CHAPTER 2

Single Phase Motor

2.1 GENERAL

The number of machines operating from single-phase supplies is greater than all other types taken in total. For the most part, however, they are only used in the smaller sizes, less than 5kW and mostly in the fractional H.P. range. They operate at lower power-factors and are relatively inefficient when compared with poly phase motors.

Single phase motors perform a great variety of useful services in the home, the office, the factory, in business establishments, on the farm, many other places where electricity is available. Since the requirements of the numerous applications differ so widely, the motor-manufacturing industry has developed several types of such machines, each type having operating characteristics that meet definite demands. For example, one type operates satisfactorily on direct current or any frequency up to 60 cycles; another rotates at absolutely constant speed, regardless of load: another develops considerable starting torque and still another, although not capable of developing much starting torque, is nevertheless extremely cheap to make and very rugged.

2.2 TYPES OF SINGLE PHASE MOTOR

The single-phase motor may be of the following types:

1. **Single phase Induction Motor :**

A . Split-phase motors

(i) Resistance-start motor (ii) Capacitor-start motor

(iii) Permanent-split (single-value) capacitor motor

(iv) Two-value capacitor motor.

B . Shaded-pole induction motor.

C . Reluctance-start induction motor,

D . Repulsion-start induction motor,

2. **Commutator-Type, Single-Phase Motors:**

A . Repulsion motor. B . Repulsion-induction motor.

C . A.C series motor. D . Universal motor.

3. **Single-phase Synchronous Motors:**

A . Reluctance motor. B . Hysteresis motor.

C . Sub-synchronous motor.

2.3 SINGLE-PHASE INDUCTION MOTORS

Single-phase induction motors are in very wide use in industry, especially in fractional horse-power field. They are extensively used for electric drive for low power constant speed apparatus such as machines tools, domestic apparatus, and agricultural machinery in circumstances where a three-phase supply is not readily available.

The main disadvantages of single-phase induction motors are:

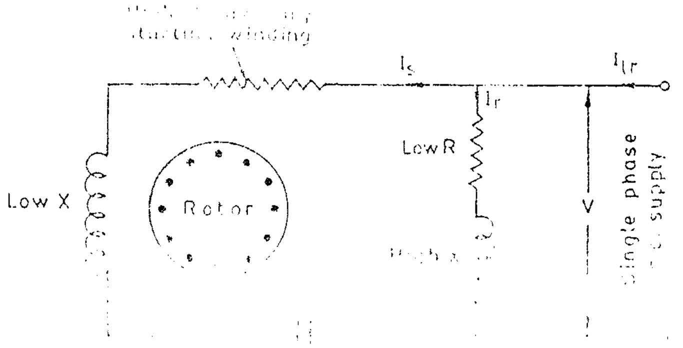
1. Their output is only 50% of the three-phase motors, for a given frame size and temperature rise.
2. They have lower power factor.
3. Lower efficiency .
4. These motors do not have inherent starting torque.
5. More expensive than three-phase motors of the same output.

2.3.1 Split-phase Motors

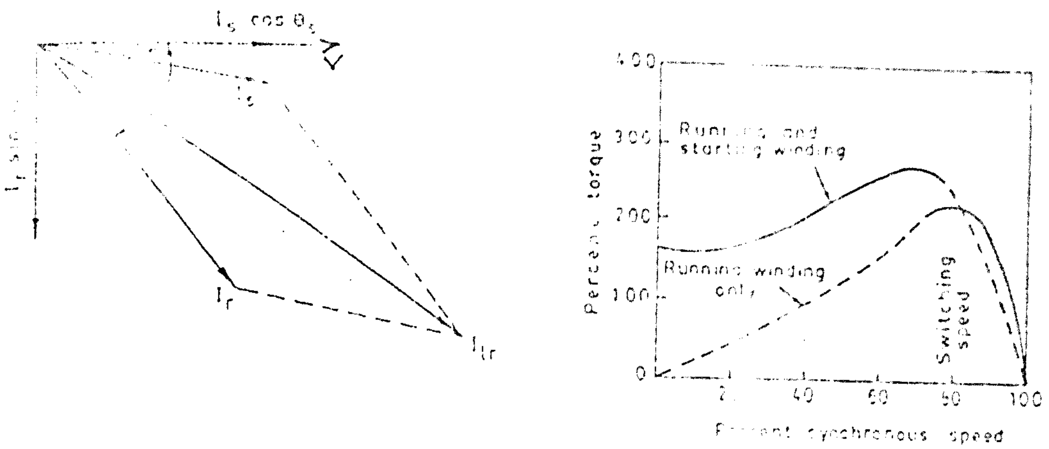
Since the single-phase induction is not self-starting, means must be provided to create an initial torque. But the initial torque is only possible if a rotating flux is created in the stator. It is known that a rotating flux is produced when there is a difference of 90 between the currents of two stationary coils. Or if the stator possesses two fluxes having a large phase difference, the result is a rotating flux.

2.4 SPLIT-PHASE RESISTANCE-START INDUCTION MOTOR

In a split-phase induction motor the stator is provide with two parallel windings displaced 90° electrical degrees in space and somewhat less than 90° in time . Fig 2.1 (a) shows the winding diagram of the two windings of a split-phase induction motor.The starting winding has fewer turns and is wound of smaller diameter copper than the running winding. The starting winding, has a high resistance and low reactance.The running or main, winding (heavier wire of more turns) has low resistance and high resistance.



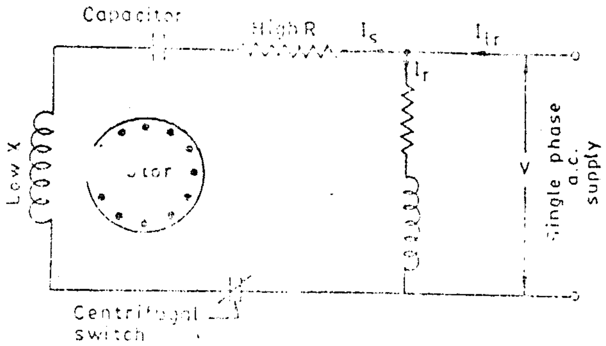
(a)Connection diagram



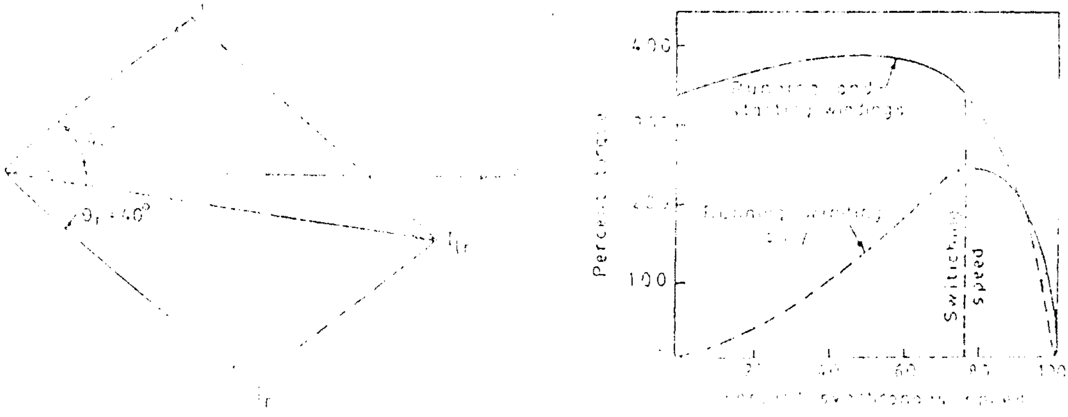
(b)Phase relations (c) Typical torque speed characteristic

Fig.2.1 Split phase resistance-start induction motor

2.5 SLIP-PHASE CAPACITOR-START INDUCTION MOTOR



(a)Circuit diagram



(b) Vector diagram (c) Typical torque-speed characteristic

Fig.2.2Capictor- start induction motor.

Another method of splitting the single-phase supply into two phases to be applied to the stator windings is placing a capacitor in series with the starting auxiliary winding. In this manner, the current in the starting winding may be made to lead the line voltage. Since the running winding current lags the line voltage, the phase displacement between the two currents and be made to approximate 90° on starting. The current of capacitor-start motor is shown in Fig.2.2 (a), while the vector diagram of the current and voltage is shown in Fig.2.2(b).The value of the angles shown are fairly representative, and are rounded off for convenience. One of the factors upon which the starting torque depends is the sine of the angle between the currents in the two windings. The value of series capacitor may therefore be reduced, while maintaining a phase-shift angle of about 90°.

The increase in phase angle between starting and running winding current is not the only difference between the split-phase and capacitor start-motors. . The split phase motor must keep the number of starting-winding turns low, so that the current may be nearly in phase with the line voltage. This, however, is unnecessary in a capacitor-start motor, since the capacitor can overcome the inductance of the winding while still providing the proper phase shift. There are thus more auxiliary starting turns in the capacitor-start motor than in the comparable split-phase motor. This provides a greater number of ampere-turns, hence a larger rotating flux, and therefore a further increase in the starting torque.

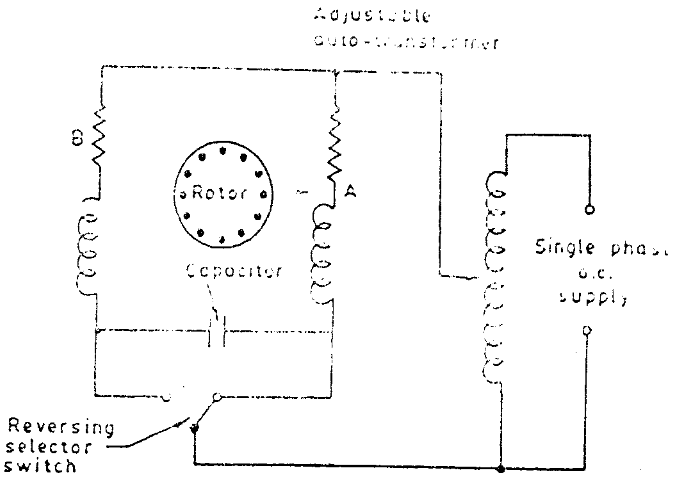
Also it is seen that for the same magnitudes of field currents, the current I_{lr} is less in capacitor-start motor, because of the greater angle between the two field currents. In addition, the starting power factor is also better. For a given line current, the starting torque thus much higher for a capacitor-start motor than for a slip-phase induction motor. The starting torque of capacitor start motor is form 3to 4.5 times the full-load torque, while that of split-phase resistance start induction motor rarely exceeds twice the full-load torque.

2.6. PERMANENT-SPLIT CAPACITOR INDUCTION MOTOR

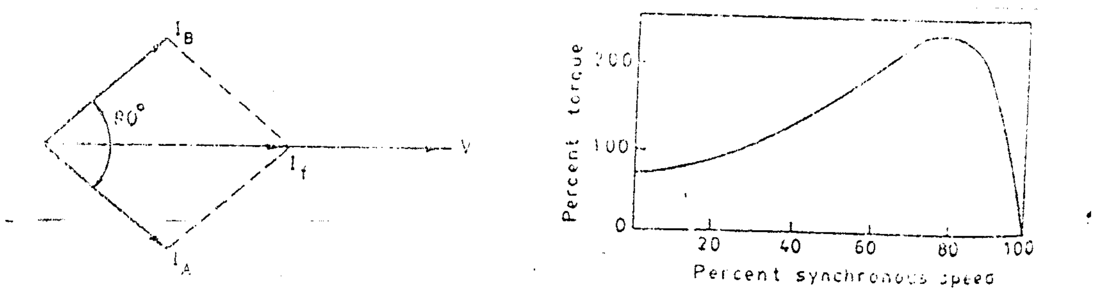
A permanent-split capacitor motor (also call single-value capacitor motor) is a single-phase induction motor which has the same capacitor in series with the starting (or auxiliary) winding for both starting and running. Because it runs continuously as a permanent split-phase motor, no centrifugal switch is required.

The motor starts and runs by virtue of the quadrature phase-splitting produced by the two identical windings. As a result, it does not possess the high running torque produced by either the resistance-start or the capacitor-start motor.

Further more, the capacitor used is designed for continuous duty and is of an oil-filled type. The value of the capacitor is based on its optimum running rather than its starting characteristics. The result is that this motor has a very poor starting torque, about 50 to 100 per cent rated torque.Fig.2.3 shows the connection diagram and phase relations of a permanent split-phase motor. Because of the fairly uniform rotating magnetic field created by equal windings whose currents are displaced by almost 90, the torque is fairly uniform and the motor does not exhibit the characteristic pulsating hum developed by most single-phase motors when loaded.



(a)Connection diagram



(b)Vector diagram or phase relation

(c) Typical torque-speed characteristic

Fig.2.3 Permanent split-phase motor

This motor possesses the following merits:

(i) Higher power factor at full-load
(ii) Lower full-load line current
(iii) Higher full-load efficiency
(iv) Increased pull-out torque.

2.7. TWO-VALUE CAPACITOR INDUCTION MOTOR

Refer Figs.2.4. The two value capacitor combines the quite operation and limited speed control advantages of a running permanent-split capacitor with high starting torque of the capacitor-start motor. Two capacitors (Fig.2.4) are employed during the starting period. One of these, an electrolytic starting capacitor, similar to that used for the intermittent duty of the capacitor-start split-phase motor, is of fairly high capacity (about 10 to 15 times the value of the running capacitor) and is cut out of the circuit by a centrifugal switch when slip reaches about 25 per cent.

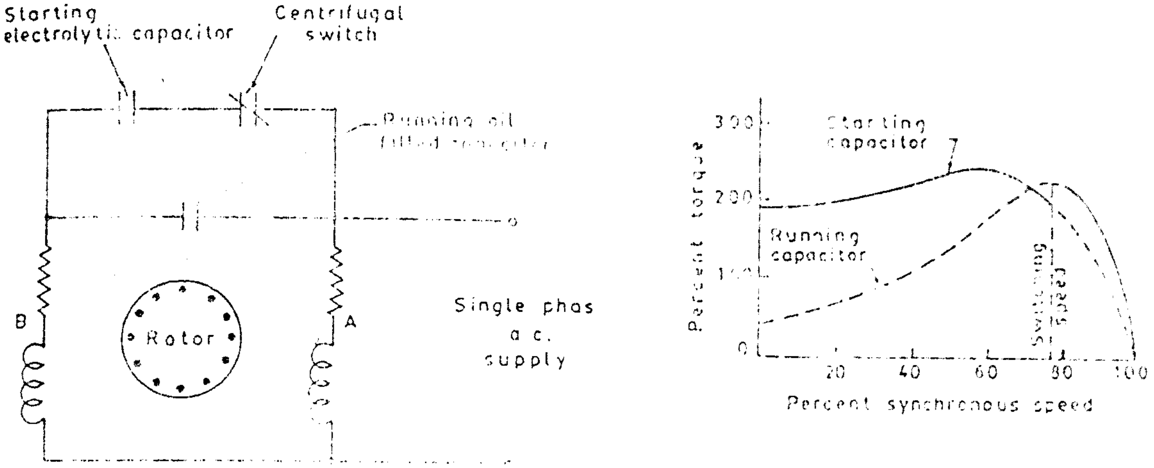


Fig.2.4

(a)Connection diagram for two-value capacitor motor (b)Typical torque-speed characteristic

The major advantage of the two value capacitor motor is its starting torque, coupled with quiet operation and good running torque.

2.8. SHADED-POLE INDUCTION MOTOR

A shaded-pole motor is one of the simplest and cheapest of manufactured motors. It is essentially an induction machine, since its squirrel-cage rotor receives power in much the same way as does the rotor of the poly phase induction motor. The field of the shaded-pole motor is not constant in magnitude but merely shifts from one side of the pole to the other. Because the shaded-pole motor does not create a true revolving field, the torque is not uniform but varies from instant to instant.Shaded pole motors are built up to about 40W.

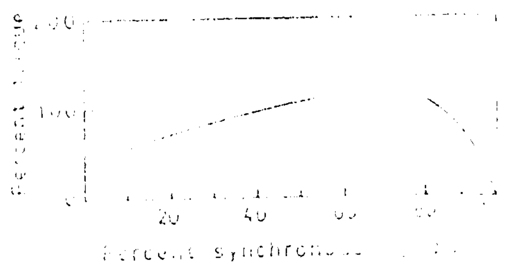


Fig.2.5.Typical torque- speed characteristic of shaded pole motor

Merits:

(i) Rugged construction (ii) Small in size (iii) Requires little maintenance

(v)Its stalling locked-rotor current is only slightly higher than its normal rated current, so that it can remain stalled for short periods without harm.

Demerits:

(i) Very low starting torque (ii) Low efficiency (iii) Low power factor

Uses. Its low starting torque limits its application to phono-motors or turntables, motion picture projectors, small fans and blower, bending machines, rotating store-window display tables, and relatively light loads.

2.9. RELUCTANCE-START INDUCTION MOTOR

Its characteristics are similar to that of shaded pole motor. In this motor too the magnetic field shifts across the pole, but the effect is obtained by the non-uniform air gap of salient poles. Where there is a greater air gap, the flux in that portion is more nearly in phase with the current. There is a greater lag between flux and current where there is a lower reluctance or where the air gap is smaller. Since both fluxes are produced by the same current, the flux across the lager air gap leads the flux across the smaller one. The two fluxes are obviously displaced in time, and so the magnetic field shifts across the poles from larger air gap to the shorter gap. Thus the direction of rotation is firmly fixed by the construction, and the motor cannot be reversed at all.

For most small power applications, the shaded pole preferred, and the reluctance-start motor has limited use, usually only where starting torque requirements are low.

2.10. SINGLE-PHASE COMMUTATOR MOTORS

The commutator motors are so called because the wound rotor of this kind of motor is equipped with a commutator and brushes. This group consist of the following two classes:

1. Those operating on ' repulsion principle' (repulsion motors) in which energy is inductively transferred from the single phase stator field winding to the rotor.
2. Those operating on the principle of the series motor in which the energy is conductively carried both to the rotor armature and its series-connected single phase stator field.

2.11. REPULSION MOTOR

A repulsion motor in its simplest form consists of a field comprising a distributed winding housed in slots, in a smooth-cored stator and an armature carrying a distributed winding connected to a commutator. The stator winding, which produces the main field, is connected to the main supply. The armature or rotor winding is not connected electrically to the main circuit, but the brushes, which are set at an angle to the direction of the main flux, are short-circuited as shown in Fig.2.6 The direction of rotating of a simple repulsion motor may be reversed by swinging the brushes into the position shown dotted.

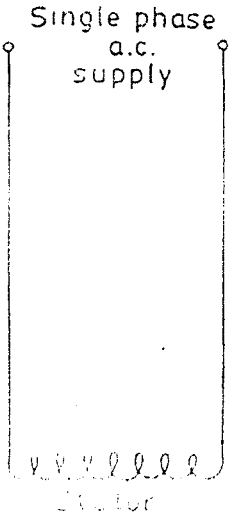


Fig.2.6.Repulsion motor

2.12. REPULSION-START INDUCTION MOTOR

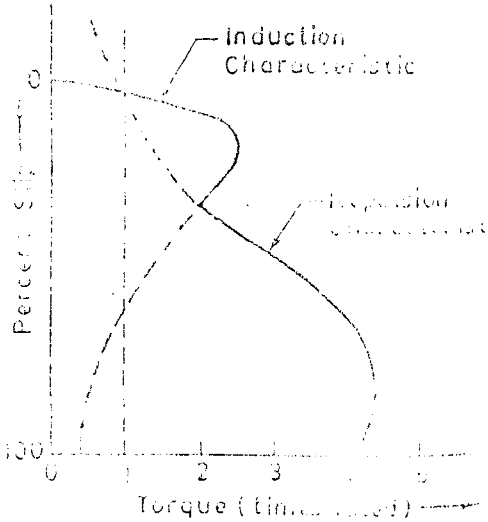


Fig.2.7.Speed- torque characteristic of repulsion-start induction motor

The repulsion-start induction motor starts as a repulsion motor with its brushes set to The maximum torque position. When the load has been accelerated to about 75 per cent of synchronous speed, a built in centrifugal device places a shorting ring in contact with the commutating bars, converting the armature to squirrel-cage rotor. This type of motor was used almost exclusively where high starting in nearly all cases by the capacitor motors of the following reasons:

(i) Requires more maintenance.
(ii) More expensive.
(iii) Makes quite a bit of noise on starting.
(iv) Causes radio interference when starting.
(v) Cannot be reversed easily.

Repulsion-start motors, despite these disadvantages, are still used in integral-horsepower sizes because of the following reasons:

(i) High starting torque.
(ii) Low starting current.
(iii) Ability to accelerate a heavy load more rapidly than high-capacitance dual-capacitor motors.

2.13. REPULSION-INDUCTION MOTOR

A single-phase repulsion-induction motor combines the constant-speed characteristics of the single-phase induction motor with the good starting characteristics of the repulsion motor.

The stator of this machine has a simple single-phase winding like that of single-phase induction motor. The rotor, however, is built up to laminations, each of which has two concentric sets of slots. These slots contain two distinct windings; in the outer slots is wound the commutator winding similar to that of a D.C. armature, while in the inner slots is a cost aluminium squirrel-cage winding which clamps the laminations.

The repulsion-induction motor has the following merits:

(i) High starting torque. (ii) Fairly good speed regulation.
(iii) Major virtue is the ability to continue to develop torque under sudden, heavy applied loads without breaking down.

Such motors are suitable for all simple-phase power applications which require a high starting torque and constant speed when running; they also operate at a very high power factor. They are particularly well adapted to drive machine tools, lifts,hoists, mixing machines, centrifugal pumps, fans and blowers.

2.14 A.C. SERIES MOTOR

The series motor due to its desirable speed-torque characteristics is almost exclusively used in railway service. While the D.C. motor is entirely satisfactory for this class of work service and is generally used on street railway cars and trolley coaches, the fact that it is more convenient and more economical to transmit power and to transform voltages in A.C, systems than with direct currents has lead to the development of the A.C. series motor for use on some of the important steam-road electrifications. The working principle of an A.C. series motor is the same as that of the D.C. series motor. The armature and field are wound and interconnected in the same manner as the D.C. series motor.

2.15. UNIVESAL MOTOR

Fractional-horsepower series motors that are adapted for use on D.C or A.C. circuit of a given voltage are called universal motors.

The universal motor is designed for commercial frequencies from 60 cycles down to D.C.(zero frequency), and for voltage from 250V to 1.5V.A commercial universal motor may have a somewhat weaker series field and more armature conductors than a D.C. series motor of equivalent horsepower. It is manufactured in ratings up to ¾ H.P., particularly for vacuum cleaners and industrial sewing machines. In smaller sizes of ½ H.P. or less, it is used in electric hand drills.

Like all series motors, the no-load speed universal motor is universally high. Quite frequently, gears trains are built into the motor housing of some universal motors provide exceedingly high torque at low speeds.

When these motors are used in commercial appliances such as electric shavers, sewing machines, office machines and small hand hair dryers or vacuum cleaners, they are always directly loaded with little danger of motor runway.

Advantages of a universal motor:

1. High speed from above 3600 r.p.m. to around 25000 r.p.m.
2. High power output small physical sizes for use in portable tools.
3. High torque at low and intermediate speeds to carry a particularly severe load.
4. Variable speed by adjustable governor, by line voltage or especially by modern pulse techniques.

Disadvantages:

1. Increased service requirement due to use of brushes and commutators. The life of these parts is limited in severe service.

2. Relatively high noise level at high speeds.
3. Moderate to severe radio and television interference due to brush sparking.
4. Requirement for careful balancing to vibration.
5. Requirement for reduction gearing in most portable tools.

Universal motors are manufactured in two types:

1. Concentrated-pole, non-compensated types:
2. Distributed field compensated type (high H . P rating).

2.16. RELUCTANCE MOTOR

Single-phase salient-pole synchronous motors, are generally called reluctance motors.

2.17. HYSTERESIS MOTOR

Single-phase cylindrical (non-salient pole) synchronous-inductions or shaded pole motors are classed as hysteresis motors.

2.18. SUB-SYNCHRONOUS MOTOR

When the motor has a rotor that has an overall cylindrical outline and yet is toothed as a many-pole salient-pole rotor, it is a sub-synchronous motor.

CHAPTER 3

ALTERNATORS

3.1. INTRODUCTION

A machine for generating alternating currents is referred to as an alternator.

High-speed alternators driven by steam turbines differ considerably in their construction from the slow speed types and are distinguished by the use of the terms ' turbo-alternator' or ' turbo generator' whilst the slow engine-driven machines are often described as being of the ' flywheel-type'.

3.2. CLASSFICATION AND OPERATING PRINCIPLE

In D.C. generators, the field poles are stationary and the armature conductors rotate. The alternating voltage induced in armature conductors is converted to a direct voltage at the brushes by means of the commutator. A.C. generators commonly called alternators, have no commutators as they are required to supply electrical energy with an alternating voltage. Therefore, it is not necessary that armature be the rotating member.Alternators, according to the construction, are divided into the following two classifications:

1. Revolving-armature type.
2. Revolving-field type.

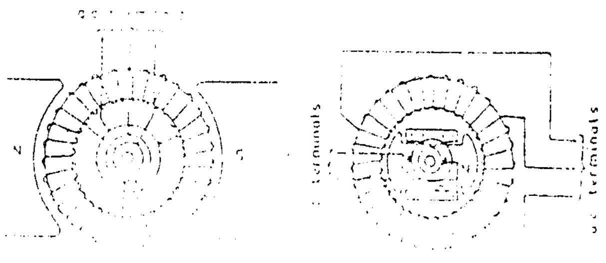


Fig.3.1 Operating principle of a three phase alternator

1.Revolving-armature type alternator

It has stationary field poles and revolving armature. It is usually of relatively small kVA capacity and low-voltage rating. It resembles a D.C. generator in general appearance except that it has slip-rings instead of a commutator. The field excitation must be direct current and therefore, must be supplied from an external direct current source.

2. Revolving-field type alternator:

It has a stationary armature or stator, inside of which the field poles rotate.

3.3. CONSTRUCTIONAL DETAILS

3.3.1. Stator. The stator of an alternator consists essentially of a cast iron or a welded-steel frame supporting a slotted ring made of soft laminated sheet-steel punchings (Fig.3.1) in the slots of which the armature coils are assembled.

The laminations are annealed and are insulated from each other by a thin coating oxide and an enamel (as in D.C. machines, transformers etc.)Open slots are used, permitting easy installation of stator coils and easy removal in case of repair. Suitable spacing blocks are inserted at intervals between laminations to leave radial air ducts, open at both ends, through which cooling air may circulate. The coils are shaped much like the coils of a D.C. generator, the two sides of the coil being approximately a pole pitch apart. All coils are alike, and therefore, interchangeable. They are insulated before being inserted in the slots and are further protected by a horn-fibre slot lining. When in place on the stator, the coils are connected together in groups to form a winding of the required number of phase, three phase star-connected windings being common.

A fractional rather an integral number of slots per pole is often used in order to eliminate harmonics in the waveform.

3.3.2. Rotor. The revolving field structure is usually called the rotor. There are two types of rotors.

1. Salient pole type rotor 2. Smooth cylindrical type rotor.

Salient Pole Type Rotor. This type of rotor is used for slow-speed machines which have large diameters and small axial lengths.

Smooth Cylindrical Rotor

This type of rotor is used for alternators which are coupled to steam turbines which run at very high speeds. To reduce the peripheral speed of the alternator the diameter of the rotor is reduced and axial length is increased. The numbers of pole of the rotor are two or four.

3.3.3. Bearings:

For horizontal shafts these will be self-contained ring-coiled bearings wherever design conditions permit.

Two principal types of thrust bearings are used on vertical alternators: the pivoted shoe type and the spring type.

3.4. FREQUENCY

In case of a generator which has two poles, the induced e.m.f passes through one complete revolution in one revolution of the machine. In a multi polar machine one cycle of e.m.f.

would be generated when the field structure rotates through an angle subtended by a double pole pitch. Therefore, in a machine with p-poles, the number of cycle of e.m.f. in one revolution will be p/2. If a machine has speed of N_s revolutions per minute, the frequency will be

$$\left(\frac{p}{2}\right)\times\frac{N_s}{60} \text{ per second.}$$

$$f=\frac{p}{2}\times\frac{N_s}{60}=\frac{N_s p}{120}\,Hz \qquad (3.1)$$

In order to keep the frequency constant, the speed N_s must remain unchanged. Therefore, a synchronous generator (i ,e, alternator) run at a constant speed known as synchronous speed.

3.5. ARMATURE WINDINGS

3.5.1. Winding Types. A wide variety of winding types are possible to produce a desired voltage in the proper number of phases and with a suitable wave shape. Practical considerations, mainly economic, limit the usual alternator winding to a double-layer 3-phase top winding, arranged in 60°phase belts in open slots. The number of coils, the number of turns per coil, the pitch, the number of circuits, and the connection of the phase are selected to give the desired voltage and waveform.

Double-layer windings in open slots permit the use of form-wound coils which are all alike in a given machines. These coils have the characteristic diamond shape in the end area. Three-phase windings may be either Δ- or Y-connected; Y-connected machines are much more common, particularly in the larger sizes. The winding may be arranged to be connected either Y orΔ, with leads brought out from both ends of each phase to make this possible.

Double-layer windings in open-slots have the following advantage over single layer windings in semi-enclosed slots:

a. Ease in manufacture of coils and lower cost of winding.
b. Less number of coils are required as spare in the case of winding repairs.
c. Fractional slots windings can be employed.
d. Fractional pitch coils can be used.

Single-layer windings have the following advantages:

(i) Higher efficiency and quieter operation because of narrow slot openings.
(ii) Space factor for slots is higher owing to because of inter layer separator.

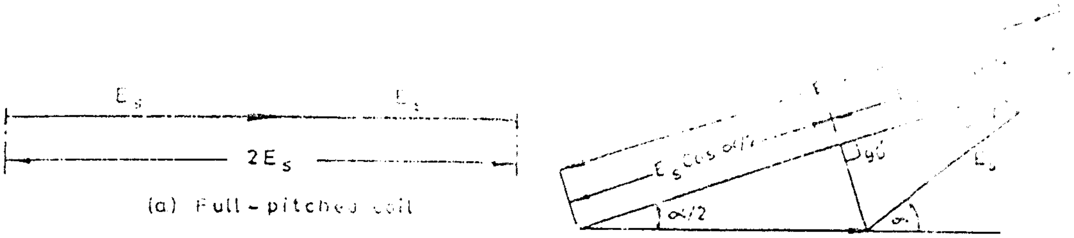
Modern practice all over the world favours use of double layer windings. Single layer windings are popular only in the continent.

3.6. PITCH FACTOR

In a full pitch coil, the e.m.fs. in the two coil sides are in phase and therefore the coil e.m.f is twice the e.m.f of each coil side. In a short pitch coil the e.m.fs. of the two coil sides are not in phase and must be added vectorially to give the coil e.m.f. The factor by which the e.m.f. per coil is reduced, because of the pitch being less, is known as pitch factor (or coil span factor) k_p. Thus,

$$k_p = \frac{\textit{vectoror phase sum of induced e.m.fs. percoil}}{\textit{arithmetic sum of the induced e.m.f spercoil}} \qquad (3.2)$$

It is always less than unity.



(a)Full-pitched coil

(b)Short-pitched coil

Fig.3.2.

Let E_s be induced e.m.f. in each side of the coil. If the coil were full-pitch, then the total induced e.m.f. in the coil would have been $2E_s$ [Fig.3.2(a)].

If it is short-pitched by angle $\alpha°$ (electrical) then their resultant [Fig. 3.2(b)] is E which is vector sum of two voltages, $\alpha°$ (electrical) apart.

$$\therefore E = 2E_s \cos \alpha/2$$

$$\therefore k_p = \frac{\textit{vector sum}}{\textit{arithmeti sum}}$$

$$= \frac{2E}{2E_S} = \frac{2E_S \cos\frac{\alpha}{2}}{2E_S} = \cos \alpha/2 \qquad (3.3)$$

3.7. DISTRIBUTION OR BREADTH OR WINDING FACTOR

The ratio of the vector of the sum of the e.m.fs. induced in all the coils distributed a number of slots under one pole to the arithmetic sum of the e.m.fs. induced (or to the resultant of the e.m.fs. induced in all the coils concentrated in one slot under one pole) is known as distributed factor k_d.

$$\text{or } k_d = \frac{e.m.f.\,induced\ in\ a\ disbuted\ winding}{e.m.f.\,induced\ if\ the\ winding\ would\ have\ been\ concentrated}$$

$$= \frac{vector\ sum}{arithmetic\ sum}$$

The distribution factor is always less than unity.

Let n = number of slots/pole

q = number of slots/pole/phase

E_s = induced e.m.f. in each coil side

β = angular displacement between the slots

$$= \frac{180°}{n}$$

The e.m.fs. induced in different coils of one phase under one pole are represented by side AB,BC,CD,DE....which are equal in magnitude (say each equal to E_s) and differ in phase (say $\beta°$) from each other. If bisectors are drawn on AB,BC,CD,DE....they would meet at common point (say at 0). The point 0 would be the circumcentre of the circle having AB,BC,CD,DE...as the chords and representing the e.m.fs. induced in the coils in different slots.

E.m.f. induced in each coil side,

$$E_s = AB = 20A \sin \frac{\beta}{2}$$

Arithmetic $$= q \times 2 \times OA \sin \frac{\beta}{2}$$

The resultant e.m.f. induced in one polar group of one phase would be the vector sum as represented by the vector AF as shown in Fig.3.3.

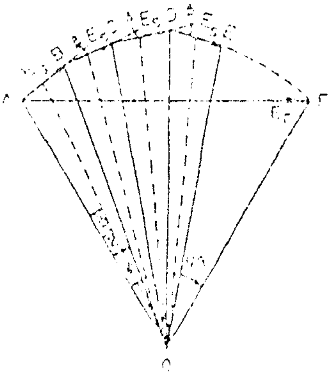


Fig.3.3 Calculation of distribution factor

∴ The resultant e.m.f.,

$$E_r = AF$$

$$= 2 \text{ x } OA \sin \frac{AOF}{2} = 2 \text{ x } OA \sin\left(\frac{q}{2}\right)$$

Distribution factor,

$$K_d = \frac{vector\,sum}{arithmetic\,sum.}$$

$$= \frac{2 \times OA\,sin\left(\frac{q\beta}{2}\right)}{q \times 2 \times OA\,sin\frac{\beta}{2}} = \frac{sin\left(\frac{q\beta}{2}\right)}{q\,sin\frac{\beta}{2}}$$

$$\text{Hence, } k_d = \frac{sin\left(\frac{q\beta}{2}\right)}{q\,sin\frac{\beta}{2}} \tag{3.4}$$

$q\beta$ is also known as the phase spread and is expressed in electrical radians.

Value of the distribution factor for nth harmonic is,

$$k_d = \frac{\sin\left(\frac{qn\beta}{2}\right)}{q\sin\left(\frac{n\beta}{2}\right)}$$

3.8. E.M.F. EQUATION

Let Z_{ph} = number of conductor or coil sides in series per phase

= $2T_{ph}$, where T_{ph} is the number of coils or turns per phase (one turn coil has two sides),

p = number of poles,

ϕ = useful flux per pole, webers,

N = rotational speed of rotor, r.p.m.,

f = frequency,Hz.

k_d = distribution factor, and

k_p = pitch factor.

Consider a conductor on the stator of the alternator. Let the alternator rotor move through one revolution in $t\left(=\frac{60}{N}\right)$ seconds, the flux by the conductor

$$= p\phi \text{ webers}$$

The average e.m.f. induced in the conductor,

$$E_{av} = \frac{d}{dt}(flux)\,volts = p\frac{\phi}{t} = \frac{p\phi}{\frac{60}{N}} = \frac{p\phi N}{60}$$

We know that, $f = \frac{Np}{120}$ or $N = \frac{120f}{p}$

Substituting the value of N in above eqn. we get

$$E_{av} = \frac{p\phi \times 120f}{60 \times p} = 2f\phi \text{ volts/conductor}$$

Average e.m.f. per phase,

$$E_{av}/\text{phase} = 2f\phi \times 2T_{ph} = 4f\phi\, T_{ph}$$

$$E_{r.m.s}/\text{phase} = E_{av} \times \text{form factor} = 4f\phi\, T_{ph} \times 1.11$$

$$= 4.44 f\phi\, T_{ph} \text{ volts} \qquad (3.5)$$

The above equation of e.m.f. induced per phase is true only, *if the winding is concentrated in one slot but practically it is not true,* as the winding for each phase under each pole is *distributed* and for such cases k_p and k_d must be considered.

Thus, e.m.f. induced (for sinusoidal wave) per phase will be

$$E_{r.m.s.}/\text{phase} = 4.44 f\phi\, T_{ph}\, k_p\, k_d \text{ volts} \qquad (3.6)$$

For full-pitched and concentrated windings $k_p = 1$, $k_d = 1$.

If the alternator is ~~stator~~ star-connected (as is usually the case) then the line voltage,

$$E_L = \sqrt{3}E_{r.m.s}\,phase = \sqrt{3} \times 4.44 f T_{ph} k_p k_d \text{ volts.}$$

3.9. ALTERNATOR ON LOAD

When load on an alternator varies, its terminal voltage also varies. This variation in terminal voltage is due to the following reasons.

(i) Voltage drop due to armature resistance

(ii) Voltage drop due to armature leakage reactance X_L, and

(iii) Voltage drop due to armature reaction.

(i) **Armature Resistance.** The voltage drop caused by armature resistance per phase R_s is IR_s and

is in phase with current I. This drop, however, is practically negligible.

Effective Resistance. The effective resistance of the armature winding is greater than the conductor resistance as measured by direct current.