ALTERNATOR

1. Types of alternator and their constructional features.

A: The construction of an alternator consists of field poles placed on the rotating fixture of the machine. An alternator is made up of two main parts: a rotor and a stator. The rotor rotates in the stator, and the field poles get projected onto the rotor body of the alternator. The armature conductors are housed on the stator. An alternating three-phase voltage represented by aa', bb', cc' is induced in the armature conductors thus resulting in the generation of three-phase electrical power. All modern electrical power generating stations use this technology for generation of 3-ϕ power, and as a result, an alternator (also known as a synchronous generator) has made itself a subject of great importance and interest for power engineers. An alternator is basically a type of AC generator. The field poles are made to rotate as synchronous speed $N_s = 120f/P$ for effective power generation. Where, f signifies the alternating current frequency and the P represents the number of poles.

There are mainly two types of rotors used in construction of alternator.

(1) Salient pole type (2) Cylindrical rotor type.

The Salient feature of pole field structure has the following special feature.

(1) They have a large horizontal diameter compared to a shorter axial length.

(2) The pole shoes covers only about 2/3rd of pole pitch.

(3) Poles are laminated to reduce eddy current loss.

(4) The salient pole type motor is generally used for low - speed operations of around 100 to 400 rpm, and they are used in power stations with hydraulic turbines or diesel engines.

Salient pole alternators driven by water turbines are called hydro - alternators or hydro generators.

Cylindrical Rotor Type :-

The cylindrical rotor alternators are generally designed for 2-pole type giving very high speed of

Where, f is the frequency of 50 Hz

The cylindrical rotor synchronous generator does not have any projections coming out from the surface of the rotor. Rather, the central polar area is provided with slots for housing the field windings. ~~as we can~~

The field coils are so arranged around

these poles that flux density is maximum on the polar central line and gradually falls away as we move out towards the periphery. The cylindrical rotor type machine gives better balance and quieter operation along with lesser windage losses.

1.2 Basic working principle of alternator and the relation between speed and frequency.

A: The working principle of an alternator is very simple. It is just like the basic principle of DC generator. It also depends upon Faraday's law of electromagnetic induction which says the current is induced in the conductor inside a magnetic field when there is a relative motion between that conductor and the magnetic field. For understanding working of alternator let us think about a single rectangular turn placed in between two opposite magnetic poles. While the turn further proceeds to its vertical position the current is ~~zero~~ again reduced to zero. So if the turn continues to rotate the current in turn continually alternate its direction. During every full revolution of the turn, the current in turn gradually reaches to its maximum value then reduces to zero and then again it comes to its maximum value but in opposite direction and again it comes to zero.

In this way, the current completes one full sine wave cycle during each 360° revolution of the turn. so, we have seen how alternating current is produced in a truth is rotated inside a magnetic field. from this, we will now come to the actual working principle of an alternator.

1.3 Terminology in armature winding and expressions for winding factors (pitch factor, Distribution factor).

Winding Terminology:

1. Conductor: - The part of the wire, which is under the influence of the magnetic field and responsible for the induced e.m.f is called active length of the conductor. The conductor are placed in the armature slots.

2/ Turn: A conductor in one slot, ~~forms a~~ when connected to a conductor in another slot forms a turn. so two conductors constitute a turn.

3) Coil Side:- coil consists of many turns. part of the coil in each slot is called coil side of a coil.

(4) Coil:- As there are number of turns, for simplicity the number of turns are grouped together to form a coil. such a coil is called multiturn coil.

(5) pole pitch: It is centre to centre distance between the two adjacent poles. we have seen that for one rotation of the conductors, 2

2 poles are responsible for 360° electrical of e.m.f
4 poles are responsible for 720° electrical of e.m.f
and so on, so 1 pole is responsible for 180°
electrical of induced e.m.f.

(6) Slot angle (β) :- The phase difference contributed by one slot in degrees electrical is called slot angle β. As slots per pole contributes 180° electrical which is denoted as 'n'. we can write,

$$\therefore \ 1 \text{ Slot angle} = 180°/n$$

$$\boxed{\beta = \frac{180°}{n}}$$

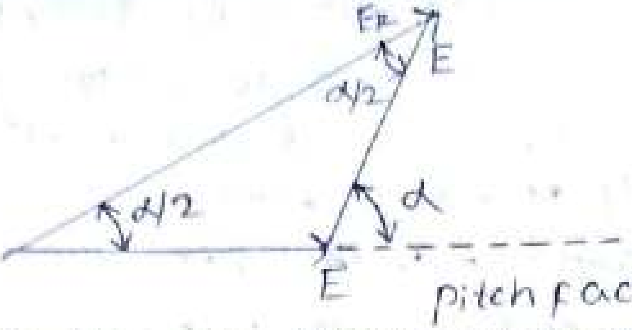
In the above example, $n = 18/2 = 9$, while $\beta = 180°/n = 20°$

• Pitch factor:

The ratio of phasor sum of induced EMFs per coil to the arithmetic sum of induced EMFs per coil is known as pitch factor K_p or coil span factor K_c. Its value is always less than unity.

Let us consider, the coil ~~span fa~~ has a pitch short by an angle α electrical degrees from the full pitch. The induced emf in each coil side be E. Now, if the coil is said to be full pitch, then total induced emf in the coil would be 2E. for a coil, that is short-pitched by α electrical degrees, the resultant induced emf E_R is the phasor sum of two voltages α electrical degrees.

$$E_R = 2E\cos\frac{\alpha}{2}$$



pitch factor

The formula for pitch factor is given by

$$\text{pitch factor}, K_p = \frac{\text{phasor sum of coil side emfs}}{\text{Arithmetic sum of coil side emfs}}$$

$$= \frac{2E\cos\frac{\alpha}{2}}{2E} = \cos\frac{\alpha}{2}$$

The pitch factor in the above equation is for fundamental component of emf.

If the coil span is reduced by one slot, then the phase angle α between the induced EMFS in the two sides of the coil is given as

$\alpha = \frac{180°}{n}$ where n is the number of slots per pole.

* Distribution factor:

If all the coil sides of any one phase under one pole are bunched in one slot, the winding obtained is known as concentrated winding.

The ratio of the phasor sum of the EMFs induced in all the coils distributed in a number of slots under one pole to the arithmetic sum of the EMFs induced (or to the resultant of EMFs induced in all coils concentrated in one slot under one pole) is known as breadth factor K_b or distribution factor K_d. Its value is always less than unity.

$$K_d = \frac{\text{EMF induced in distributed winding}}{\text{EMF induced if the winding would have been concentrated}}$$

$$K_d = \frac{\text{Phasor sum of component emfs}}{\text{Arithmetic sum of component emfs}}$$

Let n be the number of slots per pole.

m be the number of slots per pole per phase.

E_c be the induced emf in each coil side.

Angular displacement between the slots.

$$\beta = \frac{180}{n}$$

1.4 Explain harmonics, its causes and impact on winding factor.

A:- A harmonic is wave or signal whose frequency is an integral (whole number) multiple of the frequency of the same reference signal or wave.

Its causes

Harmonics is defined as the content of the signal whose frequency is an integral multiple of the system frequency of the fundamentals. Harmonics current generated by any non-linear load flows from the load into the power system. These harmonic currents degrade the power system performance and reliability and can also cause saftey problem. Harmonics need to be clearly located, sources identified and corrective measures taken to prevent them.

Electrical load is categorised under two categories.

1. Linear load: such load draws voltage and current in essentially sine wave shape but at varied phase shift (power factor). Example: resistors, inductors, capacitors and their combinations are classified as linear load. Linear loads have smooth, straight & predictable response.

Non-linear load:- power supplies in non-linear load draw current in abrupt pulses rather than in smooth sinusoidal wave. It indicates distorted or suddenly changing response.

Example- Modern electronic / electrical equipment consisting of rectifying, charging/discharging and phase control circuits.

Impact on winding factor:

The winding factor is the method of improving the rms generated voltage in a three-phase AC machine so that the torque and the output voltage do not consist of any harmonics which reduces the efficiency of the machine. Winding factor is defined as the product of the Distribution factor (K_d) and the coil span factor (K_c). The distribution factor measured the resultant voltage of the distributed winding regards concentrate winding and the coil span is the measure of the number of armature slots between the two sides of a coil. It is donoted by kw. The EMF equation is given below:

$$E_p = 4.44 k_w f \phi T_p \quad \text{--- (1)}$$

It is assumed that the induced voltage is sinusoidal. The coil span factor, distribution factor, and winding factor will be different for each harmonic voltage.

1.5 E.M.F equation of alternators. (Solve numerical problems)

problem:-1

A 3-phase, 50Hz alternator is running at 600 rpm has a 2-layer winding, 12 turns/coil, 4 slots/pole/phase, and coil-pitch of 10 slots. Let us find the induced EMF per phase if the flux/pole is 0.035 webers.

A: Given data:

The number of poles can be calculated as follow:

$$P = \frac{120f}{n} = 4$$

The total numbers of slots

$$S = 4 \times 3 \times 10 = 120$$

Slot angle

$$\alpha = \frac{180 \times 10}{120} = 15^\circ$$

$$K_d = \frac{\sin \frac{4 \times 15^\circ}{2}}{4 \times \sin \frac{15^\circ}{2}} = 0.958$$

Solt angle

$$\text{pole-pitch} = \frac{120}{10} = 12 \text{ slots}$$

$$\beta = (12-10) \times 15^\circ = 30^\circ$$

$$K_p = \cos 30/2 = 0.966$$

The emf equation of an alternator is

$E_{rms} = 4.44\ \phi\ f T k_p k_b = 4.44 \times 0.035 \times 50 \times 480 \times 0.9$

$E_{rms} = 3451V$

1.6 Explain Armature reaction and its effect on emf at different power factors of load.

A: When current flows in the armature conductors a flux surrounds these conductors. The direction of this armature flux is such that it reduces the flux from the field poles, resulting reduction in both generated voltage and terminal voltage. So we can say that the interaction between armature flux and field flux is called armature reaction.

The method for reducing armature reaction:

- Compensating windings
- High reluctance pole tips
- Horizontal slots in main field pole.

Its effect

Armature reaction is the effect on the main field flux of that flux setup by the currents in the armature winding. the effect is the same for both lap- and wave-wound machines.

When load power factor is zero lagging:

A: When a pure inductive load (zero p.f. lagging) is connected across the terminals of the alternator. Current the condition when the alternator is supplying resistive load, there that e.m.f. as well as current in phase R1R2 is maximum in the position. When the alternator is supplying a pure inductive load, the current in phase R1R2 will not reach its maximum value until N-pole advanced 90° electrical. Now the armature flux is from right to left and field flux is from left to right. All the flux produced by armature reaction is directly demagnetizing. Hence at zero p.f. lagging, the armature reaction weakens the main flux. This causes a reduction in the generated e.m.f.

- When load power factor is zero leading

A: When a pure capacitive load (zero p.f. leading) is connected across the terminals of the alternator, the current in armature windings will lead the induced emf by 90°. The effect of armature reaction will be the reverse that for pure inductive load. Thus armature flux now aids the main flux and the generated e.m.f is increased. When the alternator is supplying a pure capacitive load, the maximum current in R1R2 will occur 90° electrical before the occurrence of maximum induced emf. Therefore, maximum current in phase R1R2 will occur if the position of the rotor remains 90° behind as compared to its position under resistive load.

For intermediate values of p.f, the effect of armature reaction is partly distorting and partly weakening for inductive loads. For capacitive loads the effect of armature reaction is partly distorting and partly strengthening.

~~The vector diagram of loaded alternator. (solve numerical problems)~~

1.7 Testing of alternator (solve numerical problems)

1.7.1 Open circuit test

* A 500 V, 50 KVA single-phase alternator has an effective armature resistance of 0.2 Ω. An excitation current of 10 A produces 200 A armature current on short-circuit and an e.m.f of 450 volt on open circuit. Calculate the synchronous reactance.

A:- $Z_s = \frac{\text{Open circuit voltage per phase}}{\text{short-circuit armature current}} = \frac{450}{200} = 2.25\ \Omega$

$X_s = \sqrt{Z_a^2 - R_a^2} = \sqrt{2.25^2 - 0.2^2} = 2.241\ \Omega$

1.7.2 Short circuit test

A 3-phase 2300V, 50Hz, 1500 KVA star-connected alternator has a resistance between each pair of terminals as measured by direct current is 0.16 Ω. Assume that the effective resistance is 1.5 times the ohmic resistance. A field current of 70A produces a short - circuit current equal to full - load current of 376A in each line. the same field current produces an e.m.f of 700 volt on open circuit. calculate the synchronous reactance of the machine and its full - load regulation at 0.8 power factor lagging.

A: $Z_s = \frac{\text{open circuit voltage perphase}}{\text{short - circuit armature current}} = \frac{700\sqrt{3}}{376}$

$= 1.075\,\Omega$

Ohmic resistance perphase $= \frac{0.16}{2} = 0.08\,\Omega$

Effective resistance perphase $= R_a = 1.5 \times 0.08 = 0.12\,\Omega$

Synchronous reactance $= X_s = \sqrt{Z_a^2 - R_a^2} = \sqrt{1.075^2 - 0.12^2}$

$= 1.068\,\Omega$

$S_{3\phi} = \sqrt{3}\, V_L I_L$; $\Rightarrow 1500 \times 10^3 = \sqrt{3} \times 2300\, I_L$;

$\Rightarrow I_L = 376A$

Rated voltage per phase $= V_p = 2300/\sqrt{3}$

$= 1328V$

phase current $I_{ap} = I_L = 376A$

$E_p = V_p + I_{ap} Z_s$

Let V_p be taken as reference phasor:

$V_p = V_p \angle 0° = 1328 \angle 0°$ volts $= 1328 + j0$ volts

$I_{ap} = I_{ap} \angle \cos^{-1} 0.8 = 376 \angle -36.87° A$

$Z_a = R_s + jX_s = 0.12 + j1.068 = 1.075 \angle 83.59°\,\Omega$

$E_p = 1328 + j0 + (376 \angle -36.87°)(1.075 \angle 83.59°)$

$= 1328 + 404.2 \angle 46.72°$

$= 1328 + 277.1 + j294.26 = 1605.1 + j294.26 = 1631 \angle 10.39°$ volt

Percentage Regulation = $\frac{E_P - V_P}{V_P} \times 100$

$= 22.8\%$

1.8

Determination of voltage regulation of Alternator by direct loading and synchronous impedance method (Solve numerical problems)

A:- The voltage regulation of a synchronous Generator is the rise in voltage at the terminals when the load is reduced from full load rated value to zero, speed and field current remaining constant. It depends upon the power factor of the load. For unity and lagging power factors, there is always a voltage drop with the increase of load, but for a certain leading power, the full load voltage regulation is zero.

The voltage regulation is given by the equation shown below:

Per unit voltage Regulation $\triangleq \frac{|E_a| - |V|}{|V|}$ ---- ①

Percentage voltage Regulation $\triangleq \frac{|E_a| - |V|}{|V|}$ ---- ②

There are mainly two methods that are used to determine the regulation of voltage of smooth cylindrical rotor type alternators. They are named as a direct load test method & indirect methods of voltage regulation. The indirect method is further classified as synchronous impedance method, Ampere turn method & zero power factor method.

All the above methods other than direct loading are valid for non-salient pole machines only. As the alternators are manufactured in large capacity direct loading of alternators is not employed for determination of regulation. Other methods can be employed for predetermination of regulation. Hence the other methods of determination of regulations will be discussed in the following sections.

Synchronous impedance method or EMF method :-

This method is also known as synchronous impedance method. Here the magnetic circuit is assumed to be unsaturated. In this method the MMFs (fluxes) produced by rotor and stator are replaced by their equivalent emf, and hence called emf method.

As the terminals of the stator are short circuited in SC test, the short circuit current is circulated against the impedance of the stator called the synchronous impedance. This impedance can be estimated from the OC & SC characteristics.

The ratio of open circuit voltage to the short circuit current at a particular field current, or at a field current responsible for circulating the rated current is called the synchronous impedance.

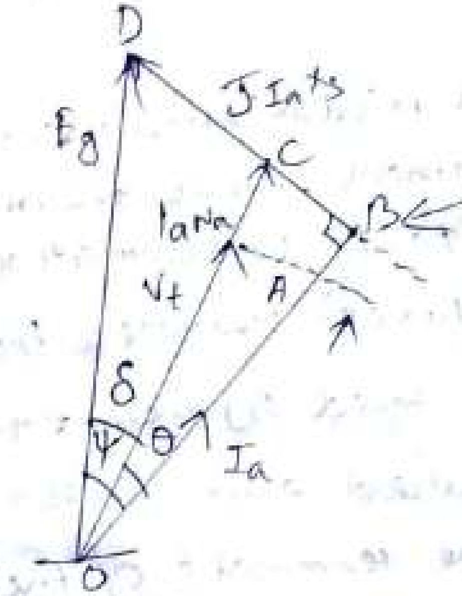
synchronous impedance Z_s = (open circuit voltage per phase) (short circuit current per phase) for same if

Hence $Z_s = (V_{oc}) / (I_{sc})$ for same if

Synchronous impedance $Z_s = V/I_{sc}$

Armature resistance R_a of the stator can be measured using voltmeter - Ammeter method.

. Using synchronous impedance and armature resistance synchronous reactance and hence regulation can be calculated as follows using emf method.



$Z_s = \sqrt{[(R_a)^2 + (X_s)^2]}$ and synchronous reactance $X_C = \sqrt{[(Z_s)^2 - (R_a)^2]}$

Hence induced emf per phase can be found as $E_g = \sqrt{[(V_t \cos\theta + I_aR_a)^2 + (V_t \sin\theta \pm I_aX_s)^2]}$

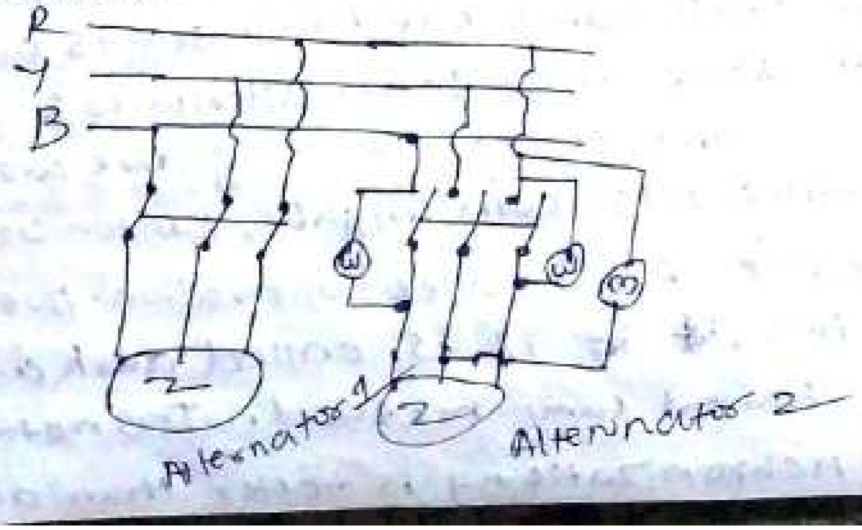
Where E_g = no-load induced emf / phase,
V_t = rated terminal voltage/phase

Synchronous impedance method is easy but it gives approximate results. This method gives the value of regulation which is greater (poor) than the actual value and hence this method is called pessimistic method.

1.9

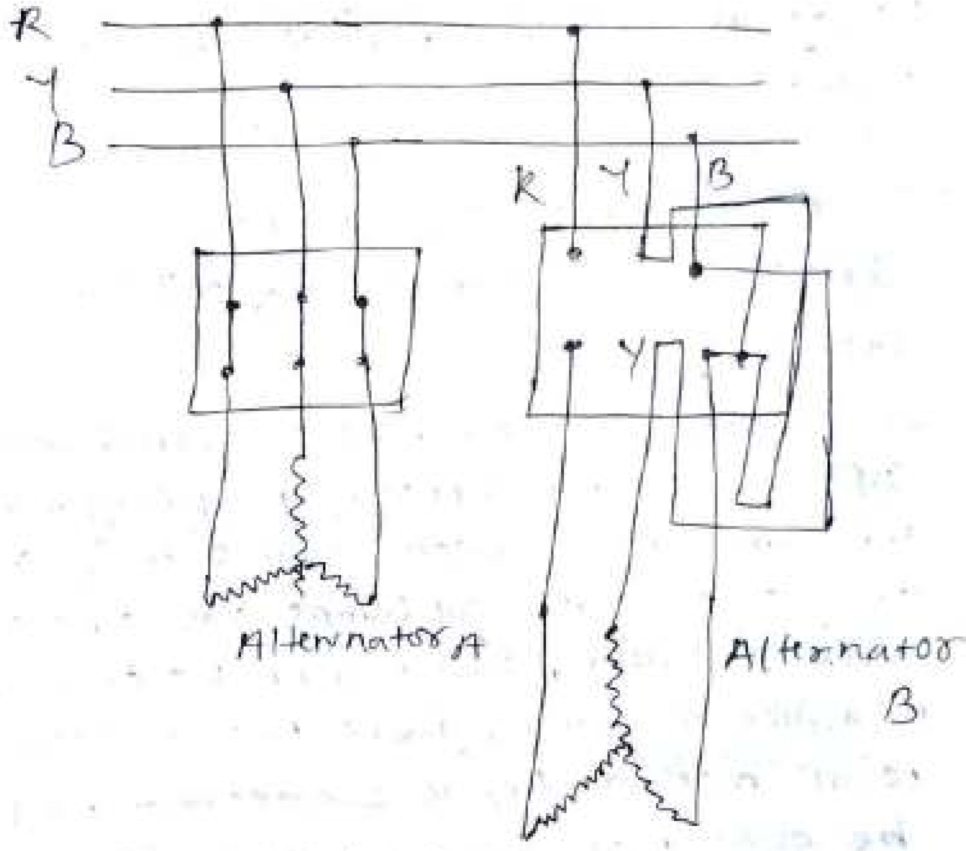
Parallel operation of alternator using synchro-scope and dark & bright lamp method.

(1) Dark Lamp method:- In this method after checking voltage, frequency, polarity the lamps are connected with same phase of two alternators. When all lamps are completely in dark position, switch ON the circuit for parallel operation, due to this it is called dark lamp method. Before connecting the lamps be sure that rated voltage of lamps be and alternator should be the same, such as for 440 volt alternator connect two lamps in series.



2. Bright Lamp Method:-

In this method after checking voltage, polarity, the lamps are connected across two different phases of an alternator and when all lamps are completely bright, switch ON the circuit for parallel operation. Due to this it is called bright lamp method.



(3) Dark and Bright Lamp Method:-

It is combination of above two methods i.e, two-lamp sets are connected across two phases and one lamp set is connected with same phase of an alternators. When one lamp set is completely dark and two lamps sets fully bright, switch ON the circuit for parallel operation. Due to this, ~~it is~~ it is called dark and bright lamp method. This method of synchronization is better than above two methods as it indicated both dark and bright position.

Note: The rated voltage of lamps is 220/230V, so before using, lamps should be connected in series for proper voltage or use transformer for voltage control.

(3) Synchnoscope Method:-

Synchnonising by lamp methods depends upon darkness and brightness of lamps so it may give ennon. For this reason, synchronising by using instrument called synchnoscope, is mostly prefeored. The synchnoscope is connected across two phases of two terminals of two alternators as shown in the figure through P.T. when needle of synchroscope indicates zero, switch ON the circuit. Synchroscope should be switched off from the circuit after synchronizing.

Synchnoscope: The instrument used for synchronizing is called synchroscope. It consists of rotor and stator, having two winding with four terminals and connected with two different terminals of alternator of same phases through P.T. like volt meter.

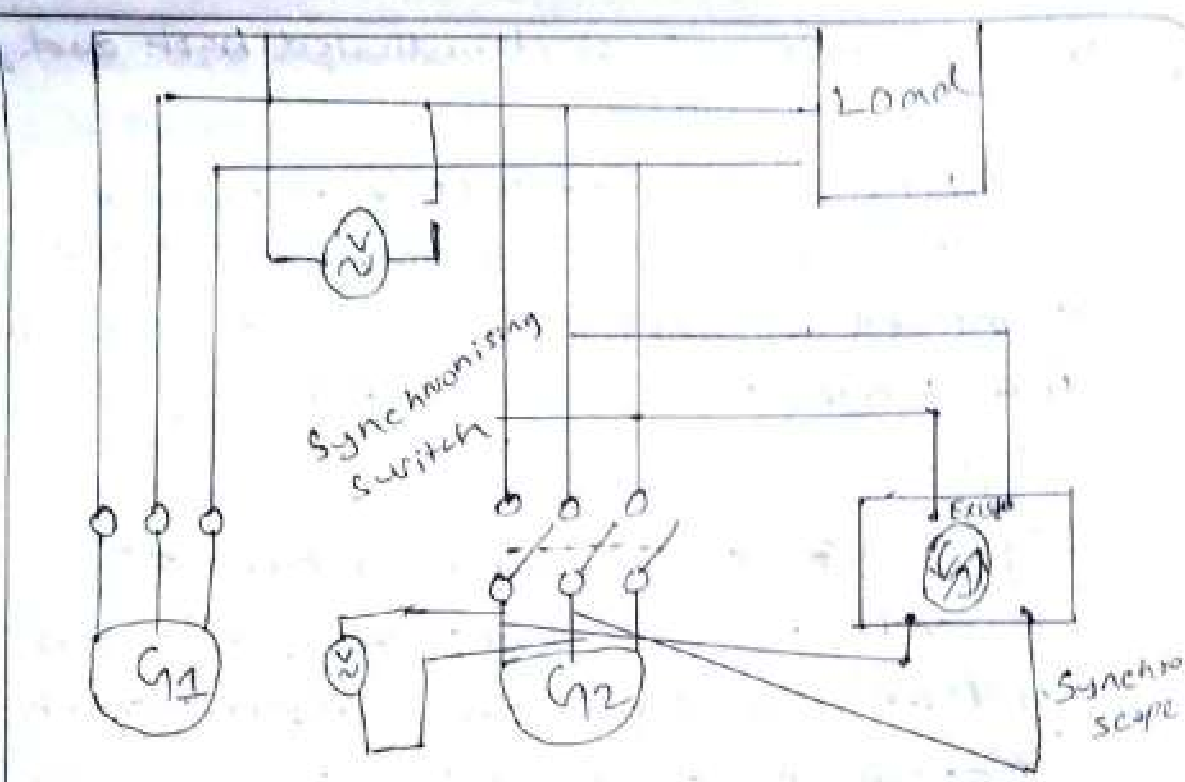


fig. (Synchnoscope Method)

1.10

Explain distribution of Load by parallel connected alternators.

A: Interconnection of the electric power systems is essential from the economical point of view and also for reliable and parallel operation. Interconnection of AC power systems requires synchronous generators to operate in parallel with each other. In generating stations, two or more generators are connected in parallel. The alternators are located at different locations forming a grid connected system.

- Reasons of parallel operation
- Necessary conditions for parallel operation of the Alternator.

they are connected parallel by means of transformer and transmission lines. Under normal operating conditions all the generators and synchronous motors in an inter connected system operate in synchronism with each other. A machine has to be adjusted for optimum operating efficiency and greater reliability if the generators are connected in parallel. As the load increases beyond the generated capacity of the connected units, additional generators are parallel to carry the load. Similarly, if the load demand decreases, one or more machines are taken off the line as per the requirement. It allows the units to operate at a higher efficiency.

2 SYNCHRONOUS MOTOR:

2.1 Constructional feature of Synchronous Motor.

A: The motor which runs at synchronous speed is known as the synchronous motor. The synchronous speed is the constant speed at which the motor generates the electromotive force. The synchronous motor is used for converting the electrical energy into mechanical energy.

Construction of synchronous motor

The stator and the rotor are the two main parts of the synchronorious motor. The stator becomes stationary, and it carries the armature winding of the motor. The armature winding is the main winding because of which the EMF induces in the motor. The rotator carry the field windings. The rotator carry the field windings. The main field flux induces in the rotor. The rotor is designed in two ways, i.e., the salient pole rotor and the non-salient pole rotor. The synchronous motor uses the salient pole rotor. The word salient means the poles of the rotor projected towards the armature windings. The rotor of the synchronous motor is made with the laminations of the steel. The laminations reduce the eddy current loss that occurs on the winding of the transformer. The salient pole rotor is mostly used for designing the medium and low-speed motor.

for obtaining the high-speed cylindrical rotor is used in the motor.

Main features of Synchronous Motor:-

- The speed of the synchronous motor is independent of the load, i.e, the variation of the load does not affect the speed of the motor.

- The synchronous motor is not self-starting. The prime mover is used for rotating the motor at its synchronous speed.
- The synchronous motor operates both for leading and lagging power factor.

2.2 Principles of operation, concept of load angle

A:- Principles of operation synchronous Motor:-

Synchronous motors are a doubly excited machine, i.e., two electrical inputs are provided to it. Its stator winding which consists of a we provide three-phase supply to three phase stator winding, and DC to the rotor winding. The 3 phase stator winding carrying 3 phase currents produces 3 phase rotating magnetic flux. The rotor carrying DC supply also produces a constant flux.

Considering the 50Hz power frequency from the above relation we can see that the 3 phase rotating flux rotates about 3000 revolutions in 1 min or 50 revolutions in 1 sec. At a particular instant rotor and stator poles might be of the same ~~sat~~ polarity (N-N or S-S) causing a repulsive force on the rotor and the very next instant it will be N-S causing attractive force. But due to the inertia of the rotor, it is unable to rotate in any direction due to that attractive or repulsive forces, and the rotor remains in standstill condition. Hence a synchronous motor is not self starting.

Here we use some mechanical means which initially rotates the rotor in the same direction as the magnetic field to speed very close to synchronous speed. On achieving synchronous speed, magnetic locking ~~circuit~~ occurs, and the synchronous motor continues to rotate even after the removal of external mechanical means.

Concept of load angle:

Load angle is nothing but an angle different between stator axis and rotor pole axis of the synchronous motor. For ideal motor, the load angle is zero since the rotor poles aligned with stator poles, but in practice, this is not possible. The motor has both mechanical and electrical losses, hence load angle is always present in the synchronous motor. Load angle can be calculated by using the below-mentioned formula,

$$T_{ind} = \frac{3 V_\phi E_A \sin\delta}{\omega_M X_S}$$

Refer above, the induced torque is directly proportional to the load angle δ.

It is denoted by δ

It is also called a power angle, torque angle and coupling angle.

Q) Derive torque, power developed.

A:- The developed Torque or induced Torque Equation in a machine is defined as the Torque generated by the electric to mechanical power conversion. The torque is also known as Electromagnetic Torque. This developed torque in the motor differs from the actual torque available at the terminals of the motor, which is almost equal to the friction and ~~windage~~ windage torques on the machine.

The developed torque equation is given as

$$T_d = \frac{\text{Mechanical power developed}}{\text{Mechanical angular velocity of the rotor}} = \frac{P_{md}}{\omega_r} \quad \text{—} (1)$$

Since,

$$P_{md} = (1-s)P_g \text{ and } \omega_r = (1-s)\omega_s$$

$$T_d = \frac{(1-s)P_g}{(1-s)\omega_s} = \frac{P_g}{\omega_s} \quad \text{—} (2)$$

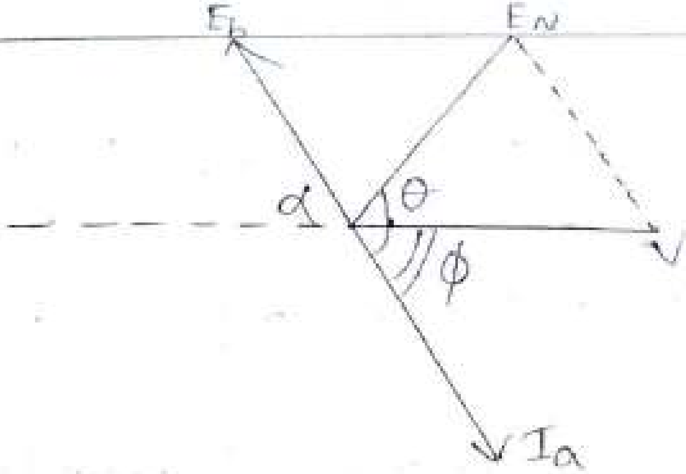
The above equation expresses the developed torque directly in terms of the air gap power P_g and the synchronous speed ω_s. Since ω_s is constant and independent of the load conditions. If the value of the P_g is known then, the developed torque can be found directly. The air gap power P_g is also called as the Torque in synchronous watts.

2.4 Effect of varying load with constant excitation

If the load motor is landed then the back emf (E_b) places back by a certain value called the "load angle" or coupling angle.

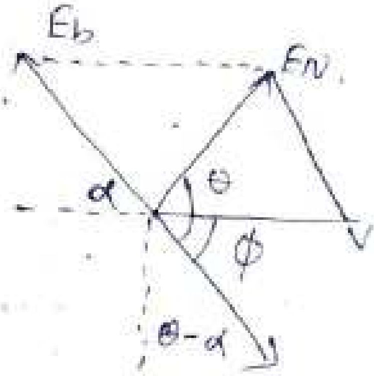
The net voltage current the armature

$$E_R = \vec{V} - E_b$$



If the motor is further loaded, its rotor further back by a greater value of load angle 'α' the resultant voltage 'E_R' is increased and the motor draws an increased armature current but at a devised power factor.

$$I_a = \frac{\vec{V} - \vec{E_b}}{Z_s} = \frac{\vec{V} - \vec{E_b}}{R_a + jX_s}$$



$$\Rightarrow V = \dot{E_b} + \dot{I_a} Z_s$$
$$= E_b + I_a(R + jX_s)$$

Where Z_s = Synchronous impedance/phase

R_a = Armature resistance/phase

X_s = Synchronous reactance/phase

The angle 'θ' is known as "initial angle" by which 'I_a' lags behind E_R.

$$\theta = \tan^{-1}\frac{X_s}{R_a}$$

φ is the phase angle by which 'I_a' lags behind 'V'.

If R_a is negligible, then $\theta = 90°$

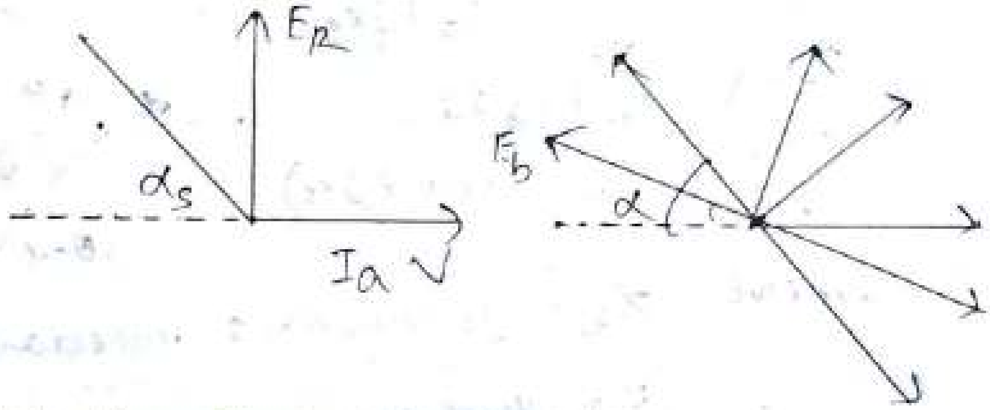
Motor I/P per phase $= V I_a \cos\phi$

Total I/P to the motor $= \sqrt{3} V_L I_L \cos\phi$

Mechanical power developed in the rotor per phase $P_m = E_b I_a \cos(\alpha - \phi)$

2.5 Effect of varying excitation with constant load.

Suppose a synchronous motor is operating with normal excitation ($E_b = V$) at unity power factor with a given ~~below~~ load. The armature is drawing a power of VI_a per phase which is enough to meet the mechanical load on the motor. The effect of changing excitation with load remains constant is discussed below.



(a) Excitation Decreases:

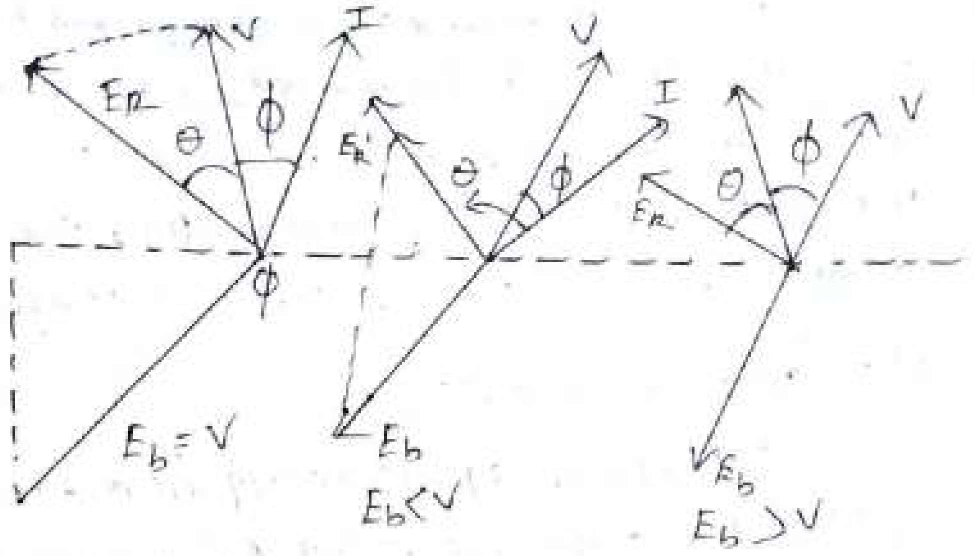
Suppose due to decrease in excitation, back emf is reduced to E_{b1}, at the same load angle 'α'. The resultant voltage E_{R1} causes a lagging armature current I_{a1}, to set flow. Even though I_{a1} is larger than I_{a2} in magnitude. It is capable of producing necessary VI_a for carrying the constant load because $I_{a1}\cos\phi$ component is less than I_a so that $VI_a\cos\phi < VI_a$

Hence, it becomes necessary for load angle to increase from α_1 to α_2, it increase back emf from E_{b1} to E_{b2} which increases resultant voltage from E_{R1} to E_{R2} consequently, the armature current increases to I_{a2} whose in phase component.

(b) Excitation Increased:

The effect of increasing field exc excitation where increased E_n is shown at the original load angle α_1. The resultant voltage causes loading current I_{a1} whose in phase component is larger than I_a. Hence armature develops more power than the load in the motor. Accordingly, load angle decreases from α_1 to α_2 which develops resultant voltage from E_{R1} to E_{R2}. Consequently armature current decreases from I_{a1} to I_{a2} whose in phase component, $I_{a2}\cos\phi_2 = I_a$. In the case armature current develops power sufficient to carry the constant load on the motor. Hence, it is seen that variation in the excitation of the synchronous motor running with given load. produces variation in its load angle only

2.b) Explain effect of excitation on Armature Current and power factor.



Consider a synchronous motor in which mechanical load is constant.

Fig (a) shows the case for 100% excitation i.e. when $E_b = V$.

The armature current I lags behind 'V' by an small angle ϕ with E_R is fixed by stator constants i.e. $\tan\theta = \frac{X_s}{R_a}$.

In fig (b), the excitation is less than 100%. $E_b < V$. Here E_R is advanced in clock wise direction & also armature current. The magnitude of 'I' is increased but its power factor is decreased. The component of $I\cos\phi$ remains the same as before but wattless component $I\sin\phi$ is increased.

fig(c) represents the conduction for over excited motor i.e. $E_b > V$. Here the resultant voltage E_R is pulled in anticlockwise direction & also 'I'. Now the motor is drawing a leading current.

for same voltage of excitation, 'I' will be in phase with 'V' i.e. p.f is unity AC that the current drawn by the motor would be maximum.

2.7 Hunting in synchronous Motor.

When synchronous motor is used for driving a varying load. Then a condition known as hunting is produced. Hunting may also be caused if supply frequency is pulsating.

When a synchronous motor is loaded its rotor falls back in phase by the coupling angle 'α'. As the load is progressively increased, this angle also increases so as to produced motor torque to meet with the increased load. If now there is a sudden decreases in the motor load, the rotor is pull back to new value of 'α'. In this way rotor starts oscillating about its new position of equilibrium. corresponding to the new load. If the time period of those oscillations equals to the natural time period of the machine, then mechanical resonance is setup. The amplitude of these oscillation may become so large to throw the machine out of synchronous. To stop the oscillation's damper or damping grids are employed. These damper consists of (short-circuited copper ~~wire~~ were in the faces of the field poles of the motor. The Oscillatory motion of the rotor sets up eddy currents in the dampers which flows in such a way as to suppress the oscillations.

2.8

Describe method of starting of Synchronous motor.

(1) The fed winding is shorted. that means D.C. excitation is not given to the field winding.

(2) Reduced voltage with the help of auto-trans transformer is applied across the stator terminal.

(3) When the motors at far nearly 9% of the Synchronous speed, a d.c. excitation as applied to the field winding. At that time the motor is synchronized.

(4) Full supply voltage is applied across stator terminals by cutting out the auto transformer.

(5) The motor then can be operated at any power factor by the d.c. excitation.

(6) At light load or heavy load condition the rotor advances and backs to the stator flux respectively with an angle α. It is called the load angle.

29. State application of synchronous motor.

(1) Power factor correction:
Over excited synchronous motor having leading p.f. are widely use for improving p.f. of power systems.

(2) Constant speed application:
High speed synchronous motor (above 600rpm) are used for centrifugal pumps, belt driven reciprocating, compressor, blowers, line shafts, rubber & paper mills etc.

Low speed synchronous motors (below 600rpm) are used for drives such as centrifugal and screw type pumps, balls and tube mills, vaccum pumps, choppers and metal rolling mills etc.

(3) Voltage regulation:-
The voltage at the end of a long transmission line varies greatly when large inductive loads are present. By installing a synchronous motor with a field regulator, this voltage rise can be controlled.

By varying the excitation, the power factor (P.F) can be made lagging or leading which helps to maintain the line voltage at its normal value.

5 COMMUTATOR MOTORS

5.1 Construction, working principle, running characteristic and application of single phase series motor.

A:- This motor is a kind of motor which construction is done to work on both DC & AC single phase supply. The working principle is the same as the dc series motor and has advantages of the dc series motor like high torque.

The DC motor which runs on alternating supply called an AC series motor. However, some changes must be made in the DC series motor that is to operate satisfactorily on alternating supply.

Construction of single phase series motor.

The construction of the single phase series motor is very identical to the dc series motor except for some changes as given below:

- The magnetic circuit must be laminated.
- field circuit must be designed for much lower reactance than dc motor field in order to reduce the reactance voltage drop of field and improve power factor.

- Distributed compensating winding is required to minimize the reactance of armature winding.
- The compensating winding may be connected in series with the field and armature winding called conductively compensated and conductively compensation required armature which is designed to operate on ac and dc voltage.
- If compensation winding short-circuited to itself and received excitation voltage by transformer action called inductively coupled.
- Working principle of Single phase series motor:

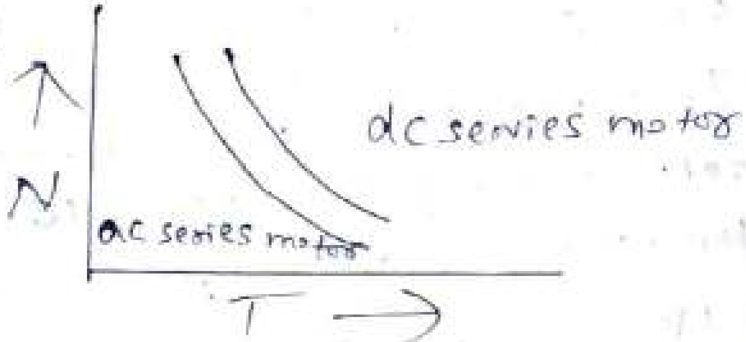
The working principle is the same as the dc series motor. When the ac series motor connected to the AC supply the alternating current start flowing through the field and armature winding. The field winding produces an alternating flux ϕ that reacts with the current flowing in armature winding to produce a torque. Since both armature and field current reverse simultaneously, the torque always produced in the same direction. Due to its high starting torque and high-speed, it finds more application.

Application

- High-speed vacuum cleaner
- sewing machines
- Used in drills and power tools
- Electric shavers.

Running characteristics:

The torque speed characteristic of an ac series motor is shown in the below diagram



we can see from torque-speed characteristics that the series motor develops high starting torque at low speed. It is because the increase in torque increases field and armature current the result in that flux strengthened and hence speed drops. Torque is directly proportional to the square root of the current $\tau \propto I^2$. Due to the desirable Torque speed characteristics, the series motor is exclusively used in traction applications. DC series motor satisfy all requirements for this kind of work and services but the transmission of ac power is more economical than dc. This has lead to the development of the AC series motor.

5.7 Construction, working principle and application of universal motors.

• Construction of universal motors:

A motor that can be operated on both AC & DC supply at the rated voltage is called a universal motor. Basically, the universal motor is an AC series motor. It is just an improved form of a DC series motor. The core size of a universal motor is more than the core size of a DC series motor of the same rating.

The universal motor is constructed in the same way as a series wound DC motor. However, it is designed to operate with either AC to DC applied. The series-wound motor is the only type of DC motor that will operate with AC supplied.

Stator:-

It is the stationary part of the motor. It consists of a magnetic frame (or yoke), pole core, and pole shoe and field or exciting winding. The magnetic frame, pole core, and pole shoe are made of silicon steel stampings. These stampings are insulated from each other by a varnish layer. The hysteresis losses are very small in silicon steel, and eddy current losses are reduced due to stampings.

The field winding made of enameled copper is wound around the poles to produces the required flux.

Rotor:-

It is the rotating part of the motor. It consists of shaft, armature, armature winding, and commutator. A shaft is a part of the rotor which transfers mechanical power or energy to the load. It is made up of mild steel. The armature is made up of stampings of silicon steel material since it carries the magnetic field. It is attached to the shaft. The universal motor's rotary armature is made of straight or skewed slots on which the commutator and brushes rest.

Working principle of universal Motor:

When a current-carrying conductor is placed in the magnetic field, a force is exerted on it and torque develops. In other words, when the rotor field produced by the rotor current carrying conductors, tries to come in line with the main field, torque develops, and the rotor rotates. In universal motor both the armature winding and field winding is connected in series. When a DC voltage is applied to the motor, the same current flows through the stator and rotor coils. The magnetic fields around the winding interact and develop torque to turn the rotor. The direction it turns is determined by the direction the current flows through both sets of windings. When an AC voltage is applied, the direction of the current will alternate. Since the current reverses in both the rotor and stator at the same time, the magnetic fields around both windings also change simultaneously. The result is that the interaction of the two fields causes the direction of the developed torque to remain the same. Therefore, the rotor turns one way, regardless of which direction the applied current flows.

Applications of Universal Motor

Universal motors are used in many portable applications that require high horsepower for the size. A few examples are vacuum cleaners, polishers, hedge trimmers, circular saws, and mixers.

- These motors are applicable where the control of speed & the motor speed high values are required.
- They are used in handy drill machines, hair dryers, table fans, and grinders.

- This motor is used in polishers, kitchen appliances, and blowers.
- The higher rating motors are applicable in blenders and portable drills.

5.3 Working principle of Repulsion start Motor, Repulsion start induction run motor, Repulsion induction motor.

A:- A repulsion start motor is a single-phase electric motor that operates by providing input AC. The main application of repulsion motor is electric trains. It starts as a repulsion motor and runs as an induction motor, where the starting torque should be high for a repulsion motor and very good running characteristics for an induction motor. In repulsion motor direction of rotation of the motor is the same as that of brush shift.

Working principle of repulsion start motor:

The basic principle behind the working of repulsion motor is that "similar poles repel each other". This means two North poles will repel each other. Similarly, two south poles will repel each other. When the repulsion motor winding is supplied with single phase AC, it produces a magnetic flux along the direct axis. Due to this EMF, a rotor current is produced.

This rotor current in turn produces a magnetic flux that is directed along the brush axis due to commutator assembly. Due to the interaction of stator and rotor produced fluxes, an electro magnetic torque is produced.

Repulsion induction motor :-

According to the characteristics of the repulsion induction motor, it has a single phase stator winding, as a repulsion - start induction motor has, but it has two separate and independent windings on the rotor in common slots. The inner winding is a squirrel cage winding with the outer winding is a repulsion or commutator winding similar to a dc armature winding.

When the motor starts, the squirrel cage winding, due to its high reactance, does not affect and the motor starts as a repulsion motor. such a motor finds a use for applications requiring a high starting torque with essentially a constant running speed. the common ratings are 1/6 to 4 KW. Common applications are house hold refrigerators, garage airpumps, gasoline pumps, compressors, etc.

Repulsion start induction run motor:

The repulsion - start induction run motor, starts as a ~~reputation~~ repulsion motor and runs as an.

induction motor. The advantage of this starting scheme provided greater starting torque than a split phase motor could provide. The repulsion start motor rotor is wound similar to a direct current armature. The stator is energized creating an alternating magnetic field that runs through the rotor and induces a current in the rotor windings. The commutator brushes are short - circuited, and the currents induced in the armature coils set up poles on the armature surface. The brushes are set so that the poles are slightly out of ~~the~~ line with the stator poles, and the mutual repulsion between like poles on the stator and armature produces the torque.

→ Repulsion - start induction run motors pose a serious problem of maintenance of brushes, commutator and the centrifugal device.