Energy Conversion-II (EC-II) Notes

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(For 5th sem Electrical students)

EC-II

Chapter-1

Alternators

Alternator (Introduction) :→

→ An alternator is an electrical generator that converts mechanical energy to electrical energy in the form of alternating current or AC.

→ Electrical machines (generators and Motors) operated by alternating current are known as synchronous Machines.

→ An alternator is an electromechanical device that converts mechanical energy to electrical energy in the form of alternating current.

→ A.C generators are also called as alternators.

→ AC generators are used in to generate electricity in hydroelectric and thermal power plants.

→ Alternators are also used in automobiles to generate electricity.

→ For reasons of cost and simplicity, Most alternators use a rotating magnetic field with a stationary armature. Occasionaly, a linear alternator or a rotating armature with a stationary magnetic field is used.

→ Alternators in power stations driven by steam turbines are called turbo-alternators.

→ Large 50 or 60HZ, 3-ϕ alternators in powerplants generate most of the world's electric power which is distributed by electric power grids or power substations.

Construction of Alternators :→

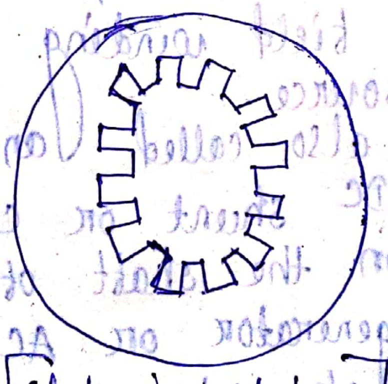
→ The construction of an alternator consists of field poles placed on the rotating fixure of the machine. An alternator is made up of two main parts, a rotor and a stator.

→ The rotor rotates in the stator, and the field poles get projected on to the rotor body of the alternator.

→ The construction of an alternator is very similar to the DC generator but the main difference between them is, in DC generator the armature winding is the rotating part and field winding is the stationary part whereas in an alternator the armature winding is stationary and field winding is the rotary or the rotating part.

→ AC generator or alternator has mainly two parts. These are :-
(1) stator and (2) Rotor.

① **stator** :→ The stationary part of the alternator is known as stator. It provides housing and support for the rotor.



Slots in stator

→ slots are provided in the inner side of the stator to fix poles or windings. The slots are provided in the inner periphery of the core and the armature conductors or coils are assembled in it.

→ Generally, open slots are used permitting easy installation or removal of the stator coil.

→ The armature winding of an alternator is usually connected in star and its neutral is connected to the ground.

Q:→ Why is the armature winding of an alternator connected in star?

Ans:→ (1) The phase voltages in star connection are 57.7% of the line voltages i.e. the armature winding in star connection is less exposed to voltage as compared to the delta connection which in turn prove more economic if we consider insulation, breakdown strength, the requirement of conductor material etc.

(2) In star connection, if the neutral is grounded then it also provides a path for the zero-sequence currents during faults, whereas in the delta connection the zero sequence currents flow within the delta ckt and hence increasing the load on the winding.

② Rotor:→ The revolving field structure of the electrical machine is called as the rotor. It is also the rotating part of an alternator.

→ In a synchronous generator or an alternator, the rotor carries a field winding which is supplied by the DC source.

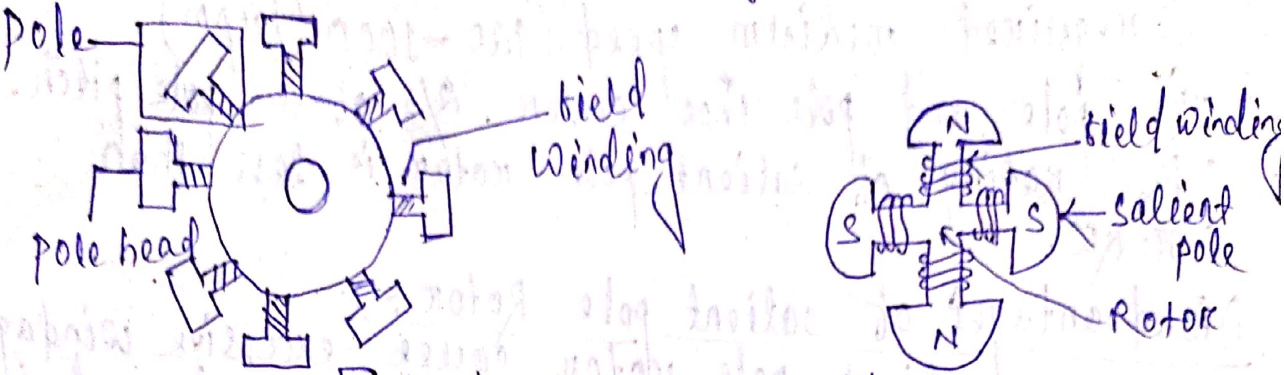
→ The DC source is also called an exciter which is generally a small DC shunt or compounded generator mounted on the shaft of the alternator or the synchronous generator or AC generator.

→ There are two types of rotor construction. These are:→

(a) salient pole type or projected pole type.

(b) cylindrical type (non-salient pole type) or smooth cylindrical type.

(a) salient (or projected) pole type :→



[salient pole type Rotor]

→ As the name suggests, the poles are made with projections. This type of rotor is used for low and medium speed/rpm machines or alternators, (less than 1200 rpm) where more no. of poles are required. may be 20 or 30 poles and have the large diameter and small axial length.

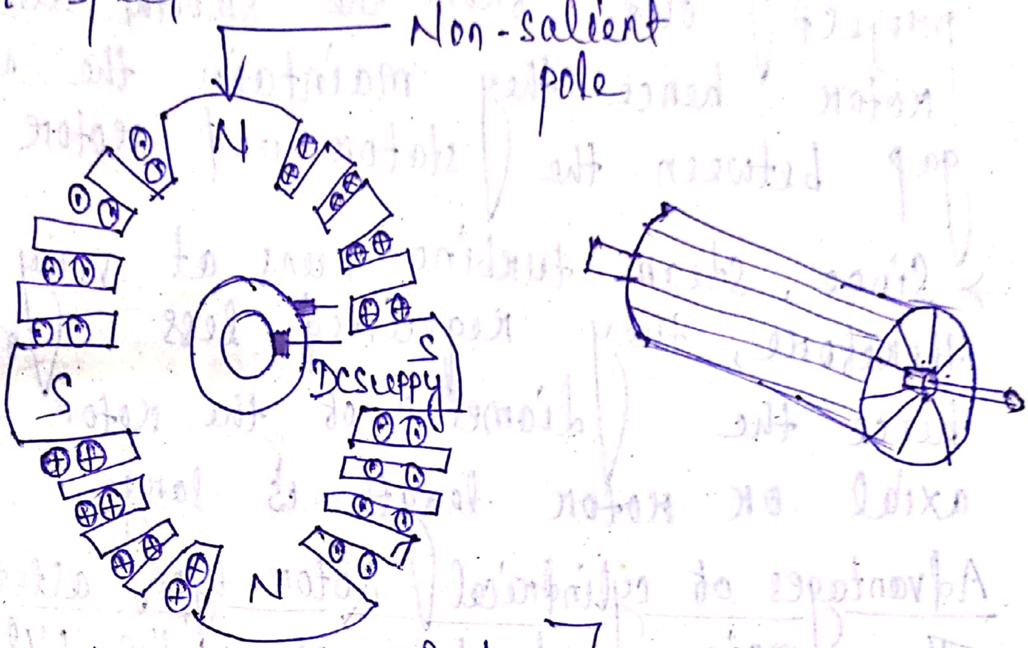
→ The poles are made up of steel or cast iron lamination to reduce eddy current heating loss and the pole winding is excited by a d.c generator driven by the shaft of alternator and the pole winding is also attached to a rotor by means of the dovetail joint.

→ In salient pole rotor, the poles are always projected in the outward direction as shown in the figure.

→ The field winding in the salient pole type is connected in series in such a way that when the field winding is energised by the exciter, then the adjacent poles will have opposite polarities. The no. of poles does not affect the no. of phases in the alternator output.

(b) Smooth cylindrical Rotor or Non-salient pole type alternator :→

→ This type of Rotor is used for steam driven alternator i.e. turbo alternator which runs at very high speed.



[cylindrical type Rotor]

→ The rotor is made up of steel cylinder with no. of slots cut on the periphery of the cylinder.

→ The field windings of cylindrical type rotor are connected in series to the slip rings through which they are excited by the DC exciter. The field windings are placed in the slots. These axial alternators have more length and smaller diameter.

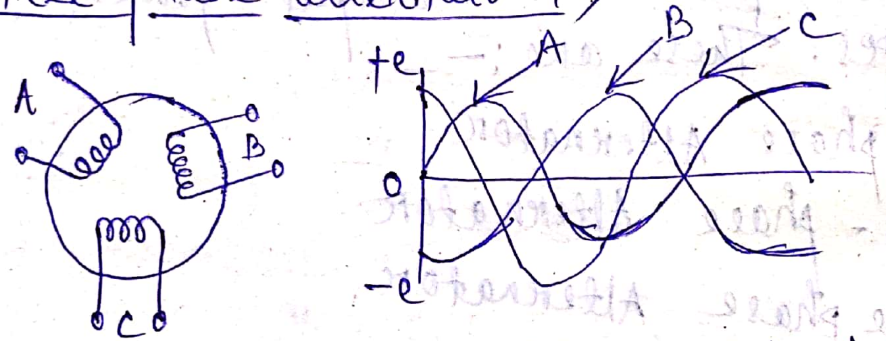
→ The top portion of the slot is covered with the help of steel or manganese wedges and the unslotted portion of the cylinder acts as the poles of an alternator.

(2) Two phase alternator :→

→ In a two-phase alternator, there are two single-phase windings spaced physically so that the AC voltage induced in one is 90° out of phase with the voltage induced in the other.

→ The windings are electrically separate from each other. suppose in the first quarter first winding produce maximum flux, then the second winding generates zero flux and in the second quarter the second winding generates maximum flux and first winding generates zero flux. This condition establishes a 90° relation between the two phases.

(3) Three phase alternator :→



→ A three-phase alternator has 3 sets of single-phase windings arrangement so that the voltage induced in each winding is 120° out of phase with the voltages in the other two windings. These windings are connected in the star to provide a three-phase output.

Advantages of 3-φ Alternator :→

(1) The three-phase alternator gives the most constant output than the single phase alternator.

(2) 3-φ power supply is more economical than the other two phases because three separate 1-φ voltage can be delivered at the same time from the power system.

Arrangement of synchronous Generators :→

→ The arrangement or the system used for the excitation of the synchronous machine is known as excitation system. To excite the field winding of the rotor of the synchronous machine, direct current is required. Direct current is supplied to the rotor field of the small machine by a DC generator called exciter.

→ There are two possible arrangements of armature in an alternator. These are :→

(1) stationary armature winding and rotating poles.

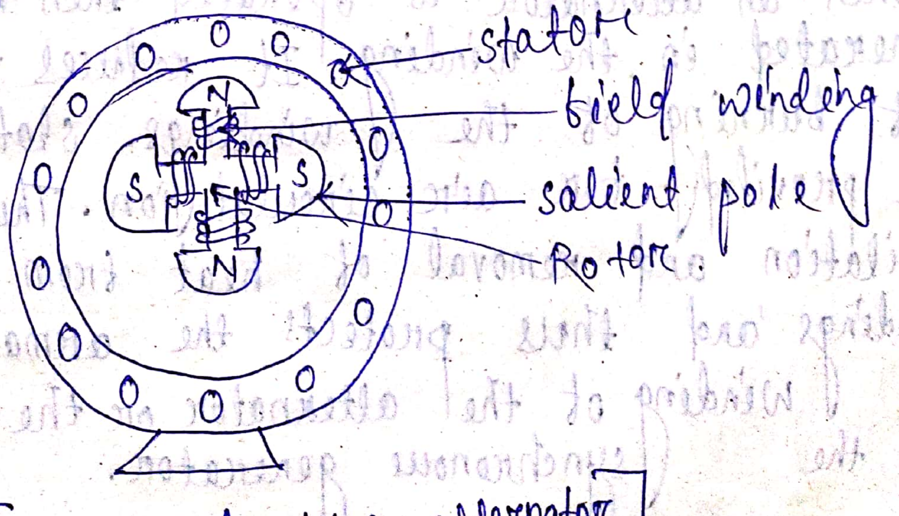
and (2) Stationary poles and rotating armature winding.

(1) stationary armature winding and rotating poles :

→ The stator is provided with slots where the armature winding along with insulation is placed.

→ The rotor has magnetic poles arranged alternately as North (N) and south (S)

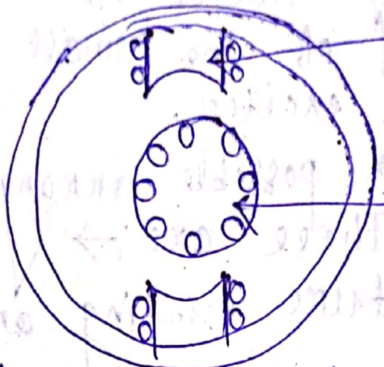
→ The nos. of poles vary according to the speed of the primemover.



[salient pole type alternator]

(2) Stationary poles and rotating armature winding:→

→ In this type of arrangement the poles are fixed in the stator and the armature winding is provided on the rotor.



→ First type of arrangement is preferred over the second arrangement because of the following reasons:→

(a) More space is available for armature windings, therefore more coils and insulator can be provided. This allows achieving voltages as high as 33 KV.

(b) Less no. of slip rings are required.

(c) simple in design and construction.

(d) Less rotor weight and reduced mechanical power required to move the rotor.

(e) When an alternator is operated then heat is generated in the winding. It reduces the chances of burning of the windings. slots and fans are provided for air circulation. This helps in ventilation and removal of heat from the windings and thus protects the armature winding of the alternator or the AC generator or the synchronous generator.

Terms used in an Alternator or AC generator :→

(1) Armature :→ The part of the alternator where emf is induced.

(2) Winding :→ Insulated copper wires are wound over steel structure to induce magnetic field when current is supplied.

(3) Slip rings :→ Two rings are provided to supply current to the rotor winding.

(4) Brushes :→ The brushes rest on the slip rings to provide contact for supplying current.

(5) Pole :→ It is made up of cast iron or steel of good magnetic quality which acts as north (N) or south (S) pole alternately.

(6) Primemover :→ The mechanical system to provide the rotation to the alternator is known as primemover.

Relationship between speed (N), frequency (f) and no. of poles (P) :→

$$\text{Frequency } (f) = \frac{PN}{120} \text{ cycle/sec. or Hz.}$$

where, P = No. of poles

N = speed in rpm.

→ The o/p frequency of an alternator depends on the no. of poles and rotational speed. The speed corresponding to a particular frequency is called the synchronous speed (N_s) for that frequency. In India the frequency of AC is 50Hz. This is the standard frequency for generation and distribution of electricity.

→ So, the synchronous speed (N_s) is given by,

$$N_s = \frac{120f}{P} \text{ r.p.m.}$$

where, f = frequency in Hz or cycle/sec.
and P = No. of poles.
and N_s = synchronous speed.

Problems :→

① Q:→ Calculate the frequency of the alternating current if the speed is 300 r.p.m. and the no. of poles is 8 ?

Soln :→ Given Data :→

N = 300 r.p.m

P = 8

Frequency is given by;

$$F = \frac{PN}{120} = \frac{8 \times 300}{120} = 20 \text{ Hz or } 20 \text{ cycle/sec.}$$

⇒ $F = 20$ Hz (Ans)

② Q:→ Calculate the no. of poles when a steam turbine rotates at 1000 r.p.m. to generate 50Hz alternator current ?

③ Q:→ A four pole 3 phase alternator is running at 1500 r.p.m. has 96 slots. What is the frequency?

Sol^n:→ Given Data:→

$P = 4$

$N = 1500$ r.p.m.

$f = ?$

frequency, $f = \frac{PN}{120} = \frac{4 \times 1500}{120} = 50$ c/s or Hz.

$\Rightarrow$ $f = 50$ Hz or c/s (Ans)

④ Q:→ At what speed must a 2 pole alternator be run to give a frequency of 50 c/s?

⑤ Q:→ Calculate the synchronous speed of an alternator where there is a 50 Hz supply is given to the alternator and there are two poles present in that alternator?

Synchronous speed:→ It is a significant parameter for the rotating magnetic field-type AC motor.

→ It is determined by the frequency and the number of magnetic poles.

Principle of Alternators :→

principle of operation :→

→ The working principle of an alternator or AC generator is similar to the basic working principle of a DC generator.

→ The working principle of an alternator is just similar to DC generator as the emf induced in the coils of the generator is always alternating.

→ Whenever conductors rotated in the magnetic field or vice versa, the emf is generated in that conductors, however, in case of an alternator generally magnetic field is rotated instead of armature due to various advantages.

→ According to Faraday's laws of electromagnetic induction, whenever a conductor moves in a magnetic field EMF gets induced across the conductor. If the close path is provided to the conductor, induced emf causes current to flow in the ckt.

→ Faraday's law of electromagnetic induction which also 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 the working of an alternator let us think about a single rectangular turn placed in between two opposite magnetic poles that is shown in figure below.

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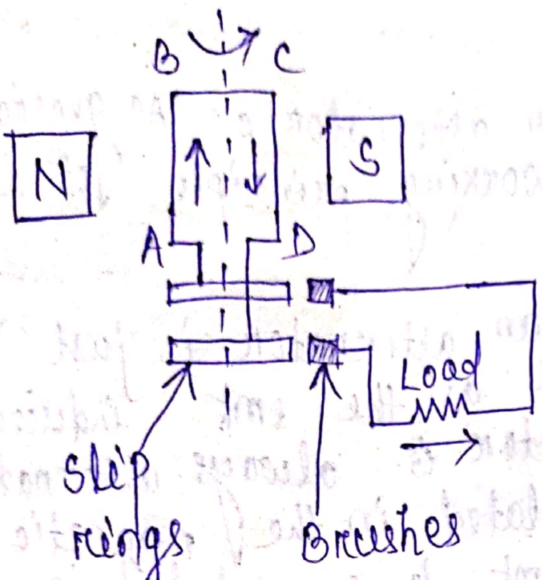
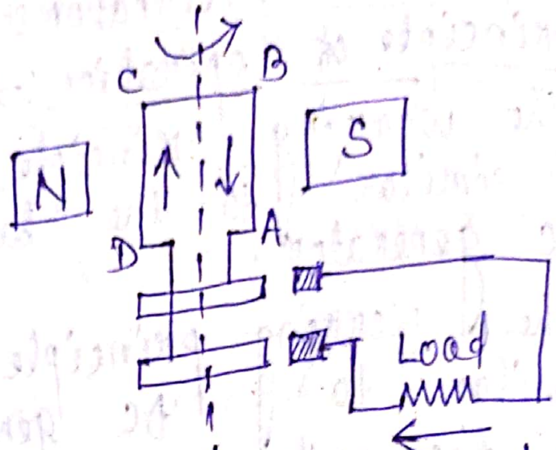


[Case-1]



[case-2]

→ In the figure, let the conductor coil ABCD is placed in a magnetic field. The direction of magnetic flux will be from N pole to S pole. The coil is connected to the slip rings and the load is connected through brushes resting on the slip rings.

→ Now, consider the case-1, the coil is rotating clockwise, in this case the direction of induced current can be given by Fleming's Right Hand Rule and it will be along ABCD.

→ As the coil is rotating clockwise, after half of the time period, the position of the coil will be in the direction of the induced current according to Fleming's Right Hand Rule will be along DCBA.

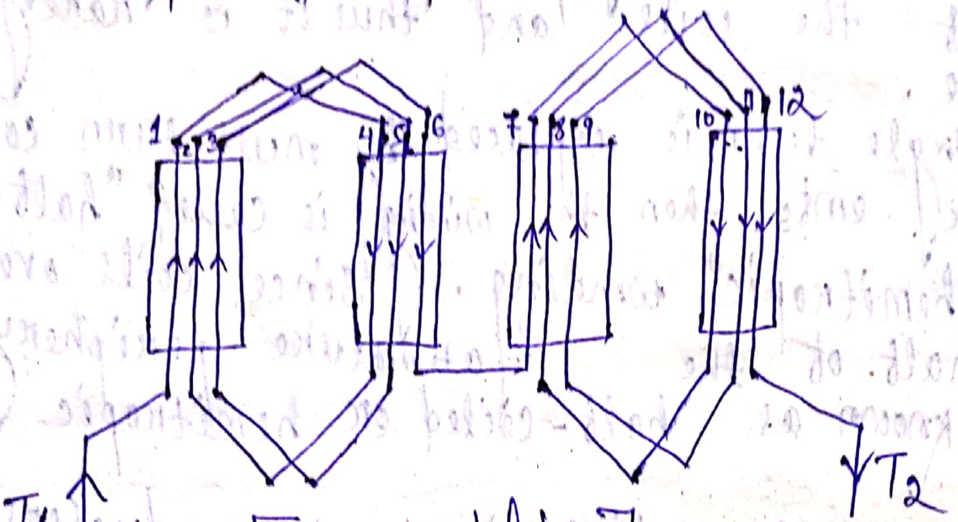
→ It shows that, the direction of the current changes after half of the time period that means we get an alternating current.

Lap Winding :→

→ If the conductors are joined in such a way that there parallel paths and poles are equal in number, then it is a lap winding. i.e. A = P, where A is the no. of parallel paths of a conductor and P is the no. of poles.

→ Lap winding is employed in stator of high speed synchronous machine applications.

→ The below figure shows the structure of lap winding of a 4 pole, 12 slots, 12 conductor alternator.



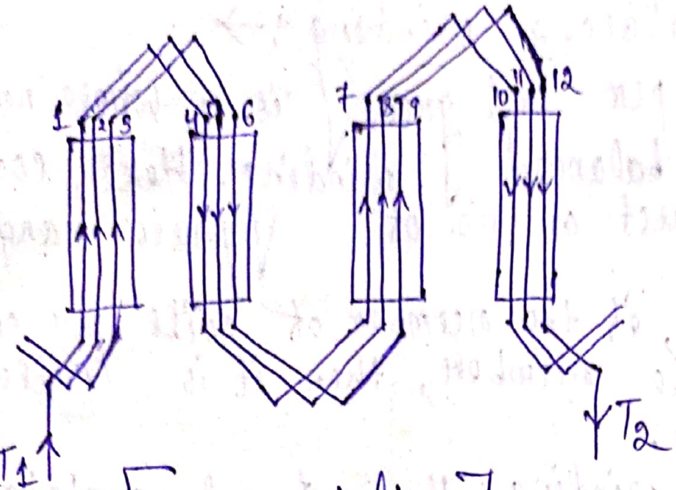
[Lap winding]

Wave Winding :→ In wave winding the no. of parallel paths (A) is always equal to 2. i.e. A = 2.

The no. of conductors per pole will be equal to the conductors in front end and back ends.

→ Wave windings are much suitable for the rotors of induction type motors.

→ The below figure shows the structure of wave winding of a 4 pole, 12 slots, 12 conductor Alternator.



[Wave winding]

Concentric or spiral winding :→

→ In this winding, the coils are in spiral structure and they are of different pitches. Let us say, the outer coil pitch is 6, the middle coil pitch is 5 and the inner coil pitch is 4, etc... They are widely used in slow speed applications.

Poly phase armature winding :→

→ Poly phase winding arrangements are similar to that of the single phase winding, the only difference is that, in two phase alternators there are two separate single phase winding placed 90 electrical degrees apart and in three phase winding, there are three separate winding placed 60 electrical degrees apart for convenience.

Balanced and unbalanced winding :→

→ If the no. of coils per coil group is a whole number, then it is called balanced winding. Here, coil group is the product of no. of phases and no. of poles.

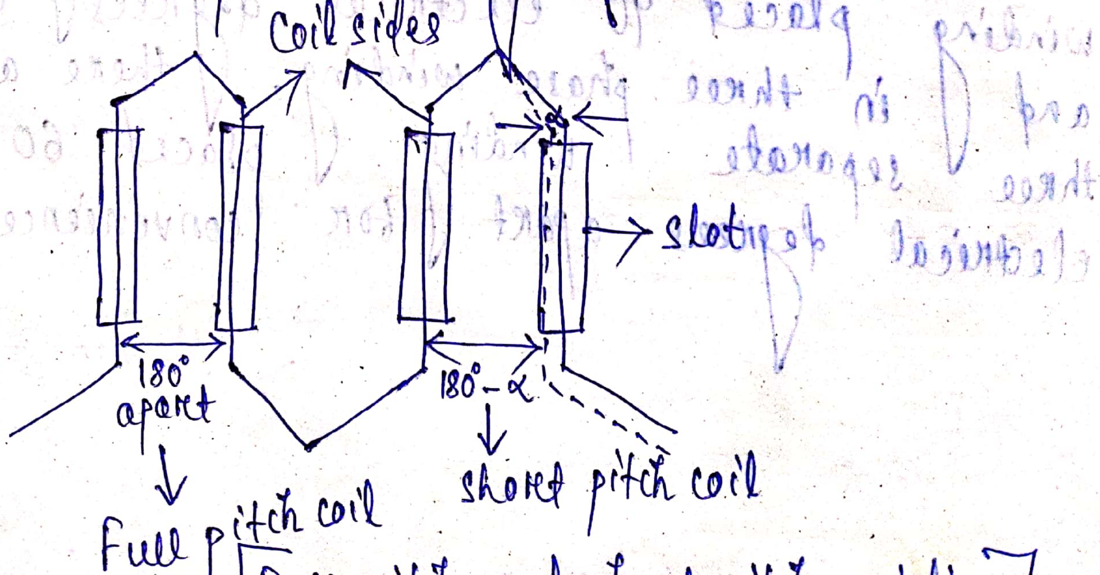
→ On the other hand, if the number of coils per coil group is not a whole number, then it is called unbalanced winding.

→ In unbalanced winding, the each pole contains unequal number of coils in different phases. But there should be equal number of coils in each phase.

Full pitch and short pitch winding :→

→ When the two coil sides forming a complete coil of a winding are 180 electrical degrees or 180° apart, the winding is called as full pitch winding.

→ When the coil span of the winding is less than 180 electrical degrees or 180° i.e. the two coil sides forming a complete coil of a winding are less than 180 electrical degrees apart or 180° apart, then the winding is known as short pitch winding or the fractional pitch winding.



[Full pitch and short pitch winding]

Integral slot and fractional slot winding:→

→ When the no. of slots per pole per phase, 'm' is an integer value, then the winding is called integral slot winding.

→ When the number of slots per pole per phase, 'm' is an fractional number, then the winding is called fractional slot winding. This type of winding is little complicated but has certain advantage as well as ease in manufacturing.

→ However, in both cases, if the number of slots per phase must be a whole number, so that each phase will have the same no. of coils.

Distribution Factor (K_d) and pitch factor (K_p):→

Distribution Factor (K_d):→ In the alternator, the armature winding is distributed in several slots per pole so the emf induced in different coils have phase displacement with that reason it is always vector sum of the emf.

→ It is defined as the ratio between the vector sum of induced emf and arithmatic sum of induced emf. Its symbol is "K_d" and It is also called as breadth (K_b) factor.

So, $$K_d = \frac{\text{Vector sum of emf}}{\text{arithmatic sum of emf}}$$

and slot per pole per phase $= n$

So, $$K_d = \frac{\sin n\frac{\theta}{2}}{n\sin\frac{\theta}{2}} \quad [\because \theta = \text{angle}]$$

→ The angle 'θ' also replaced by α, β or γ. It is according to the question that what angle is given in the question.

Pitch factor (K_p) or coil span factor (K_c) :→

→ Pitch factor is also known as coil span factor.

→ In short pitched coil, the phase angle between the induced emf of two opposite coil sides is less than 180°.

→ In full pitched coil, the phase angle between the induced emf of two coil sides is exactly 180°.

→ In short pitched coil, the induced emf of two coil sides get vectorially added and give the resultant emf of the loop. In short pitched coil, the phase angle between the induced emf of two opposite coil sides is less than 180° (electrical). But we know that, in full pitched coil, the phase angle between the induced emf of two coil sides is exactly 180° (electrical).

→ In order to improve the wave formation of an induced emf in the armature winding of an alternator, normally, short pitch or long pitch windings are used. The emf induced in both sides of a coil is always less than the resultant emf due to the phase difference.

→ It is defined as the ratio between the vector sum of the induced emf in both sides of the coil and arithmatic sum of induced emf in both sides of the coil.

$$K_p \text{ or } K_c = \frac{\text{vector sum of induced emf in both sides of the coil}}{\text{Arithmatic sum of induced emf in both sides of the coil}}$$

The angle θ or $\beta = \frac{180°}{3n}$ [n = no. of slots per pole per phase or, n = no. of slots/pole/phase

$$K_p = K_c = \cos\frac{\beta}{2}$$

where, β = angle of phase displacement between the adjacent slots.

Winding Factor: → (K_w)

→ The winding factor (K_w) is the method of improving the rms (root mean square) generated voltage in a three phase AC machines so that the torque and the output voltage does not consists any harmonics which reduces the efficiency of the machine.

→ Winding factor (K_w) is defined as the product of Distribution factor (K_d) and the pitch factor or the coil span factor (K_c).

$$K_w = K_d \times K_c \quad \text{or} \quad K_w = K_c \times K_d$$

→ The distribution factor measured the resultant voltage of the distributed winding regards the concentrated winding and the coil span is the measure of the number of armature slots between the two sides of a coil.

Harmonics: → In an electrical power system, a harmonic is a voltage or current at a multiple of the fundamental frequency of the system, produced by the action of non-linear loads such as rectifiers, discharge lighting, or saturated magnetic devices.

Problems of pitch factor and distribution factor :→

Q:→ A 3 phase 4 pole alternator has 36 slots. If the coil span is 8, find the distribution factor and coil span factor ?

Sol^n :→ $K_d = ?$

K_c or $K_p = ?$

$$\text{slots per pole} = \frac{\text{No. of slots}}{\text{No. of poles}} = \frac{36}{4} = 9$$

$$n = \text{slots/pole/phase} = \frac{\text{No. of slots}}{\text{No. of poles} \times \text{No. of phase}}$$

$$= \frac{36}{4 \times 3} = \frac{36}{12} = 3$$

$\Rightarrow$ $\boxed{n = 3}$

$$\text{The angle} = \beta = \frac{180^\circ}{3n} = \frac{180^\circ}{3 \times 3} = \frac{180}{9} = 20^\circ$$

$$\text{coil span factor } (K_c) = \cos\frac{\beta}{2} = \cos\frac{20}{2} = \cos 10^\circ = 0.9848$$

$$\text{Distribution factor } (K_d) = \frac{\sin\frac{n\beta}{2}}{n \sin\frac{\beta}{2}}$$

$$= \frac{\sin\frac{3 \times 20^\circ}{2}}{3 \times \sin\frac{20^\circ}{2}} = \frac{\sin 30^\circ}{3 \sin 10^\circ}$$

$$= \frac{0.5}{3 \times 0.1736}$$

$$= \frac{0.5}{0.5208} = 0.96$$

So, Here, $\boxed{K_c = 0.9848}$

and $\boxed{K_d = 0.96}$ (Ans)

Emf equation of an alternator :→

→ The generator which runs at a synchronous speed is known as the synchronous generator or alternator. The synchronous generator converts the mechanical power into electrical energy for the grid. The derivation of EMF equation of an alternator or a synchronous generator is given below:→

Let, the alternator has :-

P = Total no. of poles
ϕ = useful flux per pole in weber (wb)
Z = Total no. of armature conductors per phase or coil sides in series per phase.
T = Total no. of coils or turns per phase.
N = speed of rotation in r.p.m [revolution per minute].
f = frequency of generated voltage in (Hz or c/s) Hertz or cycle/second.

Flux cut in one revolution = $\frac{\text{Total flux}}{\text{Time}}$

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

So, the induced emf = $\frac{\phi PN}{60}$

We know that, frequency = $f = \frac{PN}{120} \Rightarrow PN = 120f$

So, the emf = $\frac{\phi PN}{60} = \frac{\phi \times 120f}{60} = 2\phi f$ volt

$$\boxed{e.m.f = 2\phi f \text{ volt}}$$

Since, there are 'Z' conductors in series per phase, the average voltage generated or the induced emf per phase = $2\phi fZ$ volt.

i.e. the induced emf by armature conductor per phase = $2\phi f Z$ volt.

Since, one turn or coil has two sides, i.e. $Z = 2T$ and this can be written as,

induced emf per phase $= 2\phi f Z$

$= 2\phi f \times 2T$ $[\because Z = 2T]$

rms per phase is, $= 4\phi f T$ volt

For the voltage wave, the form factor is given by,

$$K_f = \frac{\text{rms value}}{\text{Average value}}$$

For a sinusoidal voltage, $K_f = 1.11$.

Therefore, the rms value of the generated voltage per phase can be written as,

Emf per phase $= K_f \times$ rms per phase

$= K_f \times 4\phi f T$

$= 1.11 \times 4\phi f T = 4.44\phi f T$ volt.

Emf per phase $= 4.44\phi f T$ volt

The induced emf in an alternator keeping the distribution factor K_d and the pitch factor or the coil span factor K_c, it is given by,

E.M.F per phase $= 4.44 K_d K_c \phi f T$ volt

(OR) Another Method (If required then it is used)

emf $= 2\phi f Z$ volt

emf, rms value $= 2K_f \phi f Z$.

$= 2 \times 1.11 \times \phi f Z$

$= 2.22 \times \phi f \times 2T$ $[\because Z = 2T]$

$= 4.44\phi f T$ volt.