Scheme of Evaluation

II/IV B.Tech (Regular\Supplementary) DEGREE EXAMINATION

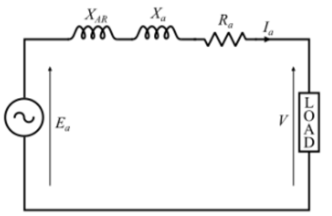
July/August,2023 | **Electrical & Electronics Engineering**

Fourth Semester | **Induction Motors & Synchronous Machines**

Time: Three Hours | **Maximum:** 70 Marks

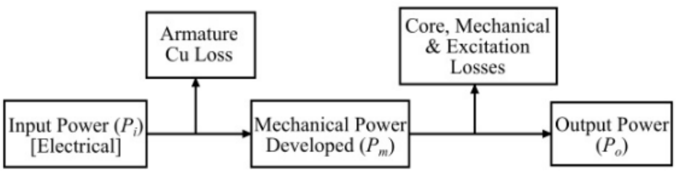
Answer question 1 compulsory. **(14X1 = 14Marks)**
Answer one question from each unit. **(4X14=56 Marks)**

			CO	BL	M
1	a)	Define slip of an induction motor. Ans: "Slip" in an AC induction motor is defined as:As the speed of the rotor drops below the stator speed, or synchronous speed, the rotation rate of the magnetic field in the rotor increases, inducing more current in the rotor's windings and creating more torque.	CO1	L1	1M
	b)	What is the condition for maximum running torque of a three phase induction motor? Ans: R_2=SX_2	CO1	L1	1M
	c)	What is the necessity of starter in three phase induction motors? Ans:To limit the starting current.	CO1	L1	1M
	d)	What is induction generator? Ans: An induction generator or *asynchronous generator* is a type of alternating current (AC) electrical generator that uses the principles of induction motors to produce electric power. Induction generators operate by mechanically turning their rotors faster than synchronous speed.	CO1	L1	1M
	e)	What is the role of centrifugal switch in a single phase induction motor? Ans: The switch is used to disconnect the starting winding of the motor once the motor approaches its normal operating speed.	CO2	L1	1M
	f)	How do you obtain the equivalent circuit of a single phase induction motor? Ans: The equivalent circuit of a Single Phase Induction Motor can be obtained by two methods named the Double Revolving Field Theory and Cross Field Theory.	CO2	L1	1M
	g)	What are the applications of shaded pole motors? Ans: The motor can be used for toys, hair dryers, desk fans, cooling fans, slide projectors, advertising displays, Air conditioner etc.	CO2	L1	1M
	h)	Define voltage regulation of an alternator. Ans: The voltage regulation of an alternator or synchronous generator is defined as the rise in the terminal voltage when the load is decreased from full-load rated value to zero. The speed and field current of the alternator remain constant	CO3	L1	1M
	i)	List the various conditions for successful parallel operation of alternators. Ans: 1.The phase sequence of the bus bar voltages and the incoming alternator voltage must be the same.2.The bus bar voltages and the terminal voltage of the incoming alternator must be in phase.3.The terminal voltage of the incoming alternator must be equal to the bus bar voltages.	CO3	L1	1M
	j)	What is the effect of armature reaction at lagging power factor loads of an alternator? Ans. Demagnetizing Effect	CO3	L1	1M
	k)	Show the equivalent circuit of an alternator. Ans:	CO3	L1	1M



			CO	BL	M
	l)	List out the various starting methods of synchronous motors. Ans: 1.Starting with an external prime mover 2.Starting with damper windings 3.Pony motor 4.Synduction Motor starting.	CO4	L1	1M
	m)	What are the effects of hunting in a synchronous motor? 1. It may lead to loss of synchronism. 2. Produces mechanical stresses in the rotor shaft. 3. Increases machine losses and cause temperature rise. 4. Cause greater surges in current and power flow. 5. It increases possibility of resonance.	CO4	L1	1M
	n)	Draw the power flow diagram for synchronous motor.	CO4	L3	1M

Ans:

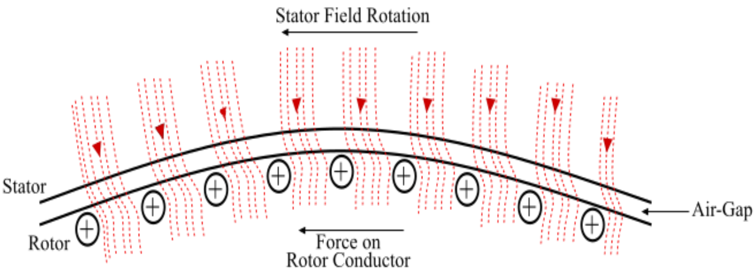


Unit-I

			CO	BL	M
2	a)	Explain the principle of operation of a three phase induction motor. Ans:	CO1	L2	7M

A *three phase induction motor* has a stator and a rotor. The stator carries a 3-phase winding called as *stator winding* while the rotor carries a short circuited winding called as *rotor winding*. The stator winding is fed from 3-phase supply and the rotor winding derives its voltage and power from the stator winding through *electromagnetic induction*. Therefore, the working principle of a 3-phase induction motor is fundamentally based on *electromagnetic induction*.

Consider a portion of a three phase induction motor (see the figure). Therefore, the working of a three phase induction motor can be explained as follows −



When the stator winding is connected to a balanced three phase supply, a rotating magnetic field (RMF) is setup which rotates around the stator at synchronous speed (N_s). Where, NS=120f/P
The RMF passes through air gap and cuts the rotor conductors, which are stationary at start. Due to relative motion between RMF and the stationary rotor, an EMF is induced in the rotor conductors. Since the rotor circuit is short-circuited, a current starts flowing in the rotor conductors. Now, the current carrying rotor conductors are in a magnetic field created by the stator. As a result of this, mechanical force acts on the rotor conductors. The sum of mechanical forces on all the rotor conductors produces a torque which tries to move the rotor in the same direction as the RMF.Hence, the induction motor starts to rotate. From, the above discussion, it can be seen that the three phase induction motor is self-starting motor. The three induction motor accelerates till the speed reached to a speed just below the synchronous speed.

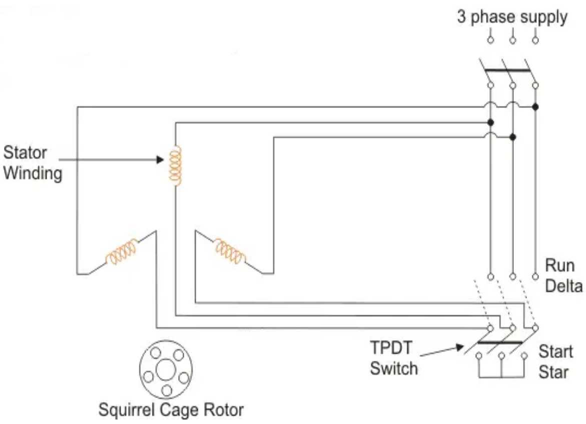
b) A three phase, 4 pole, 50 Hz induction motor has a full load speed of 1440 rpm. For this motor, calculate the following: CO1 L3 7M

(a) the synchronous speed
(b) the full load slip and (c) rotor frequency.

(OR)

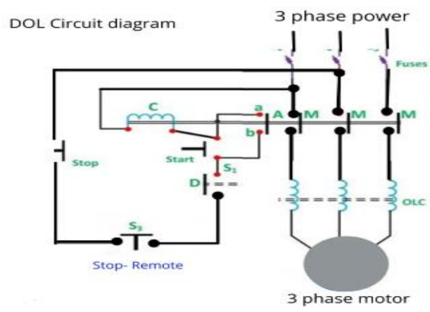
3 a) Explain the DOL & Star-Delta Starting methods of 3-phase induction motor. CO1 L3 7M

A **star delta starter** is the most commonly used method for the starting of a 3 phase induction motor. In star delta starting an induction motor is connected in through a star connection throughout the starting period. Then once the motor reaches the required speed, the motor is connected in through a delta connection.
A star- delta starter will start a motor with a star connected stator winding. When motor reaches about 80% of its full load speed, it will begin to run in a delta connected stator winding. **S**tar-delta starter is a type of reduced voltage starter. We use it to reduce the starting current of the motor without using any external device or apparatus. This is a big advantage of a star delta starter, as it typically has around 1/3 of the inrush current compared to a DOL starter. The starter mainly consists of a TPDP switch which stands for Tripple Pole Double Throw switch. This switch changes stator winding from star to delta. During starting condition stator winding is connected in the form of a star. Now we shall see how a star delta starter reduces the starting current of a three-phase induction motor.



The word DOL means Directly On-Line. The starter in which the motor is connected directly in line with the switch is called the DOL starter. It has only one contactor. There is no starting circuit to reduce the amount of starting current. The simple DOL starter example is your home water pump, it has a motor that you can run directly without any method of soft starting. All you need is a switch to connect the motor to the electricity directly.

Operating Principle And Wiring Diagram



b) Explain the Various Speed control methods of 3-phase induction motor with neat sketches. CO1 L2 7M

Ans:

The Speed of Induction Motor is changed from Both Stator and Rotor Side. The speed control of three phase induction motor from **stator side** are further classified as :

1.V / f control or frequency control.2. Changing the number of stator poles.3. Controlling supply voltage.4. Adding rheostat in the stator circuit.

The speed controls of three phase induction motor from **rotor side** are further classified as:1.Adding external resistance on rotor side.2Cascade control method.3.Injecting slip frequency emf into rotor side.

Voltage Control Method:

In this method of speed control of induction motor, the supply voltage is varied using an autotransformer. Practically, we cannot increase the voltage levels beyond the rated voltage as the insulation stress will increase and lead to insulation failure.

$$T=[3\times60/2\pi N_s]\times sE_2^2R_2/R_2^2+(sX_2)^2$$

During running, the slip is tiny; hence $(sX_2)^2$ can be neglected

$$\Rightarrow T\ \alpha\ sE_2^2$$

And the E.M. F induced in the rotor (E_2) is proportional to the stator voltage (V)

$$\Rightarrow T\ \alpha\ sV_2^2$$

The above equation makes it evident that torque will likewise drop if the supply voltage is reduced. If the voltage reduces for a given load, the slip will increase while reducing the speed to maintain the load torque constant. Voltage can be reduced to a suitable value; the motor will become unstable if we reduce the voltage below this value. This type of speed control of induction motor is rarely employed since it results in an overheated induction motor because a minor change in speed necessitates a considerable voltage reduction.

Frequency Control Method

The flux density of the stator core is inversely proportional to the applied frequency. To reduce the core losses and for the better performance of the motor, the maximum flux density (B_m) must be maintained constant.

$$B_m\ \alpha\ V/f$$

So, to maintain the maximum flux density as constant, we must vary the voltage and frequency. This method cannot be possible for frequencies greater than the rated frequency as voltage also needs to be increased, which is impossible due to insulation constraints. This method requires variable voltage and variable frequency converters, which makes this method an expansive one. Still, this method offers a wide range of speed control without affecting the efficiency of the motor.

Pole Changing Speed Control

This method of speed control of induction motor can only be applied to the squirrel cage induction motor. The number of poles in the rotor of a slip ring induction motor is fixed, whereas the squirrel cage rotor can be adapted to any number of poles. The poles of the induction motor can be changed in two ways.

1.Multiple winding sets 2.Consequent pole changing

In the first method, we use multiple winding sets of stator windings designed for different sets of poles. While in operation, any one of them can be connected according to the speed requirements of the user, and the other sets will keep in open. We know that $N_s=120f/P$

As the number of poles increases, the speed will be reduced. This method can only vary the speed in steps, and it is expansive as it involves multiple stator windings.

In the method of consequent pole changing, we can obtain another set of poles by reversing the coils. This method can only give two sets of speeds.

Stator Resistance Method

This speed control method of induction motor is similar to the voltage control method. It requires three rheostats to be connected in series with each phase of the stator winding to reduce the voltage and achieve the required speed. As there is some power loss due to the rheostats, this method will be preferred for the low-rating machines for a small duration. This method is more advantageous in starting than speed control.

Rotor Resistance Control Method

This speed control method of induction motor can be possible for the slip-ring induction motor only as we cannot access the rotor of the squirrel cage induction motor. This method connects external resistance to the rotor through the slip rings and brushes while running. Hence it leads to the reduction of the torque.

$$T=[3\times60/2\pi N_s]\times sE_2^2R_2/R_2^2+(sX_2)^2$$

For the given stator voltage, the E.M.F induced in the rotor E_2 is constant, and during running, the slip is tiny; hence $(sX_2)^2$ can be neglected.

$$\Rightarrow T\ \alpha\ s/R_2$$

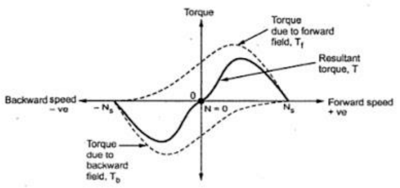
But to maintain the load torque constant, the speed of the rotor will decrease, and the slip will increase. As the operating slip increases, this method is inefficient and unsuitable for a wide range of applications. The main benefit of this method is that starting torque increases with the addition of external resistance.

Unit-II

4 a) Explain why single phase induction motor is not self-starting. CO2 L2 7M

Ans:

According to the double field revolving theory, we can resolve any alternating quantity into two components. Each component has a magnitude equal to half of the maximum magnitude of the alternating quantity, and both these components rotate in the opposite direction to each other.



double field revolving theory

Double field revolving theory

For example

A flux, φ can be resolved into two components. Each of these components rotates in the opposite direction i. e **if one $\varphi_{m/2}$ is rotating in a clockwise direction** then the other $\varphi_{m/2}$ **rotates in an anticlockwise direction**. When we apply a single-phase AC supply to the stator winding of a induction motor, it produces its flux of magnitude, φ_m.According to the double field revolving theory, this alternating flux, φ_m is divided into two components of **magnitude $\varphi_{m/2}$**.Each of these components will rotate in the opposite direction, with the synchronous speed, Ns.Let us call these two components of flux as forwarding components of flux, φ_f or T_f, and the backward component of flux, φ_b or T_b.The resultant of these two components of flux at any instant of time gives the value of instantaneous stator flux at that particular instant. Now at starting condition, both the forward and backward components of flux are exactly opposite to each other. Also, both of these components of flux are equal in magnitude. So, they cancel each other, and hence the net torque experienced by the rotor at the starting condition is zero. So, the single-phase induction motor is not self-starting motor.

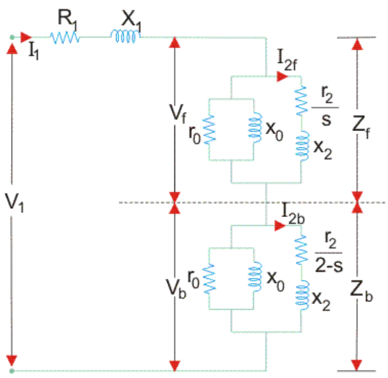
b) Explain the equivalent circuit of a single phase induction motor. CO2 L2 7M

Ans:

<u>Equivalent Circuit of a Single Phase Induction Motor</u>

There is a difference between single phase and three phase equivalent circuits. The single phase induction motor circuit is given by double revolving field theory which states that-

A stationary pulsating magnetic field might be resolved into two rotating fields, both having equal magnitude but opposite in direction. So the net torque induced is zero at standstill. Here, the forward rotation is called the rotation with slip s and the backward rotation is given with a slip of (2 – s). The equivalent circuit is-



Induction motor (single phase) equivalent circuit referred to the stator

In most of the cases the core loss component r_0 is neglected as this value is quite large and does not affect much in the calculation.

Here, Z_f shows the forward impedance and Z_b shows the backward impedance.

Also, the sum of forward and backward slip is 2 so in case of backward slip, it is replaced by (2 – s).

R_1 = Resistance of stator winding.

X_1 = Inductive reactance of the stator winding.

X_m = Magnetising reactance.

R_2' = Rotor Reactance with referred to stator.

X_2' = Rotor inductive reactance with referred to stator.

Calculation of Power of Equivalent Circuit

1. Find Z_f and Z_b.
2. Find stator current which is given by Stator voltage/Total circuit impedance.
3. Then find the input power which is given by
   Stator voltage × Stator current × Cos(Θ)
   Where, Θ is the angle between the stator current and voltage.
4. Power Developed (P_g) is the difference between forward field power and backward power. The

forward and backward power is given by the power dissipated in the respective resistors.

5. The rotor copper loss is given by- slip × P_g.
6. Output Power is given by-
   $P_g - s \times P_g$ – Rotational loss.
   The rotational losses include friction loss, windage loss, Core loss.
7. Efficiency can also be calculated by diving output power by input power.

(OR)

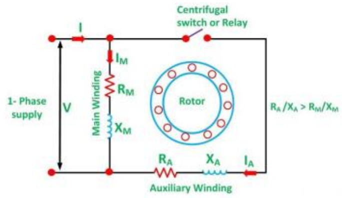
5 a) Explain the resistance phase splitting method of starting of a single phase induction motor. CO2 L2 7M

Ans:

<u>Resistance Split-Phase Motor Induction Motor</u>

If an auxiliary winding of much fewer turns, a smaller wire is placed at 90°electrical to the main winding, it can start a single-phase induction motor. With lower inductance and higher resistance, the current will experience less phase shift than the main winding.

The **Split Phase Motor** is also known as a **Resistance Start Motor**. It has a single cage rotor, and its stator has two windings known as main winding and starting winding. Both the windings are displaced 90 degrees in space. The main winding has very low resistance and a high inductive reactance whereas the starting winding has high resistance and low inductive reactance. The connection diagram of the motor is shown below:



A resistor is connected in series with the auxiliary winding. The current in the two windings is not equal as a result, the rotating field is not uniform. Hence, the starting torque is small, of the order of 1.5 to 2 times the stated running torque. At the starting of the motor both the windings are connected in parallel.As soon as the motor reaches the speed of about **70** to **80 %** of the synchronous speed the starting winding is disconnected automatically from the supply mains. If the motors are rated about 100 Watt or more, a centrifugal switch is used to disconnect the starting winding and for the smaller rating motors relay is used for the disconnecting of the winding.A relay is connected in series with the main winding. In the starting, the heavy current flows in the circuit, and the contact of the relay gets closed. Thus, the starting winding is in the circuit, and as the motor attains the predetermined speed, the current in the relay starts decreasing. Therefore, the relay opens and disconnects the auxiliary winding from the supply, making the motor runs on the main winding only.

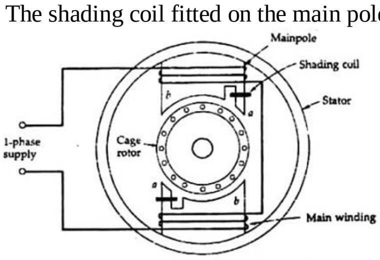
b) Explain the construction and principle of operation of a shaded pole motor. CO2 L2 7M

Ans:

A shaded pole induction motor is a simple single-phase induction motor, which is self-starting with one of the poles shaded by the copper ring. The other name of the copper ring is a shaded ring, where it acts as a secondary winding motor. It rotates only in one direction particularly and reverses moment is impossible. This motor has very high power induction losses and also has a very low power factor. Starting torque induced in the motor is very low. Due to these reasons, it has poor efficiency. This, it has low power ratings. It is also a salient pole split phase motor.

<u>Shaded Pole Motor Construction</u>:

It has two poles as shown in the basic construction. This motor is made up of stator and a rotor which is cage type. The stator has projected poles also called main poles in it. The supply winding on the main poles forms the main winding. The poles in this motor are unequally divided into two halves where the smaller portion is shaded portion that carries a copper band. Copper ring, which is a single turn is fitted on the smaller part. This ring is also known as a shading coil. The shading coil fitted on the main pole is called shading pole.



In the core, when a single phase is applied an alternating flux is generated. This flux links with the shaded coil in fraction amounts. Then voltage gets induced in the coil due to the variation in the flux linking. Hence, the shaded portion is short-circuited due to which it produces the circulating current in it. In such a way, the direction is opposing the main flux. The main core flux is opposed by the flux in the ring that is developed by the circulating current. Hence, flux is induced in the shaded portion of the motor along with the unshaded portion with a phase difference, which is lagging behind the unshaded pole flux. There is also a space displacement that is less than 90 degrees between a shaded ring flux and the main motor flux. Due to this space displacement, a rotating magnetic field is produced which leads to a torque on the cage motor. In order to obtain reversal in the direction of rotation, we have to provide two shading coils.

<u>Unit-III</u>

6 a) Derive the emf equation of an alternator when the winding is distributed and short pitched. CO3 L3 7M

Ans:

EMF Equation of Alternator

Let, P = Number of poles

φ = Flux per pole in webers

N = Rotor speed in RPM

f = Frequency of the induced EMF in Hz

Z = Number of conductors in series per phase

T = Number of coils or turns per phas$e$

As the flux per pole is φ, hence, in one revolution, each stator conductor cut a flux of,

$$d\varphi=P\varphi d\varphi=P\varphi$$

And the time taken to complete one revolution is,

$$dt=60N dt=60N$$

Therefore, according electromagnetic induction, the average EMF induced in one stator conductor is given by,

$$\text{EMF per conductor}=d\varphi dt=P\varphi N60$$

Since there are Z conductors in series per phase, thus,

$$\text{EMFperphase}=\text{EMFperconductor}\times Z=(P\varphi N60)\times Z_{\text{EMF}}\text{perphase}Z$$

$$\because \text{Speed of the rotor,}N=120fP\because \text{Speedoftherotor,}N=120fP$$

$$\therefore \text{EMFperphase}=P\varphi Z60\times 120fP=2f\varphi Z\ldots(1))$$

Equation (1) gives the value of average induced EMF per conductor per phase. Since, one turn has two conductors, i.e., $Z = 2T$ and hence the expression for the average induced EMF per phase can be written as,

$$\text{EMF per phase}=4f\varphi T\ldots(2)\text{EMFperphase}=4f\varphi T\ldots(2)$$

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

$$\text{F.F.}=\text{RMS Value /AverageValue}$$

$$\because \text{RMSvalueofEMF/phase}=(\text{AverageValue/Phase})\times \text{FormFactor}\because$$

$$\therefore \text{RMSvalueofEMF/phase}=4f\varphi T\times(\text{RMSValueAverageValue}$$

For a sinusoidal voltage wave, form factor = 1.11.

Thus, the RMS value of the induced EMF per phase can be written as,

$$E_{RMS}/\text{Phase}=1.11\times 4f\varphi T=4.44f\varphi T\ldots(3)$$

Equation (3) gives the RMS value of the induced EMF with the following assumptions −

- All the armature conductors are concentrated in one stator slot.
- Coils got have full pitch.

Again, taking the coil span factor and distribution factor into account, the actual induced EMF per phase is given by,

$$E_{ph}=4.44kckdf\varphi T\ldots(4)E_{ph}=4.44kckdf\varphi T\ldots(4)$$

$$(\because Z=2T)(\because Z=2T)$$

$$\therefore E_{ph}=2.22kckdf\varphi Z\ldots(5)\therefore E_{p}h=2.22kckdf\varphi Z\ldots(5)$$

Equations (3) and (4) are called as the **EMF equation of an alternator**.

Sometimes, the coil span factor and the distribution factor of a winding are combined into a single factor, known as **winding factor (k_w)** which is given by,

$$k_w=k_c k_d$$

Hence, the EMF equation can also be written as,

$$E_{ph}=4.44kwf\varphi T\ldots(6)E_{ph}=4.44kwf\varphi T\ldots(6)$$

For a star-connected alternator, the line voltage is the √3 times of the phase voltage, thus,

$$E_L=\sqrt{3}E_{ph}$$

b)	A three phase, 10 pole, star connected alternator runs at 600 rpm. It has 120 slots with 8 conductors per slot and conductors of each phase are connected in series. The armature winding short pitched by 2 slots. Determine the phase and line electromotive forces if the flux per pole is 56 mWb. Ans:	CO3	L3	7M

(OR)

7 a) Explain Two-reaction theory of salient pole synchronous generator with a neat Sketch. CO3 L3 7M

<u>Blondel's Two Reaction Theory</u>

Andre Blondel proposed the Two Reaction Theory of synchronous machines. The two reaction theory was proposed to resolve the given armature MMF (Fa) into two mutually perpendicular components, with one located along the d-axis of the salient-pole rotor. This component is known as the **direct axis or d-axis component** and is denoted by (Fd).

The other component is located perpendicular to the d-axis of the salient pole rotor. It is known as the **quadrature axis or q-axis component** and denoted by (Fq). The d-axis component (Fd) is either magnetising or de-magnetising while the q-axis component (Fq) results in a cross-magnetising effect.

If ψ is the angle between the armature current (Ia) and the excitation voltage (Ef) and the amplitude of the armature MMF is given by (Fa), then

The *d-axis component (*Fd*)* is given by,

$$Fd=Fa\sin\psi$$

And *the q-axis component* (Fq) is given by,

$$Fq=Fa\cos\psi$$

$$E_f = V + R_a I_d + R_a I_q + jX_d I_d + jX_q I_q$$

$$E_f = V + R_a I_a + jX_d I_d + jX_q I_q$$

b) Explain any method to synchronize the alternator to an infinite bus bar. CO3 L2 7M

The process of connecting two alternators or an alternator and an infinite bus bar system in parallel is known as synchronizing. Generally, alternators are used in a power system where they are parallel with many other alternators.

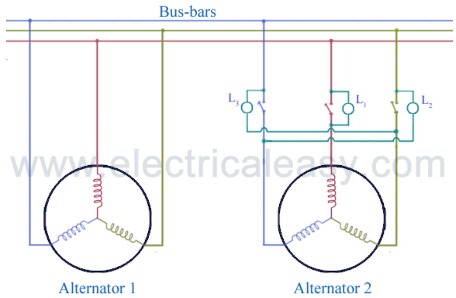
Synchronization methods for three phase alternator :

1.Synchronization using incandescent lamp

2.Synchronization using synchroscope.

Conditions to be satisfied for synchronizing alternators are:

Synchronization Of Alternator Using Incandescent Lamp



Let, alternator 2 is to be synchronized in a grid and the alternator 1 is already in the grid as shown in above figure. The alternator 2 is connected to grid through three synchronizing lamps (L1, L2 and L3) as shown in above figure. If the speed of the alternator 2 is not such that the frequency of output voltage is equal to the frequency of the grid, there will also be a phase difference in the voltages, and in this case the lamps will flicker. Three lamps are connected asymmetrically, because if they were connected symmetrically, they would glow or dark out simultaneously (if the phase rotation is same as that of bus-bars). Asymmetrically connected lamps indicate whether the incoming machine is running slower or faster. If the alternator 2 is running slower, the phase rotation of alternator 2 will appear to be clockwise relative to the phase rotation of the grid and the lamps will light up in the order 3,2,1;3,2,1 .... If the alternator 2 is running faster, the phase rotation of alternator 2 will appear to be anticlockwise relative to the phase rotation of the grid and the lamps will light up in the order1,2,3;1,2,3....When the speed of the alternator 2 reaches so that, the frequency and phase rotation of output voltage is similar to that of the grid voltage, lamp L1 will go dark and lamps L2 and L3 will dimly but equally glow (as they are connected between different phases and due to this there will be phase difference of 120 degree). The synchronization is done at this very moment. This method of synchronization is sometimes also known as '**two bright and one dark method**'.

<u>Unit-IV</u>

8 a) Explain the principle of operation of a synchronous motor with neat diagrams. CO4 L2 7M

The **stator** and the **rotor** are the two main parts of the synchronous motor. The stator is the stationary part of the motor and the rotor is their rotating part. The stator is excited by the three-phase supply, and the rotor is excited by the DC supply. The term excitation means the magnetic field induces in the stator and rotor of the motor. **The main aim of the excitation is to convert the stator and rotor into an electromagnet.**

The three-phase supply induces the north and south poles on the stator. The three-phase supply is sinusoidal. The polarity (positive and negative) of their wave changes after every half cycle and because of this reason, the north and south pole also varies. Thus, we can say that the rotating magnetic field develops on the stator. The magnetic field develops on the rotor because of the DC supply. The polarity of the DC supply becomes **fixed,** and thus the stationary magnetic field develops on the rotor**.** The term stationary means their north and south pole remains fixed. The speed at which the rotating magnetic field rotates is known as the **synchronous speed**. The synchronous speed of the motor depends on the frequency of the supply and the number of poles of the motor.

$$N_S = 120f/P$$

When the opposite pole of the stator and rotor face each other, the force of attraction occurs between them. The attraction force develops the torque in the anti-clockwise direction. The torque is the kind of force that moves the object in rotation. Thus, the poles of the rotor dragged towards the poles of the stator.

After every half cycle, the pole on the stator is reversed. The position of the rotor remains the same because of the inertia. **The inertia is the tendency of an object to remain fixed in one position.** When the like pole of the stator and rotor face each other, the force of repulsion occurs between them and the torque develops in the clockwise direction. Let understand this with the help of the diagram. For simplicity, consider the motor has two poles. In the below figure, the opposite pole of the stator and rotor face each other. So the attraction force develops between them. After the half cycle, the poles on the stator reverse. The same pole of the stator and rotor face each other, and the force of repulsion develops between them. The non-unidirectional torque pulsates the rotor only in one place and because of this reason the synchronous motor is not self-starting.

	b)	A 2300 V three phase star connected synchronous motor has synchronous impedance of (0.2+j2.2) Ω/phase. The motor is operating at 0.5 power factor leading with line current of 200 A. Determine back emf per phase.	CO4	L3	7M

(OR)

9	a)	Explain the concepts of V & Inverted V curves of synchronous motor with neat diagrams.	CO4	L2	7M

The graphs plotted between armature current (I_a) and field current (I_f) for different constant loads are known as the V curves of the synchronous motor.

The power factor of a synchronous motor can be controlled by changing the field excitation, i.e., by variation of field current (I_f). Also, the armature current (I_a) changes with the change in the excitation or field current (I_f).

Now, let us assume that the synchronous motor is operating at no-load. If the field current (I_f) is increased from a small value, the armature current (I_a) decreases until I_a becomes minimum. The power factor of the motor corresponding to this minimum armature current is unity. Up to the point of minimum armature current, the motor was operating at lagging power factor. If a graph is plotted between armature current (I_a) and field current (I_f) at noload, the lowest curve in Figure-1 is obtained. In order to obtain a family of curves as shown in Figure-1, the above procedure is to be repeated for various increased loads.

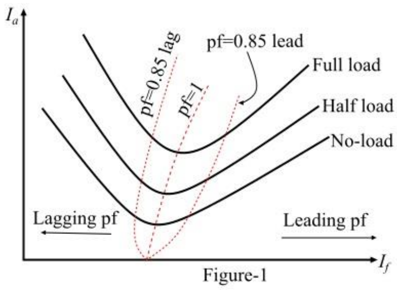


Figure-1

Because the shape of the curves plotted between armature current (I_a) and field current (I_f) resembles the letter "V", thus these curves are known as *V curves of a synchronous motor*.

The point corresponding to unity power factor is the point at which the armature current is minimum. The curve connecting the unity power factor points (or lowest points) of all V curves for various loads is called the unity power factor compounding curve. Similarly, the compounding curves for 0.85 power factor lag and 0.85 power factor lead are shown by dotted curves in Figure-1.

Therefore, *the compounding curves may be defined as the loci of constant power factor points on the V curves of a synchronous motor*. The compounding curves give the information about the manner in which the field current (I_f) of the motor should be varied to maintain constant power factor under changing loads.

Hence, the V curves are useful in adjusting the field current of the synchronous motor. From the V curves shown in Figure-1, it is clear that decreasing the field current below that for minimum armature current results in lagging power factor. Similarly, increasing the field current beyond the level of minimum armature current results in leading power factor. Therefore, by changing the field excitation of a synchronous motor, the reactive power supplied to or consumed from the power system can be controlled.

Inverted V Curves of Synchronous Motor

Inverted V curves of a synchronous motor are defined as the graphs plotted between power factor and field current (I_f) of the motor.

A family of inverted V curves of a synchronous motor obtained by plotting the power factor versus field current is shown in Figure-2.

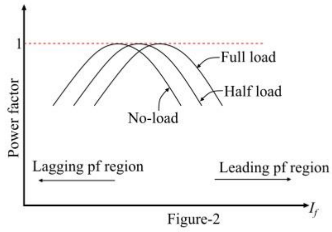


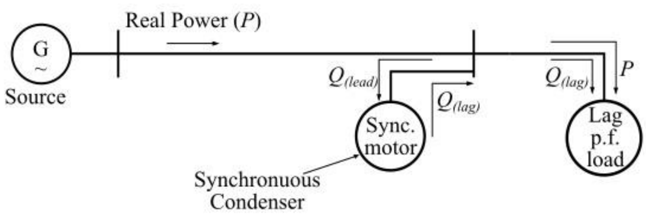
Figure-2

The peak point on each of these curves indicates unity power factor. From the curves, it can be seen that the field current (I_f) for unity power factor at full-load is greater than the field current (I_f) for unity power factor at no-load.

The inverted V curves also show that if the synchronous motor at full-load is operating at unity power factor then removal of the mechanical load from the shaft of the motor causes the motor to operate at a leading power factor.

b) What is synchronous condenser? Explain the use of synchronous condenser. CO4 L2 7M

An over-excited synchronous motor running on no-load is called the **synchronous condenser**. It is also known as *synchronous capacitor* or *synchronous compensator or synchronous phase modifier*.



A synchronous motor can deliver or absorb reactive power by changing the DC excitation of its field winding. It can be made to draw a leading current from the supply with over-excitation of its field winding and therefore, it supplies lagging reactive power (or absorbs leading reactive power).

Under-excited Synchronous Motor

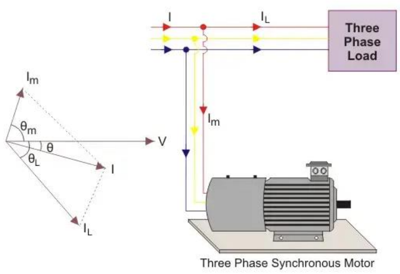
When the synchronous motor is under-excited, then it draws a lagging current form the source and hence supplies leading reactive power (or absorbs lagging reactive power). Therefore, the current drawn by a synchronous condenser can be changed from lagging to leading smoothly by varying its field excitation.

Over-excited Synchronous Motor at No Load:

When an over-excited synchronous motor is operated at no-load, it takes a leading current and hence, behaves as a capacitor. As the over-excited motor draws a leading current from the supply, it absorbs leading reactive power and delivers the lagging reactive power.

When such a machine connected in parallel with induction motors or other inductive load, i.e., devices that operate at lagging power factor and absorbs the lagging reactive power, this lagging reactive power demand is met by the synchronous condenser. Thus, the inductive load does not take the lagging reactive power from the supply and the power factor of the plant has been improved.

The synchronous capacitors, i.e., over-excited synchronous motors on no-load are installed in electric power systems only for power factor improvement of the system. The synchronous condensers are economical in large sizes than the static capacitors.



Suppose due to a reactive load of the power system the system draws a current I_L from the source at a lagging angle θ_L in respect of voltage. Now the motor draws a I_M from the same source at a leading angle θ_M. Now the total current drawn from the source is the vector sum of the load current I_L and motor current I_M. The resultant current I drawn from the source has an angle θ in respect of voltage. The angle θ is less than angle θ_L. Hence power factor of the system cosθ is now more than the power factor $\cos\theta_L$ of the system before we connect the **synchronous condenser** to the system. The synchronous condenser is the more advanced technique of improving power factor than a static capacitor bank, but power factor improvement by synchronous condenser below 500 kVAR is not economical than that by a static capacitor bank. For major power network we use synchronous condensers for the purpose, but for comparatively lower rated systems we usually employ capacitor bank.

Scheme Prepared by **Head of the department**

1.

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