PNS SCHOOL OF ENGINEERING & TECHNOLOGY

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LECTURER'S NOTE

ON

ENERGY CONVERSION - II

(THEORY – 2)

FOR

5TH SEMESTER, ELECTRICAL ENGINEERING

(AS PER SCTE&VT SYLLABUS)

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LECTURER IN ELECTRICAL ENGG.

2. ALTERNATOR

2.1 State types of alternator and their constructional features.

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. A.C. generators are used in to generate electricity in hydroelectric and thermal plants. Alternators are also used in automobiles to generate electricity.

CLASSIFICATION:

The alternators are classified according to following ways.

Based on output power:

1. Single Phase
2. Three Phase

Single Phase Alternator

- The single phase alternators develop voltage like 230 volt and 115 volt at a frequency of 50 or 60 Hz.

Two Phase Alternator:

- Two phase alternators have two or more single phase windings spaced symmetrically around the stator.
- 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 which establishes a 90° relation between the two phases.

Three Phase Alternator:

- The alternator which develops 3 phase voltage like 440 V. 11 Kv etc is known as three phase alternator.
- The three phase alternator has three single phase windings spaced so that the voltage induced in each winding is 120° out of phase with the voltages in the other two windings.
- A three phase, or poly phase circuit, is used in most aircraft alternators, instead of a single or two phase alternator.

Based on Cooling:

1. **Air cooling**

   The Alternator which utilizes the air for its cooling purpose is known as Air cooling Alternator.
2. **Hydrogen cooling**

   In hydrogen cooled system hydrogen gas is used as a medium for cooling.
3. **Water Cooling:**

   In Water cooled system Water is used as a medium for cooling.

Classification Based On Speed Of Operation:

Class	Speed Range	Prime Mover
Low speed alternator	60 to 500 rpm	Water turbine steam turbine
Medium speed alternator	600 to 1000 rpm	High Head Water turbine IC engine
High speed alternator	1500 to 3000 rpm	steam turbine

Classification Based On Capacity and Generation Voltage:

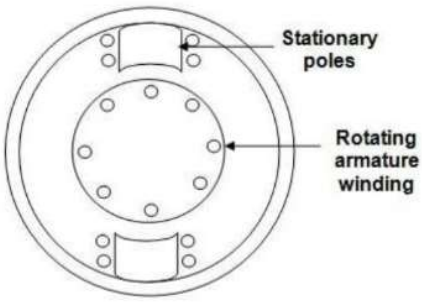
Class	Voltage Range
Small Capacity	250, 420, 1100,3500 Volt
Medium Capacity	3300 Volt,6600 Volt, 11Kv
Large Capacity	6600 Volt, 11000 Volt, 33 kv

<u>Classification Based Upon The Construction</u> :

- Revolving armature type
- Revolving field type

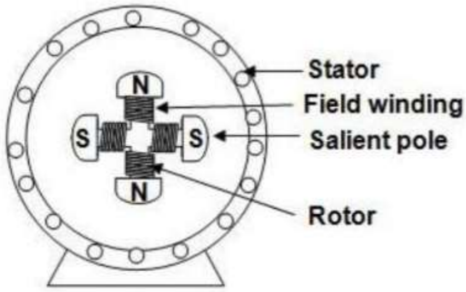
Revolving Armature Type:

- It has stationary field poles and revolving armature.
- It is usually a small KVA capacity and low voltage rating.
- In this case the commutators are replaced by slip rings. The field excitation must be direct current and supplied from an external direct current course.



Revolving Field Type:

- It has stationary armature or stator inside which the field pole rotates.
- The most of alternators are revolving field type in which the "revolving field structure" or rotor has slip ring and brushes to supply the excitation current from external dc supply.
- The armature coils are placed in slots on a lamination core called stator which is made up of thin steel punching or lamination and held in place in the steel frame of the generator.



Advantages of Rotating Field Alternator

Most alternators have the rotating field and the stationary armature. The rotating-field type alternator has several advantages over the rotating-armature type alternator.

- A stationary armature is more easily insulated for the high voltage for which the alternator is designed. This generated voltage may be as high as 33 kV.
- The armature windings can be braced better mechanically against high electromagnetic forces due to large short-circuit currents when the armature windings are in the stator.
- The armature windings, being stationary, are not subjected to vibration and centrifugal forces.
- The output current can be taken directly from fixed terminals on the stationary armature without using slip rings, brushes, etc.
- The rotating field is supplied with direct current. Usually the field voltage is between 100 to 500 volts. Only two slip rings are required to provide direct current for the rotating field, while at least three slip rings would be required for a rotating armature. The insulation of the relatively low voltage slip rings from the shaft can be provided easily.
- The bulk and weight of the armature winding are substantially greater than the windings of the field poles. The size of the machine is, therefore, reduced.
- Rotating field is comparatively light and can be constructed for high speed rotation. The armatures of large alternators are forced cooled with circulating gas or liquids.
- The stationary armature may be cooled more easily because the armature can be made large to provide a number of cooling ducts.

CONSTRUCTION OF ALTERNATOR

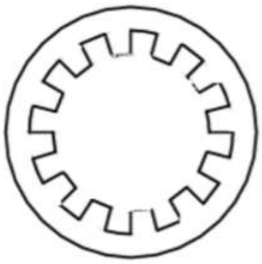
A.C. generator has mainly following parts

- Stator
- Rotor
- Brush Assembly
- Rectifier Assembly
- Cooling Fan
- Pully

- Regulator
- Drive End Bearing

☞ Stator:

- The Stationary part of the alternator is known as stator. It provides housing and support for the rotor.
- Slots are provided in the inner side of the stator to fix poles or windings`

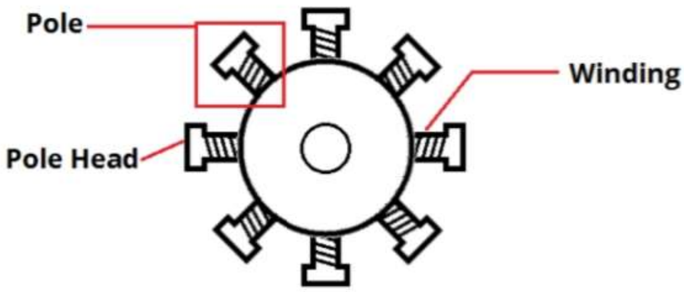


Slots in Stator

☞ Rotor:

- It is the rotating part of an alternator.
- Rotors of an Alternator**s** are classified as:
  - (i) Salient pole rotors and
  - (ii) Non-salient pole rotors.

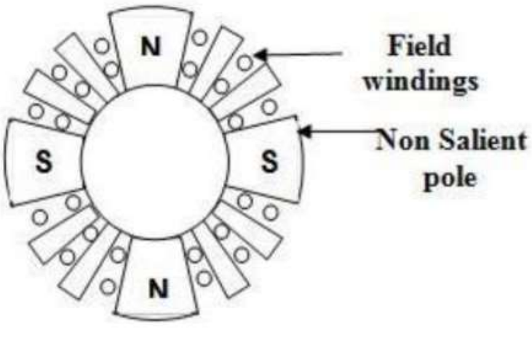
☞ (i) Salient Pole Type or Projected Rotor:



Salient pole rotor

- In **salient pole** type of rotor consist of large number of **projected poles** (salient poles) mounted on a magnetic wheel.
- The projected poles are made up from laminations of steel. The rotor winding is provided on these poles and it is supported by pole shoes.
- **Salient pole rotors** have large diameter and shorter axial length.
- They are generally used in lower speed electrical machines, say 100 RPM to 1500 RPM. **Salient pole synchronous generators** are mostly used in hydro power plants.
- As the rotor speed is lower, more number of poles are required to attain the required frequency. ($N_s = 120f / P$ therefore, $f = N_s*p/120$ i.e. frequency is proportional to number of poles). Typically number of salient poles is between 4 to 60.
- Flux distribution is relatively poor than non-salient pole rotor, hence the generated emf waveform is not as good as cylindrical rotor.
- Salient pole rotors generally need damper windings to prevent rotor oscillations during operation.

☞ (ii) Non-salient pole Type or Smooth Cylindrical rotor:



- It is cylindrical in shape having parallel slots on it to place rotor windings. They are also called as drum rotor.
- It is made up of solid steel. Sometimes,
- They are smaller in diameter but having longer axial length.
- Cylindrical rotors are used in high speed electrical machines, usually 1500 RPM to 3000 RPM.

- Windage loss as well as noise is less as compared to salient pole rotors.
- Their construction is robust as compared to salient pole rotors.
- Number of poles is usually 2 or 4.
- Damper windings are not needed in non-salient pole rotors.
- Flux distribution is sinusoidal and hence gives better emf waveform.
- Non-salient pole rotors are used in nuclear, gas and thermal power plants.

Brush & slip ring Assembly:

- The alternator brushes ride on slip rings to make a sliding electrical connection.

- The slip rings are mounted on the rotor shaft to feed a low current into the rotor windings.

Exciter/Rectifier Assembly:

- An automobile electrical system is designed to use direct current, which flows in only one direction.
- It cannot use the alternating current as it comes out of the alternator stator.
- Alternator current must be rectified (changed into direct current) before entering the electrical system.
- The direct current is given at low voltage of the order of 110 to 250 volt trough slip rings.

Cooling Fan :

- To provide cooling for the alternator, a fan is mounted on the front of the rotor shaft.
- It is normally located between the pulley and the front bearing.
- As the rotor and shaft spin, the fan helps draw air through and over the alternator.
- This cools the windings to prevent damage from overheating.

Pulley:

- The pulley is connected to the rotor shaft and the drive belt system. Rotation created by the engine the drive belt system turns the pulley beginning the charging process.

Regulator

- The voltage regulator controls the amount of power distributed from the alternator to the battery in order to control the charging process.

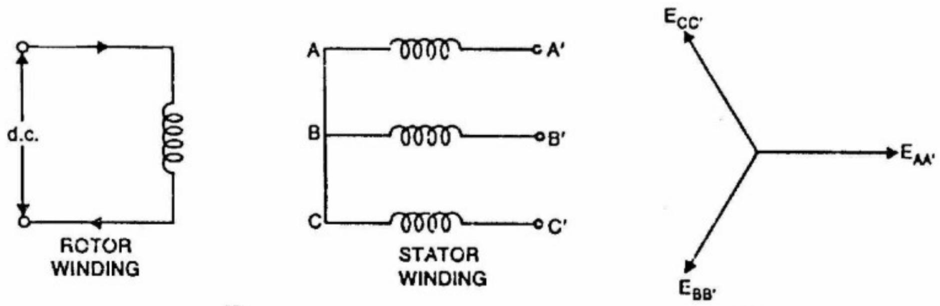
- Regulators are designed with different functions and work depending on their specification.

Drive End Bearing

- The bearings are designed to support the rotation of the rotor shaft.

2.2 Explain Working Principle Of Alternator And Establish the Relation Between Speed And Frequency.

Explain Working Principle Of Alternator



(i) (ii)

- When the rotor winding is energized from the d.c. exciter and alternate N and S poles are developed on the rotor.
- When the rotor is rotated in anti-clockwise direction by a prime mover, the stator or armature conductors are cut by the magnetic flux of rotor poles.
- Consequently, e.m.f. is induced in the armature conductors due to Farady's Law of electromagnetic induction.
- The induced e.m.f. is alternating since N and S poles of rotor alternately pass the armature conductors.
- The direction of induced e.m.f. can be found by Fleming's right hand rule and frequency is given by;

  $$f = \frac{PN}{120}$$

  Where N = speed of rotor in r.p.m.

  P = number of rotor poles
- The magnitude of the voltage induced in each phase depends upon the rotor flux, the number and position of the conductors in the phase and the speed of the rotor.
- Figure. (i) Shows star-connected armature winding and d.c. fild winding. When the rotor is rotated, a 3-phase voltage is induced in the armature winding.
- The magnitude of induced e.m.f. depends upon the speed of rotation and the d.c. exciting current.

- The magnitude of e.m.f. in each phase of the armature winding is the same and they differ in phase by 120° electrical as shown in the phasor diagram in Figure (ii).

Frequency :

The frequency of induced e.m.f. in the armature conductors depends upon speed and the number of poles.

Let N = rotor speed in r.p.m.
P = number of rotor poles
f = frequency of e.m.f. in Hz

Consider a stator conductor that is successively swept by the N and S poles of the rotor.

If a positive voltage is induced when a N-pole sweeps across the conductor, a similar negative voltage is induced when a S-pole sweeps by.

This means that one complete cycle of e.m.f. is generated in the conductor as a pair of poles passes it i.e., one N-pole and the adjacent following S-pole. The same is true for every other armature conductor.

No. of cycles/revolution = No. of pairs of poles = P/2
No. of revolutions/second = N/60
No. of cycles/second = No. of cycles/revolution × No. of revolutions/second
(P/2)(N/60) = N P/120
But number of cycles of e.m.f. per second is its frequency.

$$f = \frac{PN}{120}$$

Synchronous Speed:

- N is the synchronous speed and is generally represented by Ns.
- For a given alternator, the number of rotor poles is fixed and, therefore, the alternator must be run at synchronous speed to give an output of desired frequency.
- For this reason, an alternator is sometimes called **Synchronous Generator**.

2.3 Explain terminology in armature winding, and derive expressions for winding factors (Pitch factor, Distribution factor)

Armature Winding of Alternator

Armature windings are classified into two different types namely

- Closed type winding
- Open type winding.

Closed Type Winding

- In this type of winding, a closed path is formed around the armature. The starting point of the winding is reached again after passing through all the turns.

- The current passing through closed type of winding is through brushes placed on commutator. The commutator segments are connected to various armature coils.

- The armature current gets divided into different parallel paths.

- The current flowing through the coil changes continuously but from brush side the winding view remains same and polarity is maintained which is in effect due to use of commutator segments.

- The closed type of winding is normally used in a.c. and d.c. commutator machines. This type of winding is usually double layer.

Open Type Winding

- In case of a.c. machines, commutator is not used and hence closed winding is not required to be used.

- In such cases pen type winding is used. The armature is left open at one or more points.

- The ends of each section of the winding can be brought at the terminals to do the required type of interconnection externally.

- The open type of winding is preferred over closed type as it gives better flexibility in design and freedom of connections.

- These types of windings are either single layer type or double layer type and are mainly used in induction machines and synchronous machines.

There are different types of armature winding used in alternator. The windings can be classified as

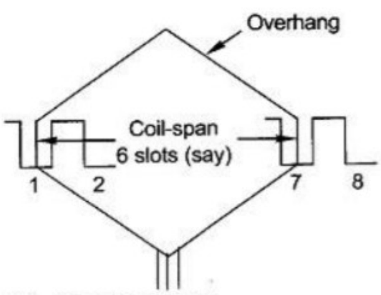
1. Single phase and poly phase armature winding.
2. Concentrated winding and distributed winding.
3. Half coiled and whole coiled winding.
4. Single layer and double layer winding.
5. Lap, wave and concentric or spiral winding and
6. Full pitched coil winding and fractional pitched coil winding.

Practically there are two types of windings

- Single-Layer Winding
- Two-Layer (Or Double-Layer).

Single-Layer Winding

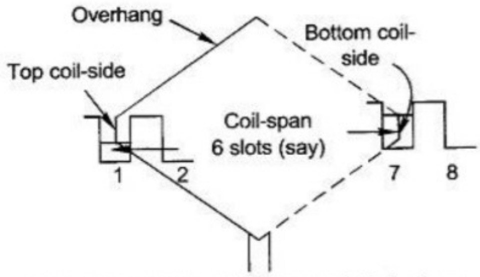
In a single-layer winding each coil-side of a coil occupies the whole slot as shown in Figure (a)



(a) Single-layer coil

Double Layer Winding

In a double-layer winding one coil-side of a coil occupies the upper position in one slot and the second coil-side occupies the lower position in a slot displaced from the first coil-side by the coil-span as shown in Figure (b).



(b) Double-layer coil (bottom coilside is shown dotted)

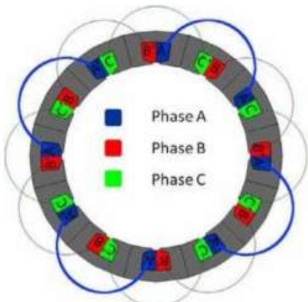
Concentrated Armature Winding

- The concentrated winding is employed where the number of slots on the armature is equal to the number of poles in the machine.
- This armature winding of alternator gives maximum output voltage but not exactly sinusoidal.

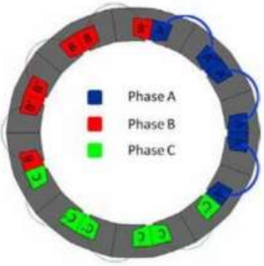
Distributed Armature Winding of Alternator

- For obtaining smooth sinusoidal emf wave from, conductors are placed is several slots under single pole.
- This armature winding is known as distributed winding.
- Although distributed armature winding in alternator reduces emf, still it is very much usable due to following reason.
    1. It also reduces harmonic emf and so waveform is improved.
    2. It also diminishes armature reaction.
    3. Even distribution of conductors, helps for better cooling.

4. The core is fully utilized as the conductors are distributed over the slots on the armature periphery.



Distributed Winding



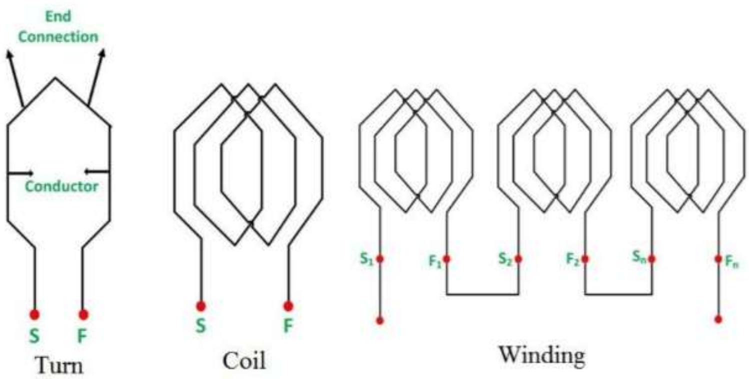
Concentrated Winding

Difference between Concentrated & Distributed Winding

Sl. No	Concentrated Winding	Distributed Winding
1	The coils of concentrated winding are co-axial. This means, all the winding coils have the same magnetic axis.	The coils of distributed windings are not co-axial. They are rather distributed in various slots along the air-gap periphery.
2	The emf induced in the such winding is independent of pitch and distribution factor. $E = 4.44 f Ø Z$	The emf induced in the distributed winding is dependent on the value of pitch factor K_p and distribution factor K_d. $E = 4.44\ K_c K_d\ f Ø Z$
3	This type of winding is used in transformer, electromagnets etc.	Distributed winding is used in armature winding of induction machine, synchronous machine, DC machine etc.
4	For concentrated winding, the number of pole is equal to number of slots.	Number of pole is not equal to number of slots.

WINDING TERMINOLOGY

- **Conductor:** it is the active length of the wire or strip embedded in slot on the armature periphery.
- **Turn**: A turn consists of two conductors connected to one end by an end connector.
- **Coil**: A coil is formed by connecting several turns in the series.
- **Winding**: A winding is formed by connecting several coils in series.



The beginning of the turn or coil is identified by the symbol **(S)** meaning **Start**, and the end of the turn or coil is represented by the symbol **(F)** meaning **Finish**.

Pole Pitch:

- The angular distance between the central line of one pole to the central line of the next pole is called Pole Pitch.
- It is usually expressed in terms of slots per pole.
- A pole pitches always 180 electrical degrees regardless of the number of poles on the machine.

Slot Pitch:

- The distance between the centers of two conjugative slots is called as slot pitch. It is expressed in electrical degree.

$$slot\ pitch\ \beta = \frac{Pole\ pitch}{No\ of\ slot\ per\ pole}$$

Coil Span / Coil Pitch:

- The distance between the two sides of a coil is called the coil span or coil pitch.
- **Full Pitch Coil:** A coil having a span equal to 180 electrical degree is called a full pitch coil.
- **Short Pitch Coil:** A coil having a span less than 180 electrical degree is called Short pitch coil or frictional pitch coil. It is also called chorded coil.
  A stator winding using frictional pitch coil is called chorded winding. if the span of coil is reduced by an angle **α** electrical degrees, the coil span will be (180-α) electrical degree.

Coil Span Factor or Pitch factor:

This factor basically represents the effect of short pitch winding on generated emf across the winding terminals of electrical machine.

- Pitch Factor or Coil Span Factor is definite as the ratio of emf generated in short pitch coil to the emf generated in full pitch coil.
- It is denoted by K_c or K_p and its value is always less than unity.
- The coil span factor is also called chording Factor.

Mathematically its is expressed as

$$K_c = \frac{Actul\ voltage\ generated\ in\ coil\ due\ to\ short\ pitch}{Voltage\ generated\ in\ full\ pitch\ coil}$$

Expression for Kc.

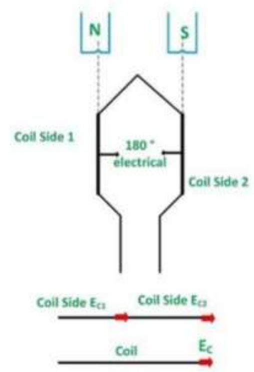


Fig-1

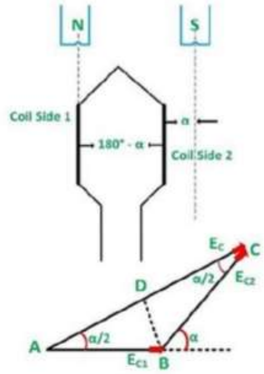


Fig-2

Emf Develop Due To Full Pitch:

In case of full pitch coil, the two coil sides span a distance exactly equal to the pole pitch of 180 electrical degrees.

As result, the voltage generated in full pitch coil is such that the coil side voltages are in phase as show in fig-1.

Let Ec1 and Ec2 be the voltages generated in the coil sides and Ec the resultant coil voltage.

$$E_c = E_{c1} + E_{c2}$$

$$E_{c1} = E_{c2} = E \quad \text{(Say)}$$

Since Ec1 and Ec2 are in phase, the resultant coil voltage Ec is equal to their arithmetic sum.

$$E_c = E_{c1} + E_{c2} = 2E$$

Emf Develop Due To Short Pitch Coil:

If the coil span of single coil is less than the pole pitch of 180 (elect. degree), the voltage generated in each coil side are not in phase. The resultant Coil voltage Ec is equal to Phasor sum of Ec1 and Ec2.

From the triangle ABC

AB=BC=E

From the triangle ABD, AD= $E\cos\frac{\alpha}{2}$

From the triangle BDC, DC= $E\cos\frac{\alpha}{2}$

$$E_C = E\cos\frac{\alpha}{2} + E\cos\frac{\alpha}{2} = 2\,E\cos\frac{\alpha}{2}$$

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

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

For a Full pitch coil $\alpha = 0^0, \cos\frac{\alpha}{2} = 1$ *and For a Short Pitch* $K_C < 1$

Advantage of Short Pitching or Chording:

1) Shortens the ends of the winding and therefore there is a saving in the conductor material.
2) Reduces effects of distorting harmonics, and thus the waveform of the generated voltage is improved and making it approach a sine wave.

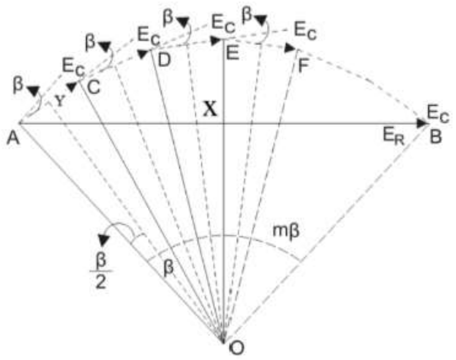
Distribution Factor or the Breadth Factor

The **Distribution Factor** or the **Breadth Factor** is defined as the ratio of the actual voltage obtained to the possible voltage if all the coils were concentrated in a single slot. The distribution factor is also always less than unity.

It is denoted by $\mathbf{K_d}$ and is given by

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

Expression for Kd :



Emf Induced If Winding is Concentrated:

Angular displacement between the slots $\beta = \frac{180}{m}$

The number of slots per pole per phase is m.

Induced emf per coil side is E_C.

Let us represent the emfs induced in different coils of one phase under one pole as AC, DC, DE, and EF and so on. They are equal in magnitude, but they differ from each other by an angle β.

If we draw bisectors on AC, CD, DE, EF ——. They would meet at common point O.

Emf induced in each coil side,

From the triangle OAY $\sin\frac{\beta}{2} = \frac{AY}{OA}$

$$AY = OA \sin\frac{\beta}{2}$$

$$E = AC = 2\ OA \sin\frac{\beta}{2}$$

As the slot per pole per phase is m, the total arithmetic sum of all induced emfs per coil sides per pole per phase,

$$\boldsymbol{E = AC = m \times 2 \times\ OA \sin\frac{\beta}{2}}$$

Emf Induced If Winding Is Distributed :

The resultant emf would be AB, as represented by the figure,

$$AD = 2\ AX$$

In OXA Triangle

$$\frac{AX}{OA} = \sin\frac{m\beta}{2}$$

$$AX = OA\ \sin\frac{m\beta}{2}$$

$$E_R = AB = 2 \times AX = 2\ \times OA\ \sin\frac{m\beta}{2}$$

mβ is also known as the phase spread in electrical degree.

$$K_d = \frac{2 \times OA\ \sin\frac{m\beta}{2}}{m \times 2 \times\ OA \sin\frac{\beta}{2}}$$

$$\boldsymbol{K_d = \frac{\sin\frac{m\beta}{2}}{m \sin\frac{\beta}{2}}}$$

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

The flux wave may consist of space field harmonics also, which give rise to the corresponding time harmonics in the generated voltage waveform. A 3rd harmonic component of the flux wave, may be imagined as produced by three poles as compared to one pole for the fundamental component.

Let the rth harmonic becomes r times the fundamental component

☞ **The pitch factor for the rth harmonic is given as,**

$$K_C = \cos\frac{r\alpha}{2}$$

e.g If 3rd Harmonics : $K_C = \cos\frac{3\alpha}{2}$

5th Harmonics: $K_C = \cos\frac{5\alpha}{2}$ etc

☞ **The Distribution factor for the rth harmonic is given as,**

$$K_d = \frac{\sin\frac{m\,r\,\beta}{2}}{m\sin\frac{r\,\beta}{2}}$$

e.g If 3rd Harmonics : $K_d = \frac{\sin\frac{m\,3\,\beta}{2}}{m\sin\frac{3\,\beta}{2}}$

5th Harmonics : $K_d = \frac{\sin\frac{m\,5\,\beta}{2}}{m\sin\frac{5\,\beta}{2}}$ e.tc

☞ **The frequency is also changed in harmonics condition** i.e $f_r = r \times f$

If the fundamental frequency is f=50 Hz

Then frequency at 3rd harmonics is given by f=3 × 50 = 150 Hz and so on.

2.5 Derive E.M.F equation. (Solve numerical problems)

Let,

P be the number of poles

ϕ is Flux per pole in Webers

N is the speed in revolution per minute (r.p.m)

f be the frequency in Hertz

$\mathbf{Z_{ph}}$ is the number of conductors connected in series per phase

$\mathbf{T_{ph}}$ is the number of turns connected in series per phase

$\mathbf{K_c}$ is the coil span factor

K_d is the distribution factor

Flux cut by each conductor during one revolution is given as Pϕ Weber.

Time taken to complete one revolution is given by 60/N sec

According to Faraday's Laws of electromagnetic Induction

Average EMF induced per conductor will be given by the equation

$$E_{avg} = \frac{d\emptyset}{dt}$$

$$E_{avg} = \frac{P\emptyset}{\frac{60}{N}} = \frac{P\emptyset\, N}{60}\ Volt$$

Average EMF induced per phase will be given by the equation shown below

$$E_{avg} = \frac{P\emptyset\, N}{60} \times Z_{ph}\ Volt$$

As we know that $N = \frac{120f}{P}$

put the value of N in above equation

$$E_{avg} = \frac{P\emptyset}{60} \times \frac{120f}{P} Volt$$

$$E_{avg} = 2\emptyset f\ Volt$$

R.M.S. value of e.m.f./phase = Average value/phase × form factor

= 2 Ø f Z 1.11 = 2.22 Ø f Z volts

Er.m.s. / phase = 2.22 Ø f Z volts

If Kp and Kd are the pitch factor and distribution factor of the armature winding, then,

$E_{r.m.s.}$ / phase = 2.22 K_c K_d Ø f Z volts

Sometimes the turns (T) per phase rather than conductors per phase are specified, in that case

$E_{r.m.s.}$ / phase = 4.44 Kc Kd Ø f T volts (∵Z=2T)

2.6 Explain Armature reaction and its effect on emf at different pf of load.

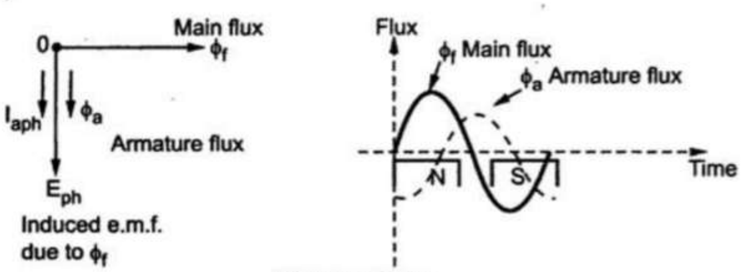
The effect of Armature (stator) flux on the flux produced by the rotor field poles is called **Armature Reaction**.

When the current flows through the armature winding of the an alternator, a flux is produced by the resulting MMF. This armature flux reacts with the main pole flux, causing the resultant flux to become either less than or more than the original main field flux.

For this purpose the alternator operation is considered under different operating power factor and loads as follows:

- Unity power factor (Pure Resistive load)
- Zero power factor lagging load (Pure Inductive Load)
- Zero power factor leading load (Pure Capacitive Load)

<u>Unity Power Factor (Pure Resistive Load)</u>

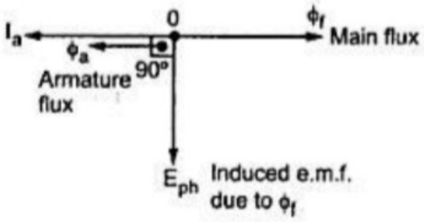


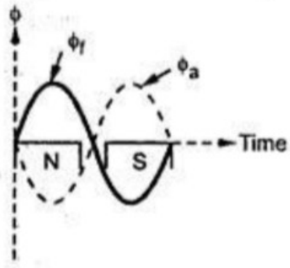
Unity power Factor

Let resistive load connected to the alternator. The induced emf per phase E_{ph} derives a current per phase I_{ph} through the load. E_{ph} and I_{ph} both are in phase. If the main flux $Ø_f$ generates E_{ph} , E_{ph} lags $Ø_f$ by an angle 90^0. The armature current I_a establish the armature flux $Ø_a$ where $Ø_a$ and I_a are in same direction. From the above figure $Ø_a$ can opposes as well as assist. Therefore average flux in air gap remains constant. In spite of maintaining a constant air gap flux distribution gets distorted. This effect of armature reaction under unit power factor condition of load is known as **Cross Magnetising effect** of armature reaction.

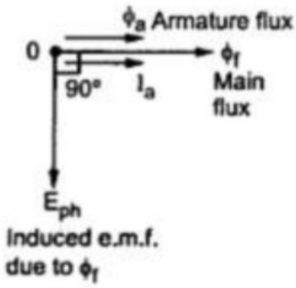
Zero Power Factor Lagging Load (Pure Inductive Load)

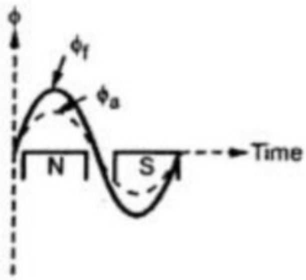
Let a pure inductive load connected to the alternator. The induced emf per phase E_{ph} derives a current per phase I_{ph} through the load. I_{ph} lags E_{ph} by an angle 90^0 . If the main flux $Ø_f$ generates E_{ph} , E_{ph} lags $Ø_f$ by an angle 90^0. The armature current I_a establish the armature flux $Ø_a$ where $Ø_a$ and I_a are in same direction. From the above figure $Ø_a$ and $Ø_f$ are exactly in opposite direction to each other. This effect of armature reaction is known as **Demagnetising effect** of armature reaction.





Zero power factor leading load (Pure Capacitive Load)





Let a pure Capacitive load connected to the alternator. The induced emf per phase E_{ph} derives a current per phase I_{ph} through the load. I_{ph} leads E_{ph} by an angle 90^0 . If the main flux $Ø_f$ generates E_{ph} , E_{ph} lags $Ø_f$ by an angle 90^0. The armature current I_a establish the armature flux $Ø_a$ where $Ø_a$ and I_a are in same direction. From the above figure $Ø_a$ and $Ø_f$ are in same direction to each other. This effect of armature reaction is known as **Magnetising Effect** of armature reaction.

Thus to summarize, the effect of armature reaction mmf on main filed mmf of alternator is tabulated below.

SL NO	**LOADING CONDITION**	**EFFECT OF ARMATURE REACTION**
1	Unity Power Factor	Cross-magnetizing
2	Zero Power Factor Lagging	Purely demagnetizing
3	Zero Power Factor Leading	Purely magnetizing

2.7 Draw the vector diagram of loaded alternator. (Solve numerical problems)

Alternator on Load

When the load on the alternator varied its terminal voltage V (phase value) of the alternator varied. The variation is due to

(i) Voltage drop I_aRa where Ra is the armature resistance per phase.

(ii) Voltage drop I_aX_L where X_L is the armature leakage reactance per phase.

(iii) Voltage drop because of armature reaction.

(i) Armature Resistance (R_a)

Since the armature or stator winding has some resistance, there will be an IaRa drop when current (Ia) flows through it. The armature resistance per phase is generally small so that IaRa drop is negligible for all practical purposes.

(ii) Armature Leakage Reactance (X_L)

When current flows through the armature winding, flux is set up and a part of it does not cross the air-gap and links the coil sides. This leakage flux alternates with current and gives the winding self-inductance. This is called armature leakage reactance. Therefore, there will be IaX_L drop which is also effective in reducing the terminal voltage.

(iii) Armature Reaction Reactance (X_{AR})

The load is generally inductive and the effect of armature reaction is to reduce the generated voltage. Since armature reaction results in a voltage effect in a circuit caused by the change in flux produced by current in the same circuit, its effect is of the nature of an inductive reactance. Therefore, armature reaction effect is accounted for by assuming the presence of a fictitious reactance X_{AR} in the armature winding. The quantity X_{AR} is called reactance of armature reaction. The value of X_{AR} is such that I_aX_{AR} represents the voltage drop due to armature reaction.

Equivalent Circuit

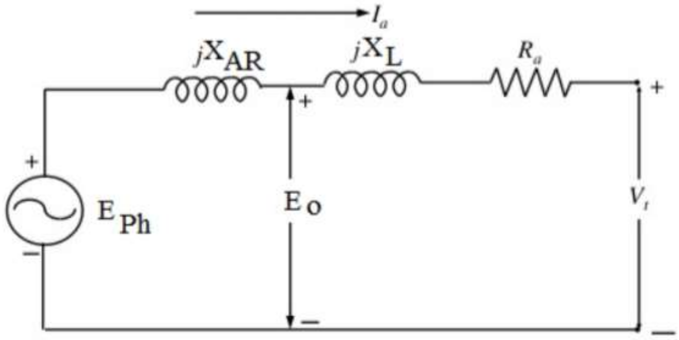


Fig shows the equivalent circuit of the loaded alternator for one phase.

All the quantities are per phase. Here

E_{Ph} = No-load e.m.f.

V = Terminal voltage.

$\therefore\ E_O = V + I_a\,(Ra + j\,X_L)$

and $E_{Ph} = E_O + I_a\,(\,j\,X_{AR}\,)$

$E_{Ph} = V + I_a\,(Ra + j\,(X_L + X_{AR}\,))$

$$\mathbf{E_{Ph} = V + I_a\,(R_a + j\,X_S)}$$

Where Xs is known as Synchronous Reactance.

Synchronous Reactance (X_S) : The overall reactance of armature winding is called **Synchronous Reactance (X_S)** i.e $\mathbf{X_S = X_{AR} + X_L}$

Synchronous Impedance (Z_S):

The impedance of the armature winding is obtained by combining the resistance and its synchronous reactance is known as **Synchronous Impedance (Z_S)**

$$Z_S = \sqrt{R_a^2 + X_S^2}\ \Omega / \ phase$$

PASOR DIAGRAM OF ALTERNATOR

The phasor diagram of alternator is drawn for lagging, leading and unit power factor respectively.

I_a= Armature Current in Amp

R_a= Armature Resistance in Ω

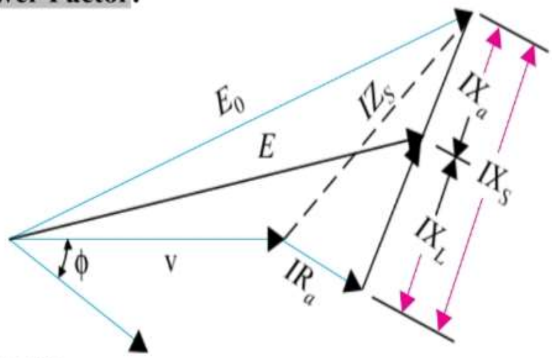
X_s= Synchronous Reactance in Ω

Cos Ø = Power Factor

E_{ph} = Emf Generated per phase in Volt

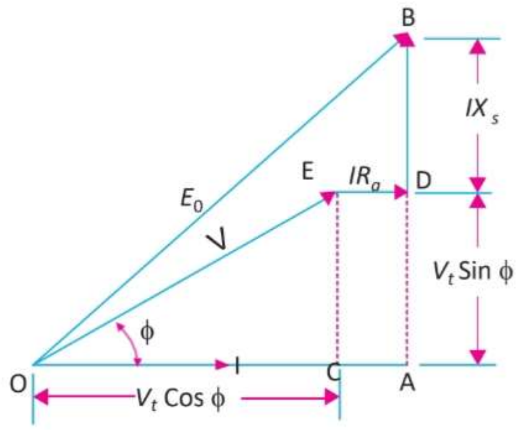
V_t= Terminal Voltage in Volt

For Lagging Power Factor:



From the Phasor Diagram

In triangle OEC



$OE=V_t$

$OC=V_t \cos Ø$

$CE=AD=V_t \sin Ø$

$AC=I_aR_a$

$OB=E_{ph}$

In triangle OAB

$$OB^2 = (OA)^2 + (AB)^2$$

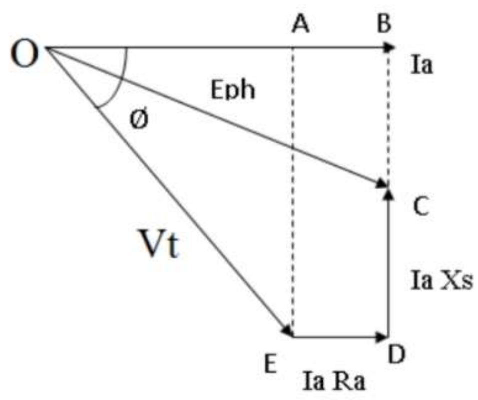
$$OB^2 = (OC + AC)^2 + (AD + DB)^2$$

$$E_{Ph}{}^2 = (V_t \cos Ø + I_aR_a)^2 + (V_t \sin Ø + I_aX_s)^2$$

$$\boldsymbol{E_{Ph}{}^2 = \sqrt{(V_t \cos Ø + I_aR_a)^2 + (V_t \sin Ø + I_aX_s)^2}}$$

$$\boldsymbol{E_L = \sqrt{3}E_{Ph}}$$

For Leading Power Factor:



From the figure

$CD = I_a X_s$

$ED = AB = I_a R_a$

$BC = BD - CD$

In triangle OBC

$OE = V_t$

$OA = V_t \cos Ø$

$BD = V_t \sin Ø$

$OC = E_{ph}$

$OC^2 = (OB)^2 + (BC)^2$

$OC^2 = (OA + AB)^2 + (BD = CD)^2$

${E_{Ph}}^2 = (V_t \cos Ø + I_a R_a)^2 + (V_t \sin Ø = I_a X_s)^2$

$\boldsymbol{{E_{Ph}}^2 = \sqrt{(V_t \cos Ø + I_a R_a)^2 + (V_t \sin Ø = I_a X_s)^2}}$

$\boldsymbol{E_L = \sqrt{3} E_{Ph}}$

For Unit Power Factor:

In unit power factor $\cos Ø = 1$ i.e $Ø = 0^o$

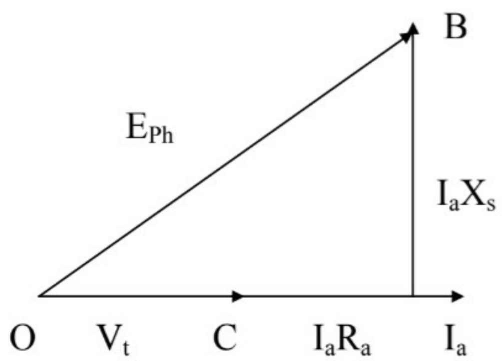
The phase displacement between voltage and current is 0^o i.e they are in phase

From The Triangle OAB

$OC = Vt$

$AC = I_a R_a$

$AB = I_a X_s$



$OB^2 = (OA)^2 + (AB)^2$

$OB^2 = (OC + AC)^2 + (AB)^2$

${E_{Ph}}^2 = (V_t + I_a R_a)^2 + (I_a X_s)^2$

$\boldsymbol{{E_{Ph}}^2 = \sqrt{(V_t + I_a R_a)^2 + (I_a X_s)^2}}$

$\boldsymbol{E_L = \sqrt{3} E_{Ph}}$

ALTERNATIVE METHOD IN COMPLEX FORM:

R_a= Armature Resistance in Ω

X_s= Synchronous Reactance in Ω

Cos Ø = Power Factor

Ø = Power factor Angle

I_a= Armature Current in Amp

$\overrightarrow{I_a} = I_a\angle - \emptyset$ (For Lagging Power Factor)

$\overrightarrow{I_a} = I_a\angle\emptyset$ (For Leading Power Factor)

$\overrightarrow{I_a} = I_a\angle 0$ (For Unit Power Factor)

E_{ph} = Emf Generated per phase in Volt

$\overrightarrow{E_{Ph}} = E_{Ph}\angle\delta$

V_t= Terminal Phase Voltage in Volt

$\overrightarrow{V_t} = V_t\angle 0$

For Lagging Power Factor:

$\overrightarrow{E_{Ph}} = V_t\angle 0 + I_a\angle - \emptyset\,(R_a + jX_s)$

$\overrightarrow{E_{Ph}} = E_{Ph}\angle\delta$

For Leading Power Factor

$\overrightarrow{E_{Ph}} = V_t\angle 0 + I_a\angle\emptyset(R_a + jX_s)$

$\overrightarrow{E_{Ph}} = E_{Ph}\angle\delta$

For Unit Power Factor

$\overrightarrow{E_{Ph}} = V_t\angle 0 + I_a\angle 0(R_a + jX_s)$

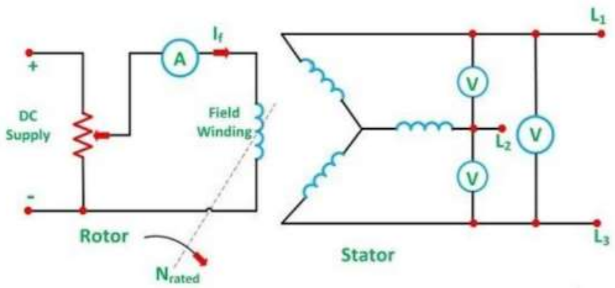
$\overrightarrow{E_{Ph}} = E_{Ph}\angle\delta$

In above Three cases E_{ph} is magnitude of Emf generated per Phase and δ is load angle.

2.8 State and explain testing of alternator (open circuit and short circuit methods)

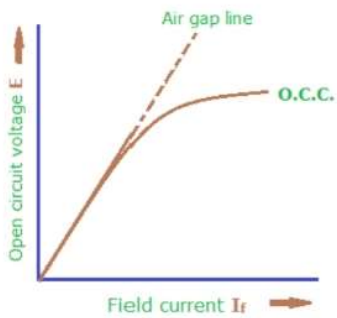
☞ Open-Circuit Characteristic (O.C.C)

The Open-circuit characteristic of an alternator is the curve between armature terminal voltage (phase value) on open circuit and the field current when the alternator is running at rated speed.

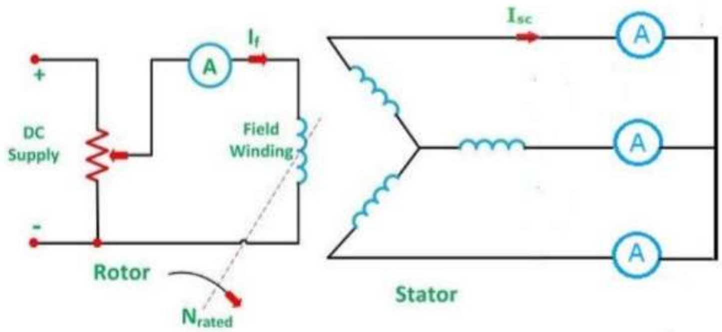


The Figure shows the circuit for determining the O.C.C. of an alternator.
The following steps are taken for Open Circuit Test

- The alternator is run on no-load at the rated speed.
- The field current If is gradually increased from zero (by adjusting field rheostat) until open-circuit voltage E_0 (phase value) is about 50% greater than the rated phase voltage.
- The graph is drawn between open-circuit voltage values and the corresponding values of I_f as shown in Figure.

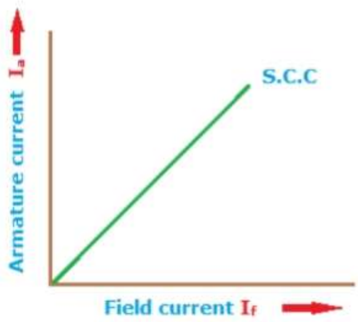


☞ **Short-Circuit Characteristic (S.C.C.)**



The following steps are taken for Short Circuit Test

- In a short-circuit test, the alternator is run at rated speed and the armature terminals are short-circuited through identical ammeters.
- Only one ammeter need be read; but three are used for balance.
- The field current If is gradually increased from zero until the short-circuit armature current I_{SC} is about twice the rated current.
- The graph between short-circuit armature current I_{SC} and field current I_f gives the Short-Circuit Characteristic (S.C.C.) as shown in Figure.



2.9 Determination of voltage regulation of Alternator by direct loading and synchronous impedance method.

Voltage Regulation:

The voltage regulation of an alternator is defined as the change in terminal voltage from no-load to full-load (the speed and field excitation being constant) divided by full-load voltage.

$$\%\ \text{Voltage regulation} = \frac{\text{No load voltage} - \text{Full load voltage}}{\text{Full load voltage}} \times 100$$

$$\%\ \text{Voltage regulation} = \frac{E_O - V}{V} \times 100$$

Where E_o = No load Voltage and V= Full load Voltage

- The value of the regulation not only depends on the load current but also on the power factor of the load.
- For lagging and unity p.f. conditions there is always drop in the terminal voltage hence regulation values are always positive.
- While for leading capacitive load conditions, the terminal voltage increases as load current increases. Hence regulation is negative in such cases.

Determination of Voltage Regulation (Small Machines)

- In the case of small machines, the regulation may be found by direct loading.
- The alternator is driven at synchronous speed and the terminal voltage is adjusted to its rated value *V*.
- The load is varied until the wattmeter and ammeter (connected for the purpose) indicate the rated values at desired p.f. Then the entire load is thrown off while the speed and field excitation are kept constant.
- The open-circuit or no-load voltage E_o is read.

$$\%\ \text{Voltage regulation} = \frac{E_O - V}{V} \times 100$$

V = Rated terminal voltage

E_o= No load induced e.m.f.

Determination of Voltage Regulation (Larger Machines)

In the case of large machines, the cost of finding the regulation by direct loading becomes prohibitive.

Methods OF Determining Voltage Regulation:

1. Synchronous Impedance Or E.M.F. Method.
2. The Ampere-Turn Or M.M.F. Method.
3. Zero Power Factor Or Potier Method.

SYNCHRONOUS IMPEDANCE METHOD

The measurement of synchronous impedance is done by the following methods. They are known as

- DC resistance test
- Open-circuit characteristic (O.C.C.)
- Short-Circuit characteristic (S.C.C.)

☞ DC Resistance Test

The armature resistance Ra per phase is determined by using direct current and the voltmeter-ammeter method. This is the d.c. value. The effective armature resistance (a.c. resistance) is greater than this value due to skin effect. we take the effective resistance 1.5 times the d.c. value i.e ($R_a = 1.5\ R_{dc}$).

☞ Open-circuit characteristic (O.C.C)

The Open-circuit characteristic of an alternator is described previously.

☞ Short-circuit characteristic (S.C.C)

The Short-circuit characteristic of an alternator is describe previously.

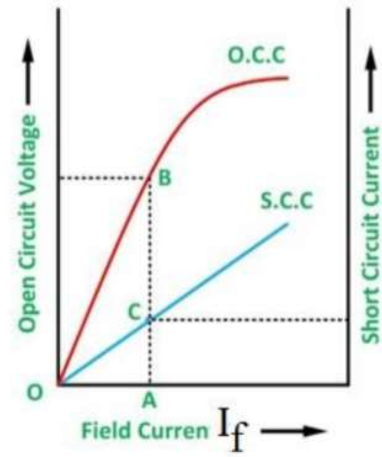
Calculation of Synchronous Impedance

The following steps are given below for the calculation of the synchronous impedance.

- The open circuit characteristics and the short circuit characteristic are drawn on the same curve.
- Determine the value of short circuit current I_{sc} and gives the rated alternator voltage per phase.

The synchronous impedance Z_S will then be equal to the open circuit voltage divided by the short circuit current at that field current which gives the rated EMF per phase.

$$Z_S = \frac{Open\ Circuit\ Voltage\ per\ Phase}{Short\ Circuit\ Armature\ Current}\ (for\ the\ same\ value\ of\ filed\ Current)$$



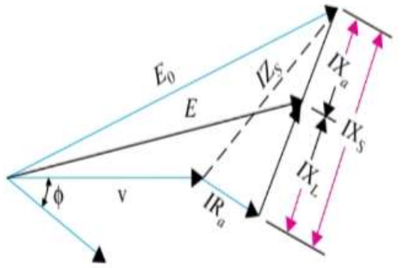
From the above graph, consider the field current I_f = OA that produces rated alternator voltage per phase. Corresponding to this field current, the open circuit voltage is AB

Therefore,

$$Z_S = \frac{AB\ (in\ Volts)}{AC\ (in\ Amperes)}$$

The synchronous reactance is determined as $X_S = \sqrt{Z_S^2 - R_a^2}$

Once we know R_a and X_s, the phasor diagram can be drawn for any load and any p.f. Fig shows the phasor diagram for the usual case of inductive load; the load p.f. being cos Ø lagging. From the phasor diagram, the phasor sum of V, I_aR_a and I_aX_s gives the no-load e.m.f. E_o.



$$\overrightarrow{E_O} = \vec{V} + \overrightarrow{I_a}\ \cos\angle - \emptyset\,(R_a + jX_s)$$

$$\%\ \text{Voltage regulation} = \frac{\mathrm{E_O} - \mathrm{V}}{\mathrm{V}} \times 100$$

2.10 Explain parallel operation of alternator using synchro-scope, dark and bright lamp method.

The process of connecting two alternators or an alternator and an infinite bus bar system in parallel is known as synchronizing.

- Running machine is the machine which carries the load.
- Incoming machine is the alternator or machine which has to be connected in parallel with the system.

Necessity of Parallel Operation of Alternators

The following are the Necessity of operating alternators in parallel:

- ☞ **Continuity of service**:
  If one alternator fails, the continuity of supply can be maintained through the other healthy units. This will ensure uninterrupted supply to the consumers.

- ☞ **Efficiency**. The load on the power system varies during the whole day; being minimum during die late night hours. Since alternators operate most efficiently when delivering full-load, units can be added or put off depending upon the load requirement. This permits the efficient operation of the power system.

- ☞ **Maintenance and repair**. It is often desirable to carry out routine maintenance and repair of one or more units. For this purpose, the desired unit/units can be shut down and the continuity of supply is maintained through the other units.

- ☞ **Load growth**. The load demand is increasing due to the increasing use of electrical energy. The load growth can be met by adding more units without disturbing the original installation.

Conditions to be satisfied for Parallel Operation:

- The phase sequence of the incoming machine voltage and the bus bar voltage should be identical.
- The RMS line voltage (terminal voltage) of the bus bar or already running machine and the incoming machine should be the same.
- The phase angle of the two systems should be equal.
- The frequency of the two terminal voltages (incoming machine and the bus bar) should be nearly the same. Large power transients will occur when frequencies are not nearly equal.

Methods of Synchronization:

The following two methods are use for synchronisation:

(i) By synchroscope

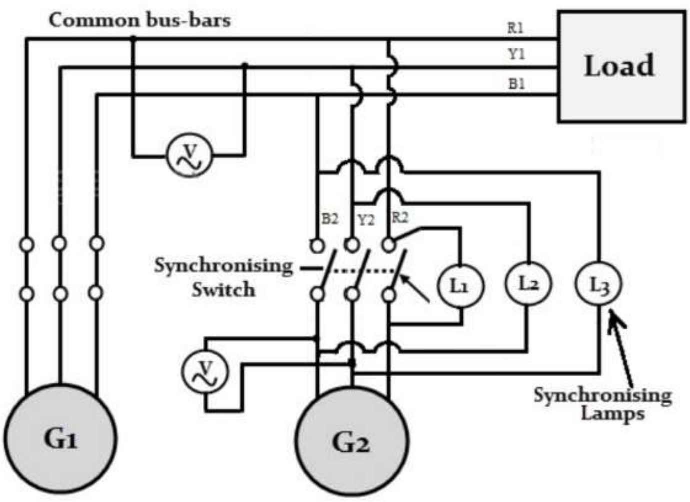
(ii) By Three Lamp (one dark, two bright) method

The Synchroscope compares the incoming voltage of the machines concerning the three-phase system. The figure of synchroscope shown below. It has a dial places on the circular calibrated scale on the motor. The position of the dial shows the phase difference between the incoming voltage and the infinite machines.

- The scale of the Synchroscope marks with two arrows which indicate the direction of rotation of the pointer. The arrow indicates the clockwise and the anti- clockwise direction of the pointer. The clockwise arrows show too fast movement and the anti-clockwise direction show slow rotation of the incoming machine.

- The arrow shows the movement of the machine concerning the bus bar. If the frequency of the incoming machine is more than that of the generator, the pointer deflects towards the fast mark. And if the frequency of the incoming machine is less then the pointer deflects towards the slow mark.
- When the frequency of the incoming machine voltage and the infinite machine becomes equal, the pointer becomes stationary. When their frequency differs then the pointer deflects in one direction.
- The deflection of pointer shows the speed of the incoming machines, i.e., the frequency of the incoming machine is higher or lower than that of the infinite bus or not. The frequency and phase position are controlled by the input of the prime mover.
- When the pointer moves slowly and passes through the zero phase point, the circuit breaker is closed, and the incoming alternator connects to the bus. The Synchroscope does not give any information about the phase sequence. It shows relation only on one phase.

Three lamp method

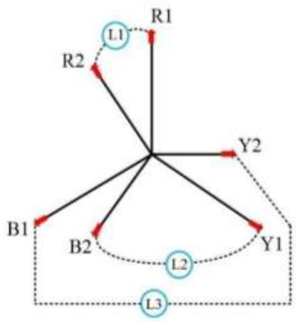


- In this method of synchronizing, three lamps L1, L2 and L3 are connected as shown in Figure The lamp L1 is straight connected between the corresponding phases (R1 and R2) and the other two are cross-connected between the other two phases.

- Thus lamp L2 is connected between Y1 and B2 and lamp L3 between B1 and Y2.

- When the frequency and phase of the voltage of the incoming alternator is the same as that of the bus bars, the straight connected lamps L1 will be dark while cross-connected lamps L2 and L3 will be equally bright.

- At this instant, the synchronization is perfect and the switch of the incoming alternator can be closed to connect it to the bus bars.



- In Phasor Diagram the phasors R1, Y1 and B1 represent the bus bars voltages

- Phasors R2, Y2 and B2 represent the voltages of the incoming alternator.

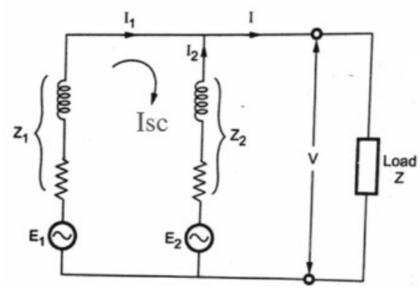
- At the instant when R1 is in phase with R2, voltage across lamp L1 is zero and voltages across lamps L2 and L3 are equal.

- Therefore, the lamp L1 is dark while lamps L2 and L3 will be equally bright.

- At this instant, the switch of the incoming alternator can be closed.

- Thus incoming alternator gets connected in parallel with the bus bars.

2.11 Explain distribution of load by parallel connected alternators.



Consider two alternators with identical speed/load characteristics connected in parallel as shown in Figure.

Let E_1, E_2 = induced e.m.f.s per phase

Z_1, Z_2 = synchronous impedances per phase

Z = load impedance per phase

I_1, I_2 = currents supplied by two machines

V = common terminal voltage per phase

$$V = E_1 - I_1 Z_1 = E_2 - I_2 Z_2$$

$$I_1 = \frac{E_1 - V}{Z_1}, \qquad I_2 = \frac{E_2 - V}{Z_2}$$

$$I = I_1 + I_2$$

$$\frac{E_1 - V}{Z_1} + \frac{E_2 - V}{Z_2}$$

$$V = (I_1 + I_2)Z = IZ$$

Circulating current on no load is

$$I_C = \frac{E_1 - E_2}{Z_1 + Z_2}$$

Short Questions

Q: **What is the general system requirements of alternator?**

A: For the generation of emf, there should be two basic systems.
(i) magnetic field system to produce the magnetic field
(ii) Armature system which houses the conductors on which the EMF is to be induced.

Q: **Will the alternators have rotating armature system or stationary armature system?**

A: Generally in alternators, the armature is stationary and the field rotates. Small low-voltage alternators often have a rotating armature and a stationary field winding.But in large alternators rotating armature field type is used.

Q: **What are the advantages of stationary armature and rotating field system?**

A: (i) The stationary armature coils can be insulated easily.
(ii) Higher peripheral speed can be achieved in the rotor.
(iii) Cooling of the winding is more efficient.
(iv) Only two slip rings are required to give DC supply to the field system
(v) Output current can be easily supplied to the load circuit. Slip-rings and brushes are not necessary.

Q: **What is meant by stator? What is meant by rotor?**

A: In any electrical machine (AC/DC motor or generator) the stationary member is called as stator. Similarly in all machines the rotating member is known as rotor.

Q: **What is meant by stator? What is meant by rotor?**

A: In any electrical machine (AC/DC motor or generator) the stationary member is called as stator. Similarly in all machines the rotating member is known as rotor.

Long Questions

1. Derive the emf equation of an alternator
2. Short notes on synchronous reactance.
3. Short notes on S.C and O.C characterstic of alternator.
4. Draw the phasor diagrams of an alternator under lagging p.f, unit p.f and leading p.f. Condition and specify the various components of phasor diagram
5. Derive the expression for distribution factor of an alternator. What is voltage regulation of alternator.
6. Write short notes on Synchronisation.
7. What is armature reaction in an alternator? Explain with phaser diagram the effect of generated voltage when the load is (a) Resistive (b) Pure inductive (c) Pure capacitive.
8. What do you mean by single phasing? What happens if single phasing occurs when the 3-Ø induction motor is running and when it is s stationary?
9. Define chording factor and distribution factor.
10. Explain parallel operaton of single phase alternator.
11. What is voltage regulation of an alternator? How do you find the regulation of an alternator by synchronous impedance method?
12. Explain Pitch factor and distribution factor.
13. Describe the synchronous impedance method for determination of voltage regulation of alternator.
14. Explain parallel operation of 3-phase alternator.
15. State condition for parallel operation of 3-phase alternators and explain the method of synchronization by 3 lamp method with circuit and phasor diagram.

Problems

1. Find the regulation up of an 20KW, 220V single phase, 50 Hz alternator with armature resistance of 1 ohm/phase at 0.8 lagging p.f. The alternator measure 200V on open circuit and 40 A on short circuit at a particular excitation.

2. A 3-phase 10 pole star connected alternator runs at 600 rpm. It has 120 stator slots with 8 conductors per slot. Determine the line and phase emf if the flux per pole is 56 mwb.

3. Calculate the speed and open circuited line and phase voltage of a 4 pole, 3 phase, 50 hz star connected alternator with 36 slots and 30 conductor per slot. The flux per pole is 0.0496 wb and is sunisoidally distributed.

4. Calculate the no load terminal voltage of a 3- phase, 8 pole, star connected alternator running at 750 rpm, flux per pole 55 mwb , no of slots on the armature is 72, number of conductor per slot =10, $k_d = 0.96$, assume full pitch coils.

5. A 3-phase, 50 Hz, 8 pole alternator has a star connected winding with 120 slots and 8 conductoctors per slot. The flux per pole is 0.05 wb sinusoidally distributed. Determine the phase and line voltage. Calculate the pitch factor for the windings which has 36 slots, 4 poles and coil span is 1 to 7 .

6. A 3-phase, 16 pole alternator has a star connected winding with 144 slots and 10 conductors per slot. The flux per pole is 0.04 wb and speed is 375 rpm. The turns per phase may be assumed to be series connected. Find the line value of generated EMF.

7. A 1200 kva, 6600 V, 3-phase alternator (star connected) with a resistance of 0.4 ohm and reactance of 6 ohm per per phase delivers full load current at p.f 0.8 lagging and normal rated voltage. Estimate the terminal voltage for the same excitation and load current at 0.8 p.f leading .

8. A 2000 Kva, 6600 v, 3-phase , star connected synchronous generator has a resistance of 0.4 ohm per phase and a synchronous reactance of 4.5 ohm per phase, calculate the percentage chanbe in terminal voltage when the rated out put of 2000 KVA at a power factor of 0.8 lagging is switched off. The speed and exiting current remain unchanged. Calculate the pitch factor for the windings which has 36 slots, 4 poles and coil span is 1 to 7 .

9. 3phase, 10 pole , Y connected alternator runs at 600 rpm. It has 120 stator slots with 8 conductors per slot and the conductors of each phase are connected in series. Determine the phase and line emf if the flux per pole is 56 mwb. Assume full pitch coil.

10. In a 50KVA, star connected, 400 V , 3-phase 50 Hz alternator, the effective armaturevresistance is 0.25 ohm/phase. The synchronous reactance is 3.2 ohm/phase and leakage reactance is 0.5 ohm/phase. Determine the rated load and unity power factor: (a) internal emf (b) no load emf (c) percentage regulation on full load (d) Value of synchronous reactance which replaces armature reaction.

11. A 100 kva, 3000v, 50 hz, 3-Ø alternator has effective armature resistance of 0.2 Ω. A field current of 40 A produce a shortcircuit current of 200A and open circuit emf of 1040 V (line value). Calculate the full load voltage regulation at 0.8 lag and 0.8 pf lead. Draw the phasor diagrams .

12. A-3 phase star connected alternator is rated at 1600 KVA, 13500V. The arematyure effective resistance and synchronous reactance are 1.5 ohm and 30 ohm respectively per phase. Caculate the percentage regulation for load of 1280 KW at power factors of 0.8 leading and unity.

13. A 3-Ø, 10 KVA, 400 V , 50 Hz, Y (star) connected alternator supplies the rated load at 0.8 p.f. Lag. If armature resistance is 0.5 ohm and synchronous reactance is 10 ohm, find the voltage regulation for 0.8 lagging power factor and also draw the vector diagram.

14. A 1000KVA, 66 KV, 3-Ø star connected synchronous generator has a synchronous reactance of 25 Ω per phase. It supplies full load current at 0.8 lagging p.f and a rated terminal voltage. Compute the terminal voltage for the same excitation when the generator supplies full load current at 0.8leading p.f . Neglate the stator resistance.

15. A 3 phase , 10 ole Y connected alternator runs at 600 rpm. It has 120 stator slots with 8 conductor of each phase are connected in series. Determine the phase and line emfs if the flux per pole is 56 mwb. Assume full pitch coils.

16. A 500 volt , 50 kva, 1-phase alternator has an effective resistance of 0.2 ohm. A field current of 10A produces an armature current of 200 A on short circuit. Calculate the full load regulation at 0.8 p.f .

17. A 415V, 30KVA, 50 Hz star connected alternator supplies the rated load at 0.75 p.f lag. If the armature resistance and synchronous reactance is 0.6 Ω and 15Ω respectively find the voltage regulation for 0.75 lagging p.f and draw the phasor diagram.

18. A 3-phase synchronous generator has 4 poles and runs at 1500 rpm. The total no of armature conductor is 360 accomodated in 36 slots. If flux per pole is 0.05 wb. Determine the magnitude of emf for a star connected armature with short pitch by two slot pitches.

19. 3 phase 16 pole alternator has a star connected winding with 144 slots and 10 conductors/ slot. The flux/pole is 30 mwb sinusoidally distributed. Find the frequency, the phase and line voltage if the speed is 375 RPM.

20. An alternator runs at 250 rpm and generates 50 HZ. There are 216 slots, each containing 5 conductors arranged in full pitched winding for 3-phase star connection. All the conductors of each phase are in series and the flux per pole at no load over the pole pitch is 35 mwb. Calculate the emf induced in each phase winding and the terminal voltage.