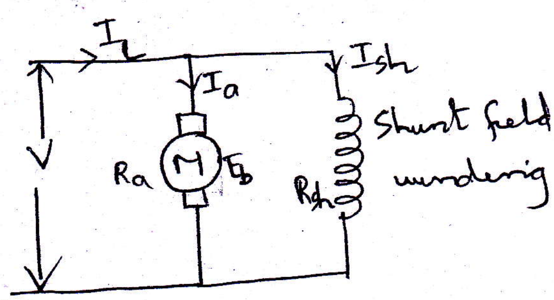


$I_L = I_a$

$V = E_b + I_a\,[R_a + R_{se}] + \text{brush drop}$

Applications – For heavy duty applications such as electric railways, rolling mills, metallurgical works, mine hoists, continous – conveyors, cranes, valve operation etc.

② **Shunt Motor** – Here the field wdg is connected in parallel with armature



$V = E_b + I_a R_a + \text{brush drop}$

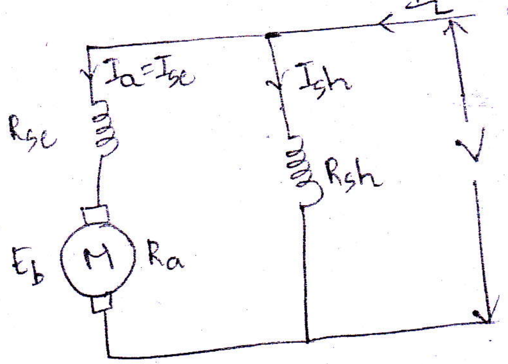
$I_{sh} = V/R_{sh}$

$I_L = I_a + I_{sh}$

Aplications – For driving constant speed line shafts, lathes, vacuum cleaners, pressure blowers, constant head centrifugal pumps, compressors, reciprocating pumps, metal cutting machines etc

③ **Compound Motor** – have both series field and shunt field –

Long shunt compound motor



$I_a = I_{se}$

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

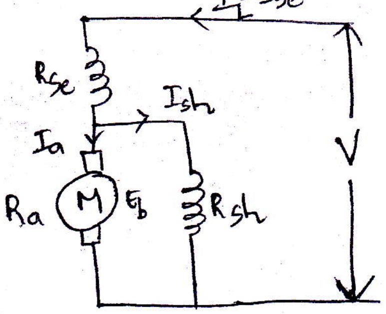
$I_{sh} = V / R_{sh}$

$V = E_b + I_a R_a + I_{se} R_{se}$ + Brush drop

$$\boxed{V = E_b + I_a [R_a + R_{se}] + \text{Brush drop}}$$

- Shunt field wdg is connected across combination of series field wdg and armature

(b) Short shunt compound motor - shunt field is connected purely in parallel with armature and series field is connected in series with combination



$I_L = I_a + I_{sh}$

$I_{se} = I$

$$\boxed{V = E_b + I_{se} R_{se} + I_a R_a + \text{brush drop}}$$

$I_{sh} R_{sh} = V - I_{se} R_{se}$

$$I_{sh} = \frac{V - I_{se} R_{se}}{R_{sh}} = \frac{E_b + I_a R_a + \text{brush drop}}{R_{sh}}.$$

Compound motors can also be classified into;

(i) Cumulatively compound motor - If the field wdgs are wound in such a manner that fluxes produced by the two always help each other

(ii) Differentially compound motor - If the fluxes produced by 2 field wdgs are trying to cancel each other.

Applications - For driving compressors, pressure blowers, presses, shears, rolling mills etc. Differentially compound motor is seldom used.

II Separately excited DC motor - armature and field coils are fed from diff. supply sources.

$I_a = I_L$, line current

$E_b = V - I_a R_a$

Transformer is a electrostatic device which is used to transfer electrical energy [voltage or current] from one circuit to another by mutual induction of two electric circuits without any change in frequency

CHAPTER 10

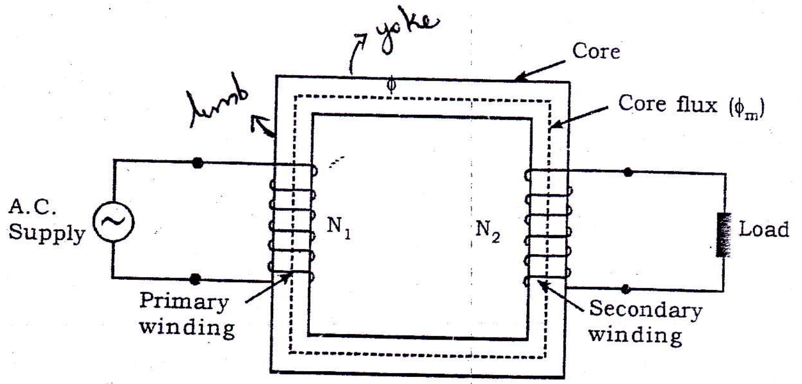
TRANSFORMERS

10.1 Introduction

Transformer is a static A.C. machine which is used either to increase or decrease the voltage of an A.C. Supply, without any change in frequency. It consists of two separate windings, called the primary winding and the secondary winding. They are insulated from each other. Transformer is used in almost every field of electrical engineering. This device plays an integral part in power distribution systems and can be found in many electronic circuits and measuring instruments.

10.2 Principle of Operation

Transformer works on the principles of mutual induction between two coils linked by a common magnetic flux. The two windings are electrically separated from each other but magnetically coupled. The two windings are wound on the same core. The coil to which the source is applied is called the primary and the coil to which the load is applied is called the secondary. The windings and the core of a simple transformer are shown in figure.



When the primary winding is connected to A.C. supply, an alternating flux is produced in it. The alternating flux in the primary winding also links with the secondary winding through the body of the core. The alternating flux in the secondary winding produces an e.m.f in it called mutually induced emf. If the secondary circuit is closed, a current will flow through the secondary circuit. When

produces self induced emf in primary winding. Acc. to Lenz's law, induced emfs acts in opp. direction to applied voltage

Self induced emf, $E_1 = -N_1 \, d\phi/dt$

Mutually induced emf, $E_2 = -N_2 \, d\phi/dt$

$I_1/I_2 = E_2/E_1 = N_2/N_1 = K =$ transformation ratio

If $N_2 > N_1$, then $E_2 > E_1$ $\rightarrow$ Step up transformer

and if $N_2 < N_1$, then $E_2 < E_1$ $\rightarrow$ Step down transformer

the number of turns in the secondary winding is more than that in the primary winding, it is called a step up transformer. When the number of turns in the secondary winding is less than that in the primary winding, it is called a step down transformer. A step up transformer has output voltage more than its input voltage and a step down transformer has output voltage less than its input voltage.

10.3 Constructional Details

The main parts of a transformer are described below.

- acts as support to body

1. Laminated Core. The material of transformer core is high grade silicon in the form of several laminations. These laminations are insulated from each other by a light coating of varnish on the surface. The laminations are assembled and presses together so as to form a continuous magnetic path, with minimum air gap. The thickness of lamination varies from 0.35 mm to 0.5 mm. The core is laminated to reduce the power loss due to eddy currents which appear in the form of heat.

- provides a low reluctance path to flow of mag flux

Insulating paper and cardboard used to isolate 1° & 2° wdg from each other and from X'mer core

Diameter of core & core loss

Based on the construction of the core, there are two types of transformers. Core type transformer and shell transformer. In core type the windings surrounds a considerable portion of the winding.

2. Windings. The primary and secondary windings are of super enameled copper wire. These windings are insulated from each other.

because of high conductivity & ductility - so need less amt of Cu

3. Transformer tank. The assembled core and windings are placed within a sheet metal tank and immersed in oil. The transformer oil provides insulation to the winding and core and dissipates the heat produced to the surrounding medium.

4. Conservator tank. It is a small tank mounted on the main tank, connected by a pipe, which takes into account the rise and fall of oil level due to heating and cooling of the coil. The main tank completely filled with oil but conservator tank is partially filled with oil. to allow oil to expand & contract as temp. varies

5. Terminal Bushings. The purpose of the bushings is to insulate and to bring out the terminals of the transformer from the container. Bushings are made of porcelain.

6. Breather. The function of the breather is to absorb moisture from the air which is taken in by the transformer due to contraction of oil in the tank due to cooling. The material used in the breather is silica gel which absorbs moisture from the incoming air. If moisture ↑, it can affect Paper insulation

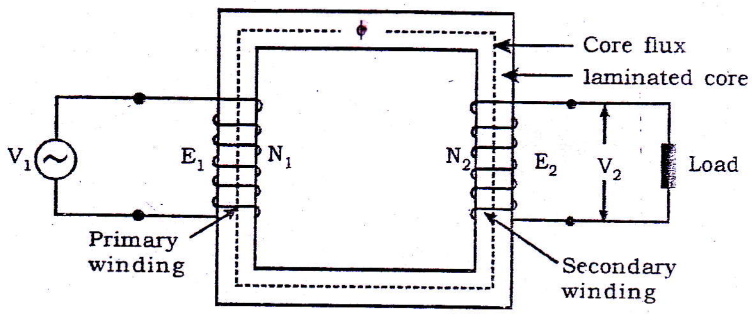
↑HC mineral oils

Transformer oil - provides insulation - cool core & coil assembly

Core & wdg completely immersed in X'mer oil

Buchholz relay - protective device housed in pipe from main tank to conservator tank. - simple relay operated by gases emitted during decomposition of X'mer oil during internal faults - senses & protects X'mer from internal faults.

10.4 E.M.F. Equation of a Transformer



Consider an alternating voltage V_1 at frequency 'f' is applied to the primary winding. An alternating flux ϕ is set up in the core and is given by

$$\phi = \phi_m \sin \omega t$$

Where ϕ_m is the peak value of flux in the core and ω is the angular velocity ($\omega = 2\pi f$)

The induced emf in the primary is given by

$$e_1 = -N_1 \frac{d\phi}{dt}$$

Where N_1 is the number of turns in the primary winding.

$$e_1 = -N_1 \frac{d\phi}{dt} = -N_1 \frac{d}{dt}(\phi_m \sin \omega t) = -\omega N_1 \phi_m \cos \omega t = -2\pi f N_1 \phi_m \cos \omega t$$

$$e_1 = 2\pi f N_1 \phi_m \sin(\omega t - 90^0)$$

From the above equation, the maximum value of induced emf in the primary is

$$E_{1m} = 2\pi f N_1 \phi_m$$

The r.m.s. value of the primary emf is

$$E_1 = \frac{E_{1m}}{\sqrt{2}} = \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$$

$$E_1 = 4.44 f N_1 \phi_m$$

$$\boxed{E_1 = 4.44 \phi_m f N_1}$$

Similarly $\boxed{E_2 = 4.44 \phi_m f N_2}$

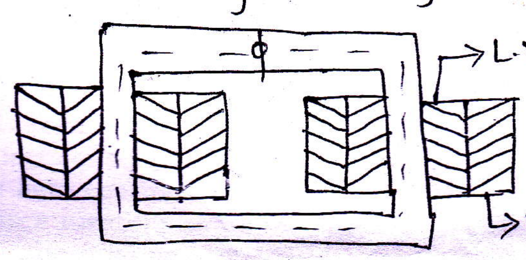
Transformer Construction

The main elements of a transformer are two windings and a core. The two coils are insulated from each other as well as from the core.

Acc. to construction, transformers are classified as

(a) Core type (b) Shell type

(a) Core type transformer - natural cooling
- coils can be easily removed by removing laminations on top yoke for maintenance

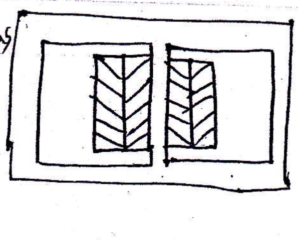


- the primary and secondary wdg are wound outside and surround the core ring.

In this, one half of each wdg is wrapped around each leg [limb] of transformer mag. circuit. Half of 1° wdg and half of 2° wdg are placed one over other concentrically on each leg inorder to increase mag. coupling allowing practically all of mag. lines of force go throu both 1° and 2° wdg at same time. LV winding is wound close to core inorder to reduce the amount of insulation required.

(b) Shell type transformer - double magnetic circuit - prefered for very high voltage transformers

- natural cooling doesnot exist as core surrounds winding



- 1° and 2° wdgs pass inside core which forms a shell around wdgs.
- 1° and 2° wdgs are wound on same central limb which has twice cross sectional area of 2 outer limbs.

- Advantage here is that mag. flux has 2 closed mag. paths to flow around external to coils on both left and right hand sides before returning back to central coils. Right and left limbs act as a low reluctance path

to [illegible]