UNIT-IV
DC GENERATOR

Introduction:

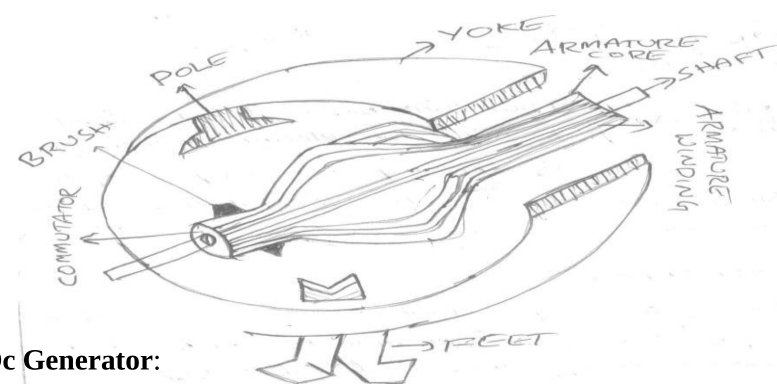
The electrical machines deals with the energy transfer either from mechanical to electrical form or from electrical to mechanical form, this process is called electromechanical energy conversion. An electrical machine which converts mechanical energy into electrical energy is called an electric generator while an electrical machine which converts electrical energy into the mechanical energy is called an electric motor. A DC generator is built utilizing the basic principle that emf is induced in a conductor when it cuts magnetic lines of force. A DC motor works on the basic principle that a current carrying conductor placed in a magnetic field experiences a force.

Working principle:

All the generators work on the principle of dynamically induced emf. The change in flux associated with the conductor can exist only when there exists a relative motion between the conductor and the flux. The relative motion can be achieved by rotating the conductor w.r.t flux or by rotating flux w.r.t conductor. So, a voltage gets generated in a conductor as long as there exists a relative motion between conductor and the flux. Such an induced emf which is due to physical movement of coil or conductor w.r.t flux or movement of flux w.r.t coil or conductor is called dynamically induced emf. Whenever a conductor cuts magnetic flux, dynamically induced emf is produced in it according to Faraday’s laws of Electromagnetic Induction. This emf causes a current to flow if the conductor circuit is closed.In a practical generator, the conductors are rotated to cut the magnetic flux, keeping flux stationary. To have a large voltage as output, a number of conductors are connected together in a specific manner to form a winding. The winding is called armature winding of a dc machine and the part on which this winding is kept is called armature of the dc machine. The magnetic field is produced by a current carrying winding which is called field winding.The conductors placed on the armature are rotated with the help of some external device. Such an external device is called a prime mover. The commonly used prime movers are diesel engines, steam engines, steam turbines, water turbines etc. The purpose of the prime mover is to rotate the electrical conductor as required by Faraday’s laws The direction of induced emf can be obtained by using Flemings right hand rule. The magnitude of induced emf = $e = BLV \sin\theta = E_m \sin\theta$. The nature of the induced emf for a conductor rotating in the magnetic field is alternating. As conductor rotates in a magnetic field, the voltage component at various positions is different. Hence the basic nature of induced emf in the armature winding in case of dc generator is alternating. To get dc output which is unidirectional, it is necessary to rectify the alternating induced emf. A device which is used in dc generator to convert alternating induced emf to unidirectional dc emf is called commutator.

Construction of DC machines: A D. C. machine consists of two main parts

1. Stationary part: It is designed mainly for producing a magnetic flux.
2. Rotating part: It is called the armature, where mechanical energy is converted into electrical (electrical generate) or conversely electrical energy into mechanical (electric into)



Parts of a Dc Generator:

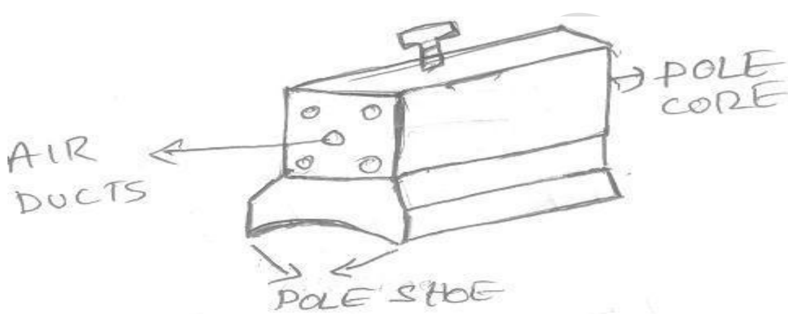
The stationary parts and rotating parts are separated from each other by an air gap. The stationary part of a D. C. machine consists of main poles, designed to create the magnetic flux, commutating poles interposed between the main poles and designed to ensure spark less operation of the brushes at the commutator and a frame / yoke. The armature is a cylindrical body rotating in the space between the poles and comprising a slotted armature core, a winding inserted in the armature core slots, a commutator and brush

Yoke:

It saves the purpose of outermost cover of the dc machine so that the insulating materials get protected from harmful atmospheric elements like moisture, dust and various gases like SO_2, acidic fumes etc. It provides mechanical support to the poles. It forms a part of the magnetic circuit. It provides a path of low reluctance for magnetic flux. Choice of material: To provide low reluctance path, it must be made up of some magnetic material. It is prepared by using cast iron because it is the cheapest. For large machines rolled steel or cast steel, is used which provides high permeability i.e., low reluctance and gives good mechanical strength.

Poles: Each pole is divided into two parts

a) pole core b) pole shoe

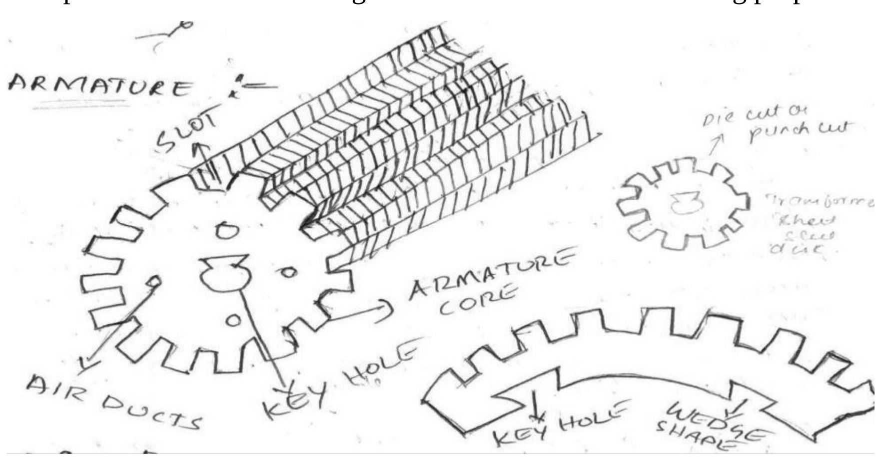


Pole core basically carries a field winding which is necessary to produce the flux. It directs the flux produced through air gap to armature core to the next pole. Pole shoe enlarges the area of armature core to come across the flux, which is necessary to produce larger induced emf. To achieve this, pole core has been given a particular shape. Choice of material: It is made up of magnetic material like cast iron or cast steel. As it requires a definite shape and size, laminated construction is used. The laminations of required size and shape are stamped together to get a pole which is then bolted to yoke.

Armature: It is further divided into two parts namely,

(1) Armature core (2) Armature winding.

Armature core is cylindrical in shape mounted on the shaft. It consists of slots on its periphery and the air ducts to permit the air flow through armature which serves cooling purpose.



Armature core provides house for armature winding i.e., armature conductors. To provide a path of low reluctance path to the flux it is made up of magnetic material like cast iron or cast steel. Choice of material: As it has to provide a low reluctance path to the flux, it is made up of magnetic material like cast iron or cast steel.It is made up of laminated construction to keep eddy current loss as low as possible.A single circular lamination used for the construction of the armature core is shown below.

Armature winding:

Armature winding is nothing but the inter connection of the armature conductors, placed in the slots provided on the armature core. When the armature is rotated, in case of generator magnetic flux gets cut by armature conductors and emf gets induced in them.Generation of emf takes place in the armature winding in case of generators.To carry the current supplied in case of dc motors. To do the useful work it the external circuit.

Choice of material: As armature winding carries entire current which depends on external load.it has to be made up of conducting material, which is copper

Field winding:

The field winding is wound on the pole core with a definite direction.
Functions: To carry current due to which pole core on which the winding is placed behaves as an electromagnet, producing necessary flux. As it helps in producing the magnetic field i.e. exciting the pole as electromagnet it is called **'Field winding'** or '**Exciting winding'.**

Choice of material: As it has to carry current it should be made up of some conducting material like the aluminum or copper. But field coils should take any type of shape should bend easily, so copper is the proper choice. Field winding is divided into various coils called as field coils. These are connected in series with each other and wound in such a direction around pole cores such that alternate N and S poles are formed.

Commutator: The rectification in case of dc generator is done by device called as commutator.
Functions: To facilitate the collection of current from the armature conductors. To convert internally developed alternating emf to in directional (dc) emf .To produce unidirectional torque in case of motor. Choice of material: As it collects current from armature, it is also made up of copper segments. It is cylindrical in shape and is made up of wedge shaped segments which are insulated from each other by thin layer of mica.

Brushes and brush gear: Brushes are stationary and rest on the surface of the Commutator. Brushes are rectangular in shape. They are housed in brush holders, which are usually of box type. The brushes are made to press on the commutator surface by means of a spring, whose tension can be adjusted with the help of lever. A flexible copper conductor called pigtail is used to connect the brush to the external circuit.
Functions: To collect current from commutator and make it available to the stationary external circuit.Choice of material: Brushes are normally made up of soft material like carbon.
Bearings: Ball-bearings are usually used as they are more reliable. For heavy duty machines, roller bearings are preferred.

Types of armature winding

Armature conductors are connected in a specific manner called as armature winding and according to the way of connecting the conductors; armature winding is divided into two types.

Lap winding**:** In this case, if connection is started from conductor in slot 1 then the connections overlap each other as winding proceeds, till starting point is reached again.

There is overlapping of coils while proceeding. Due to such connection, the total number of conductors get divided into 'P' number of parallel paths, where

P = number of poles in the machine.

Large number of parallel paths indicate high current capacity of machine hence lap winding is pertained for high current rating generators. .

Wave winding**:** In this type, winding always travels ahead avoiding over lapping. It travels like a progressive wave hence called wave winding. Both coils starting from slot 1 and slot 2 areprogressing in wave fashion.Due to this type of connection, the total number of conductors get divided into two number of parallel paths always, irrespective of number of poles of machine.

EMF equation

EMF generated/path = $\phi PN/60\ (Z/P) = \phi ZN/60$

Z = total number of armature conductors.

= number of slots x number of conductors/slot

N = armature rotation in revolutions (speed for armature) per minute (rpm) A = No. of parallel paths into which the 'z' no. of conductors are divided.

E = emf induced in any parallel path

E_g = emf generated in any parallel path

A = 2 for simplex – wave winding

A =P for simplex lap-winding

DC MOTOR

A dc motor is similar in construction to a dc generator. As a matter of fact a dc generator will run as a motor when its field & armature windings are connected to a source of direct current.

The basic construction is same whether it is generator or a motor.

Working principle:

The principle of operation of a dc motor can be stated as when a current carrying conductor is placed in a magnetic field; it experiences a mechanical force. In a practical dc motor, the field winding produces the required magnetic held while armature conductor play the role of current carrying conductor and hence the armature conductors experience a force.As conductors are placed in the slots which are on the periphery, the individual force experienced by the conductive acts as a twisting or turning force on the armature which is called a torque.The torque is the product of force and the radius at which this force acts, so overall armature experiences a torque and starts rotating.Consider a single conductor placed in a magnetic field , the magnetic field is produced by a permanent magnet but in practical dc motor it is produced by the field winding when it carries a current.Now this conductor is excited by a separate supply so that it carries a current in a particular direction. Consider that it carries a current away from an current. Any current carrying conductor produces its own magnetic field around it, hence this conductor also produces its own flux, around. The direction of this flux can be determined by right hand thumb rule. For direction of current considered the direction of flux around a conductor is clock-wise. Now, there are two fluxes present

1. Flux produced by permanent magnet called main flux

2. Flux produced by the current carrying conductor

From the figure shown below, it is clear that on one side of the conductor, both the fluxes are in the same direction in this case, on the left of the conductor there gathering of the flux lines as two fluxes help each other. A to against this, on the right of the conductor, the two fluxes are in opposite direction and hence try to cancel each other. Due to this, the density of the flux lines in this area gets weakened.

So on the left, there exists high flux density area while on the right of the conductor then exists low flux density area The flux distribution around the conductor arts like a stretched ribbed bond under tension. The exerts a mechanical force on the conductor which acts from high flux density area towards low flux density area, i.e. from left to right from the case considered as shown above.

In the practical dc motor, the permanent magnet is replaced by the field winding which produces the required flux winding which produces the required flux called main flux and all the armature conductors, would on the periphery of the armature gram, get subjected total he mechanical force.

Due to this, overall armature experiences a twisting force called torque and armature of the motor status rotating.

Direction of rotation of motor

The magnitude of the force experienced by the conductor in a motor is given by F = BIL newtons.The direction of the main field can be revoked y changing the direction of current passing through the field winding, which is possible by interchanging the polarities of supply which is given to the field winding.The direction of current through armature can be reversed by changing supply polarities of dc supplying current to the armature.

It directions of both the currents are changed then the direction of rotation of the motor remains undamaged. In a dc motor both the field and armature is connected to a source of direct current. The current through the armature winding establish its own magnetic flux the interaction both the main field and the armature current produces the torque, there by sensing the motor to rotate, once the motor starts rotating, already existing magnetic flux there wire be an induced emf in the armature conductors due to generator action. This emf acts in a direction apposite to supplied voltage. Therefore it is called Black emf.

Significance of Back emf

In the generating action, when a conductor cuts the lines of flux, emf gets induced in the conductor in a motor, after a motoring action, armature starts rotating and armature conductors cut the main flux. After a motoring action, there exists a generating action there is induced emf in the rotating armature conductors according to Faraday's law of electromagnetic induction. This induced emf in the armature always acts in the opposite direction of the supply voltage. This is according tot he lenz's law which states that the direction of the induced emf is always so as to oppose the case producing it. In a dc motor, electrical input i.e., the supply voltage is the cause and hence this induced emf opposes the supply voltage.The emf tries to set u a current throughout he armature which is in the opposite direction to that which supply voltage is forcing through the conductor so, as this emf always opposes the supply voltage, it is called back emf and devoted as Eb. Through it is denoted as Eb, basically it gets generated by the generating action which we have seen

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

Voltage equation of a Motor

The voltage v applied across the motor armature has to (1) over core the back emf Eb and

3. supply the armature ohmic drop Ia Ra

$$v = Eb + Ia\,R_a$$

This is known as voltage equation of a motor

Torque: The turning or twisting movement of a body is called Torque

$$T_{sh} = output/((2\prod N)/60)$$

$$T_{sh} = 9.55(output)/N$$

INTRODUCTION TO POLY PHASE INDUCTION MOTORS

Three-phase induction motors are the most common and frequently encountered machines in industry.

- simple design, rugged, low-price, easy maintenance
- wide range of power ratings: fractional horsepower to 10 MW
- run essentially as constant speed from no-load to full load
- Its speed depends on the frequency of the power source
    - not easy to have variable speed control
    - requires a variable-frequency power-electronic drive for optimal speed control.

CONSTRUCTION DETAILS OF INDUCTION MOTOR

An induction motor has two main parts

- a stationary stator
    - consisting of a steel frame that supports a hollow, cylindrical core
    - core, constructed from stacked laminations (why?), having a number of evenly spaced slots, providing the space for the stator winding .

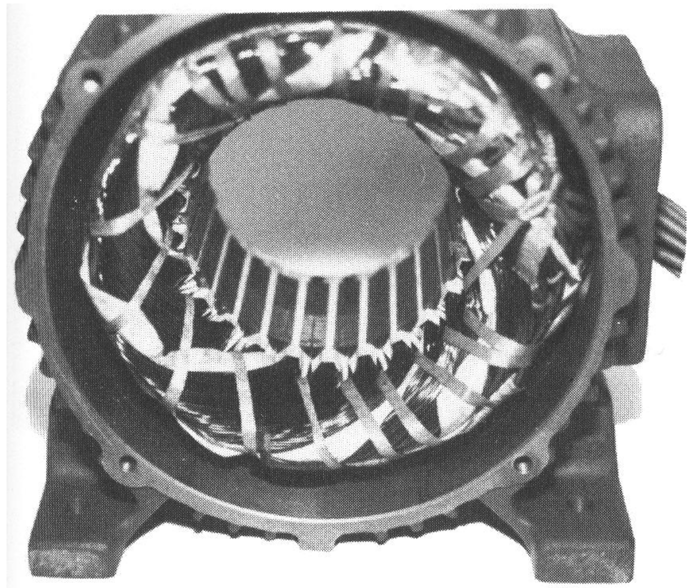


Fig: STATOR OF INDUCTION MOTOR

a revolving rotor

- composed of punched laminations, stacked to create a series of rotor slots, providing space for the rotor winding
- one of two types of rotor windings
- conventional 3-phase windings made of insulated wire (wound-rotor) » similar to the winding on the stator
- Aluminum bus bars shorted together at the ends by two aluminum rings, forming a squirrel-cage shaped circuit (squirrel-cage).

CONSTRUCTION OF CAGE AND WOUND ROTOR MACHINES

Two basic design types depending on the rotor design

Squirrel-cage: conducting bars laid into slots and shorted at both ends by shorting rings.

Wound-rotor: complete set of three-phase windings exactly as the stator. Usually Y-connected, the ends of the three rotor wires are connected to 3 slip rings on the rotor shaft. In this way, the rotor circuit is accessible.

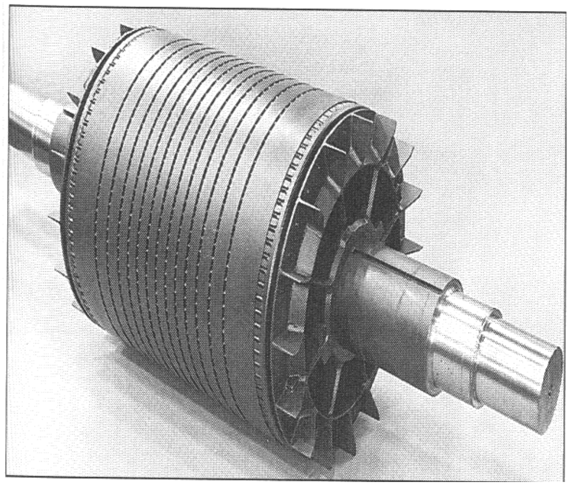


Fig:- Squirrel cage rotor

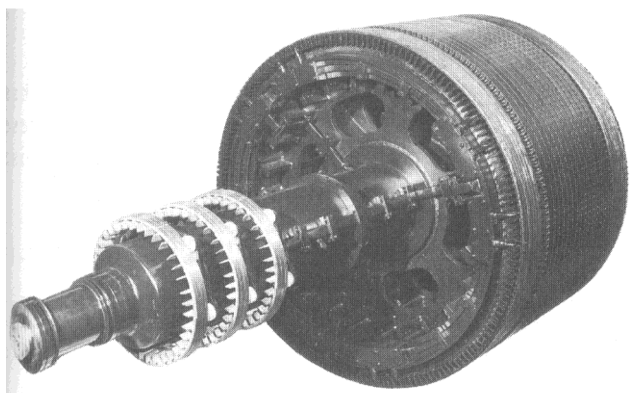


Fig: Wound rotor

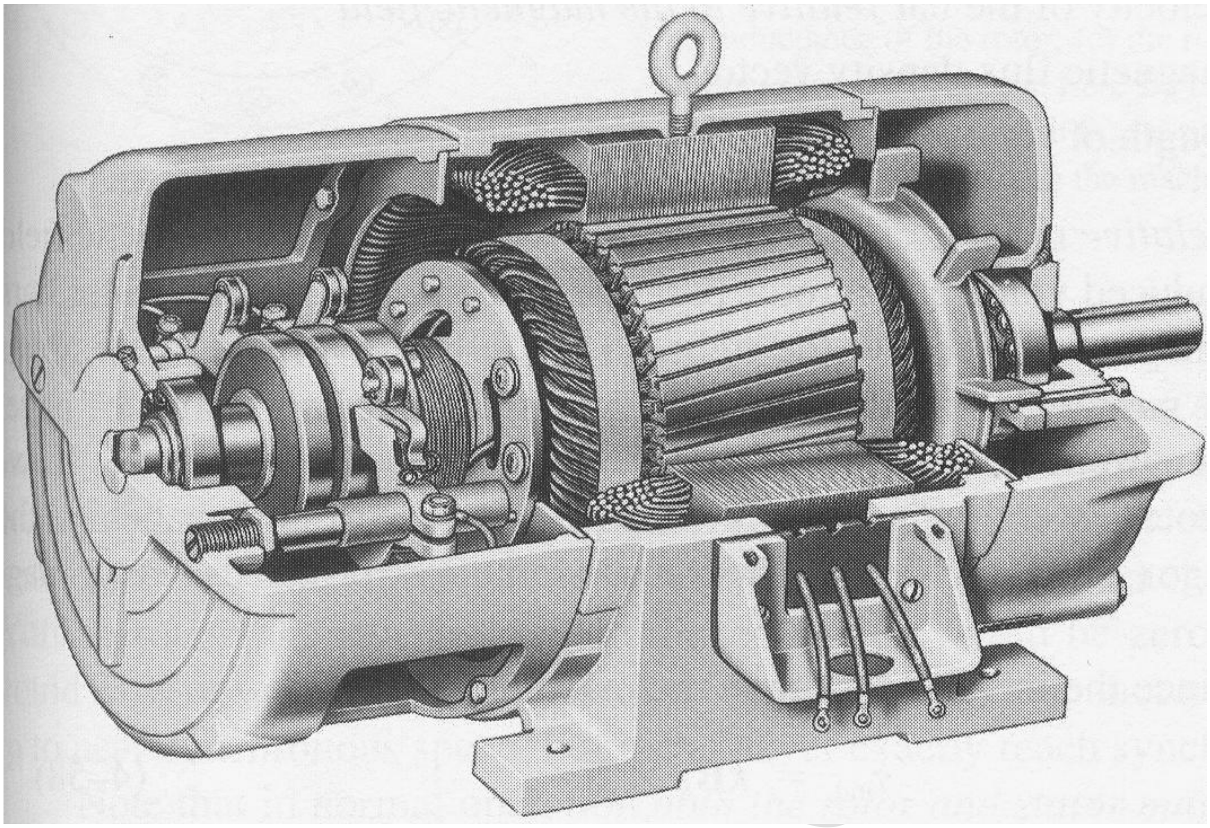


Fig:- Cutaway in a typical wound-rotor IM.

PRODUCTION OF ROTATING MAGNETIC FIELD

- Balanced three phase windings, i.e. mechanically displaced 120 degrees from each other, fed by balanced three phase source
- A rotating magnetic field with constant magnitude is produced, rotating with a speed

$$N_S=120f/p$$

Where f_e is the supply frequency and

$i_R = I_m \cos \omega t$

$i_Y = I_m \cos(\omega t - 120°)$

$i_B = I_m \cos(\omega t + 120°) = I_m \cos(\omega t - 240°)$

Please note that the phase sequence is R-Y-B. I_m is the maximum value of the phase currents, and, as the phase currents are balanced, the rms values are equal ($I_R = I_Y = I_B$)
Three pulsating mmf waves are now set up in the air- gap, which have a time phase difference of 120° from each other. These mmfs are oriented in space along the magnetic axes of the phases, R, Y & B, as illustrated by the concentrated coils in Fig. 29.2. Please note that 2-pole stator is shown, with the angle between the adjacent phases, R & Y as 120°, in both mechanical and electrical terms. Since the magnetic axes are located 120° apart in space from each other, the three mmf's are expresses mathematically as

$F_R = F_m \cos \omega t \cos \theta$

$F_Y = F_m \cos(\omega t - 120°) \cos(\theta - 120°)$ $F_B = F_m \cos$
$(\omega t + 120°) \cos(\theta + 120°)$

Wherein it has been considered that the three mmf waves differ progressively in time phase by 120°, i.e. $2\pi / 3$ rad (elect.), and are separated in space phase by 120°, i.e. $2\pi / 3$ rad (elect.). The resultant mmf wave, which is the sum of three pulsating mmf waves, is

$F = F_R + F_Y + F_B$

Substituting the values,

(θ, t)

4. F_m [cos ωt cos θ + cos (ωt −120°) cos (θ −120°) + cos (ωt +120°) cos (θ +120°)] The first term of this expression is

$\cos \omega t \cos \theta = 0.5 [\cos (\theta - \omega t) + \cos (\theta + \omega t)]$

The second term is

$\cos (\omega t - 120°) \cos (\theta - 120°) = 0.5 [\cos (\theta - \omega t) + \cos (\theta + \omega t - 240°)]$

Similarly, the third term can be rewritten in the form shown. The expression is

$F (\theta, t) = 1.5 F_m \cos (\theta - \omega t)$

$+ 0.5 F_m [\cos (\theta + \omega t) + \cos (\theta + \omega t - 240°) + \cos (\theta + \omega t + 240°)]$ Note that

$\cos (\theta + \omega t - 240°) = \cos (\theta + \omega t + 120°)$, and $\cos (\theta + \omega t + 240°) = \cos (\theta + \omega t - 120°)$.

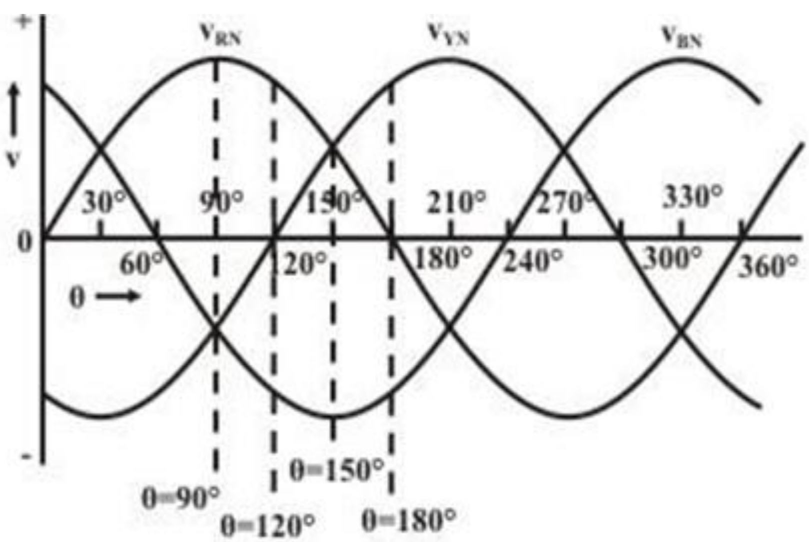
If these two terms are added, then

$\cos (\theta + \omega t + 120°) + \cos (\theta + \omega t - 120°) = -\cos (\theta + \omega t)$

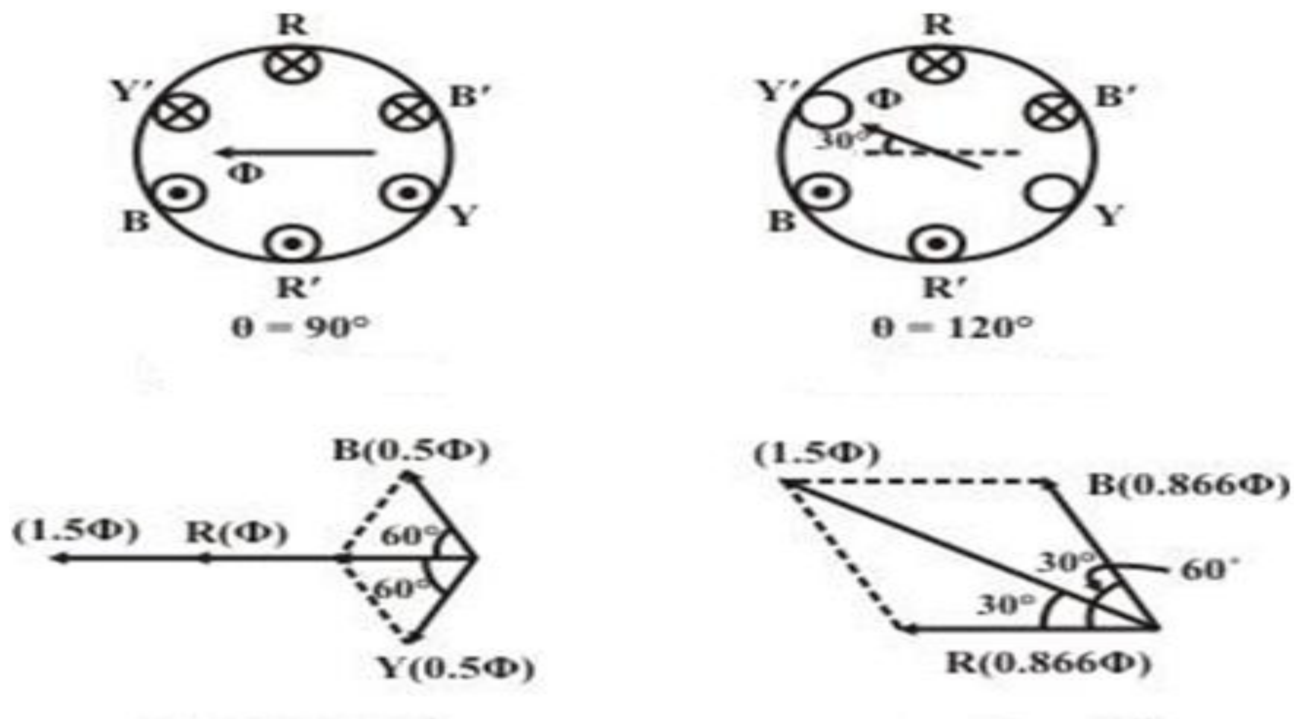
So, in the earlier expression, the second part of RHS within the capital bracket is zero. In other words, this part represents three unit phasors with a progressive phase difference of 120°, and therefore add up to zero. Hence, the resultant mmf is

$F (\theta,t) = 1.5 F_m \cos (\theta - \omega t)$

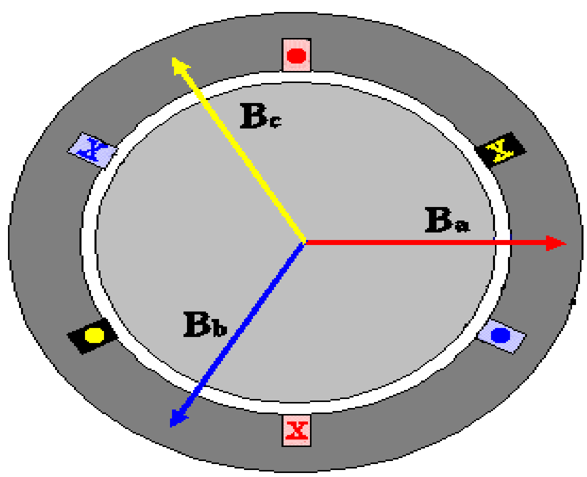
The peak value of the resultant mmf is $F_{peak} = 1.5 F_m$.



Three-phase voltage waveforms with phase sequence R-Y-B.



P is the no. of poles and n_{sync} is called the synchronous speed in *rpm* (revolutions per minute).



PRINCIPLE OF OPERATION

- This rotating magnetic field cuts the rotor windings and produces an induced voltage in the rotor windings.
- Due to the fact that the rotor windings are short circuited, for both squirrel cage and wound-rotor, and induced current flows in the rotor windings
- The rotor current produces another magnetic field
- A torque is produced as a result of the interaction of those two magnetic fields

Where τ_{ind} is the induced torque and B_R and B_S are the magnetic flux densities of the rotor and the stator respectively.

SLIP

$S = N_S - N_R / N_S$

Where s is the *slip*

Notice that: if the rotor runs at synchronous speed

$s = 0$

If the rotor is stationary

$s = 1$

Slip may be expressed as a percentage by multiplying the above eq. by 100, notice that the slip is a ratio and doesn't have units

ROTOR FREQUENCY

Frequency of the rotor's induced voltage at any speed n_m is

$F_R = SF_S$

- When the rotor is blocked (s=1) , the frequency of the induced voltage is equal to the supply frequency.
- On the other hand, if the rotor runs at synchronous speed (s = 0), the frequency will be zero.

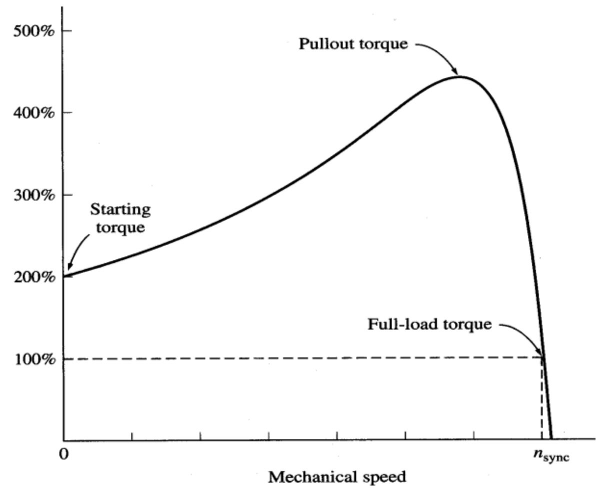
TORQUE EQUATION

- While the input to the induction motor is electrical power, its output is mechanical power and for that we should know some terms and quantities related to mechanical power
- Any mechanical load applied to the motor shaft will introduce a Torque on the motor shaft. This torque is related to the motor output power and the rotor speed.

Thus $T = \dfrac{3 \times V1^2 \times R2'}{s \times \omega s \times [(R_{new} + R2'/s)^2 + (X_{th} + X2')^2]}$

From this equation we get $R_{new} = \dfrac{\sqrt{3 \times V1^2 \times R2'}}{\sqrt{s \times \omega s \times T}} - \dfrac{R2'}{s}$

TORQUE-SLIP CHARACTERISTICS



1. The induced torque is zero at synchronous speed. Discussed earlier.
2. The curve is nearly linear between no-load and full load. In this range, the rotor resistance is much greater than the reactance, so the rotor current, torque increase linearly with the slip.
3. There is a maximum possible torque that can't be exceeded. This torque is called *pullout torque* and is 2 to 3 times the rated full-load torque.
4. The starting torque of the motor is slightly higher than its full-load torque, so the motor will start carrying any load it can supply at full load.
5. The torque of the motor for a given slip varies as the square of the applied voltage.

If the rotor is driven faster than synchronous speed it will run as a generator, converting mechanical power to electric power.