Chapter 5

Synchronous Machines

LEARNING OBJECTIVES

After reading this chapter, you will be able to understand:

- Armature windings
- Damper windings
- EMF equation
- Flux and MMF phasors in synchronous machines
- Operation of a salient pole synchronous machine
- Slip test
- Parallel operation of alternators
- Synchronizing power and synchronizing torque
- Synchronous motors
- Servomotor
- Stepper motor

Introduction

A synchronous machine is a doubly-excited AC machine, because its field winding is energized from a DC source and its armature winding is connected to an AC source. When operating as a motor, the synchronous machine absorbs active power from an AC source. During its operation as a generator, a synchronous machine delivers AC power. However, the field winding of a synchronous machine always absorbs power from a DC source.

Since a synchronous generator delivers AC output, it is also known as an alternator. Alternators operate on the same fundamental principles of electromagnetic induction as DC generators. In large synchronous machines, the field winding is always provided on the rotor because of the following advantages:

1. The output current can be led directly from fixed terminals on the stator to the load circuit.
2. Insulation of stationary armature winding for high AC voltage is easier compared to rotating armature.
3. The sliding contacts i.e. slip rings are transferred to the low-voltage, low power DC field circuit which can, therefore, be easily insulated.
4. The armature conductors can be made easily braced to prevent any deformation which could be produced by the high centrifugal forces or the mechanical stresses set up as a result of short-circuited currents.

- Small AC generators and of low voltage rating are usually made of rotating armature. In such generators the required magnetic field is produced by DC electromagnet placed on the stator.

  In large alternators placed on the excitation is usually provided from a small DC shunt or compound generator mounted on the shaft of alternator itself.

- Synchronous machines are of two types depending upon the geometrical structure of the rotor, viz., (i) salient pole or projected pole and (ii) cylindrical-rotor, round-rotor or non-salient pole type.
- The cylindrical construction is used for two or four-pole steam-turbine generators. That is why these are called turbo-generators. A cylindrical-rotor synchronous machine is characterized by long core length and small diameter so as to limit the centrifugal forces developed in the high-speed rotor.
- The salient-pole construction is the most suitable for multipolar slow-speed water-turbine generators. That is why salient-pole synchronous generators are called hydro-generators. A salient-pole synchronous machine has small core length and large diameter so that large number of field poles can be accommodated on the rotor periphery.

The frequency of the induced emf is given by f = No. of cycles/revolution × No. of revolutions/second

$$= \frac{P}{2} \times \frac{N}{60} = \frac{PN}{120} \text{ Hz}$$

Armature Windings

The armature windings in DC machines are closed winding but in case of alternator, windings are open, in the sense that there is no closed path for the armature currents in the winding itself. Hence there are no parallel paths for an AC winding.

The two types of armature windings commonly used for 3-phase alternators are

1. Single-layer winding
2. Double-layer winding

There are two types of interconnection of the 3-phase windings. One Y and other Δ. If similar terminals are joined, we get a star configuration and for delta connection dissimilar ends are connected together.

Damper Windings

Damper windings consist of low-resistance bars embedded in slots in the pole-faces of salient-pole machines. The projecting ends of the bars are short-circuited at both ends by strips of the same material as used for bars. Damper windings are not used on turbo-generators. But the solid-steel rotor cores of such machines provide path for eddy currents, especially in the quadrature axis, where the iron may form an equivalent circuit, thus producing the same effects as those of damper bars. These damper bars are useful in preventing the hunting (monetary speed fluctuations) in generators and are needed in synchronous motors to provide the starting torque. Under normal running conditions, damper bars do not carry any current because rotor runs at synchronous speed.

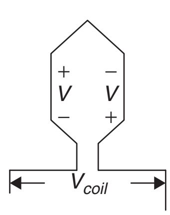
Short-pitch winding: Pitch factor/chording factor.

Short-pitched coils are used owing to the following advantages.

1. Saving of copper due to reduced length of end connections.
2. Waveform of generated emf is improved as the distorting harmonics are reduced or totally eliminated.
3. Due to the elimination of high frequency harmonics, eddy currents and hysteresis losses are reduced thereby increasing the efficiency.

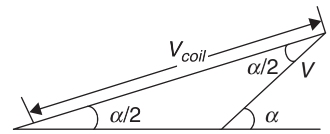
Disadvantages

Use of short-pitched coil results in decrease of induce emf. In full pitched coils, emf's induced by two coils sides are exactly 180° out of phase:



Hence $V_{coil} = 2$ V

But, in case of short-pitched coils, this angle is $180 - \alpha$ ∴ (say)



∴ Hence $V_{coil} = 2V\cos\dfrac{\alpha}{2}$

$$\text{Pitch factor} = \frac{\text{Resultant emf of short pitched coil}}{\text{Resultant emf of full coil}}$$

$$= \frac{2V\cos\alpha/2}{2V} = \cos\alpha/2 \;\; (\alpha \text{ in electrical degrees})$$

Distribution or Breadth Factor or Winding Factor or Spread Factor

In practice, not all coil slots are used. The winding is neither fully distributed in all slots, nor fully concentrated under on pole. This is indicated by distribution factor:

The distribution factor (K_d) is defined as

$$K_d = \frac{\text{e.m.f with distributed winding}}{\text{e.m.f with concentrated winding}}$$

(or)

$$\frac{\text{Vector sum of coil e.m.f. s}}{\text{Arithmetic sum of coil e.m.f. s}}$$

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

where β is slot angle

$$\beta = \frac{180°}{\text{No. of slots/pole}}$$

m = No. of slots/pole/phase

$m\beta$ is phase spread angle.

Solved Examples

Example 1: A 3-phase, 16-pole alternator has 144 slots. What is the distribution factor?

Solution: Distribution factor, $K_d = \dfrac{\sin(m\beta/2)}{m\sin\beta/2}$

n = no. of slots per pole

m = no. of slots per pole/pole

β = slot angle

$$n = \frac{144}{16} = 9; \qquad m = \frac{144}{3\times 16} = 3$$

$$\beta = \frac{180}{9} = 20°$$

$$K_d = \frac{\sin(3\times 20/2)}{3\sin\dfrac{20}{2}} = 0.96$$

Example 2: What is the distribution factor for a uniformly distributed 3-phase winding having a phase spread of 60°?

Solution: For a uniformly distributed winding, distribution factor is given by

$$k_d = \frac{\sin\sigma/2}{\sigma/2}$$

where σ = Phase spread in rad.

For $\sigma = 60°$

$$k_d = \frac{\sin 30°}{30\times\dfrac{\pi}{180}} = 0.955$$

EMF Equation

The induced emf (RMS value) of an alternator is given by

$$E/\text{Ph} = 4.44 K_p K_d f\phi T \text{ ...... } V$$

where K_p = Pitch factor
K_d = Distribution factor
ϕ = Flux per pole in webers
T = Number of turns per phase

Effect of Harmonics on Pitch and Distribution Factors

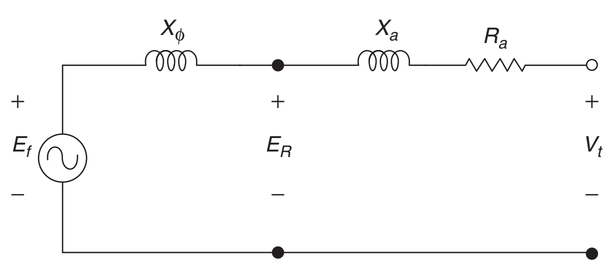
For an n^{th}-order harmonic

$$K_c = \cos\frac{n\alpha}{2} \text{ and}$$

$$K_d = \frac{\sin nm\beta/2}{m\sin n\beta/2}$$

Flux and MMF Phasors in Synchronous Machines

Synchronous machine equivalent circuit:



where $X_s = X_\Phi + X_a$
X_a = Armature Leakage Reactance
X_Φ = Reactance of air gap
R_a = Armature Resistance
E_f = emf generated
V_t = Terminal voltage

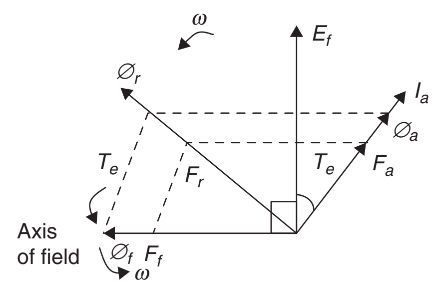


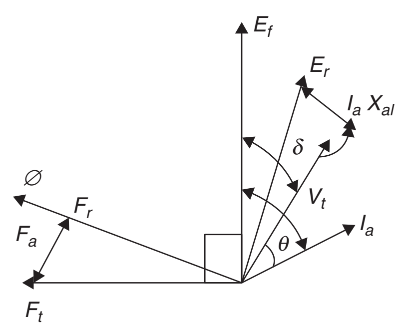
Figure 1 Axis of phase *a*

Combined space and time phasor diagram of a cylindrical rotor alternator for a lagging p.f. load.
In an alternator

1. If I_a lags the excitation emf, E_f by 90° the nature of F_a is demagnetizing.
2. If I_a leads the excitation emf, E_f by 90°, the nature of armature F_a is magnetizing.

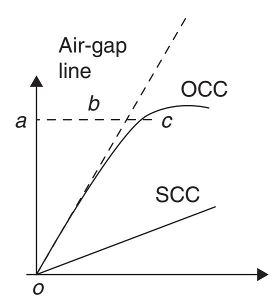
Phasor Diagram of a Cylindrical Rotor Alternator

The phasor diagram is drawn assuming that the per phase quantities, i.e. V_t the terminal voltage, I_a the armature current, r_a the armature resistance, X_{al} the armature leakage reactance and cos θ power factor, are known.



Characteristics of an Alternator Open-circuit Characteristic (OCC)

For obtaining OCC, the alternator is driven at constant rated speed and the open-circuit terminal voltage is noted as the field current is increased from zero. Thus the OCC is a graph between the field current I_f or field mmf F_f and the induced voltage. It is just like the B-H curve.



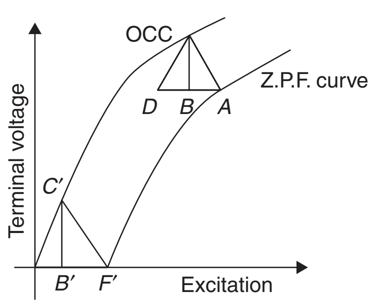
Short-circuit Characteristics (SCCs)

SCC is obtained by short-circuiting the armature (i.e. stator) windings through a low-resistance ammeter. The field current is gradually increased from zero, until the short-circuit armature current has not reached its maximum safe value, equal to 125% to 150% of the rated current. During this test, the speed which is not necessarily synchronous is kept constant.

Zero Power-factor Characteristic and Potier Triangle

Zero power factor characteristic (z.p.f.c.) of an alternator is a plot between the armature terminal voltage and its field current for constant values of armature current and speed. z.p.f.c. in conjunction with o.c.c is useful in obtaining the armature leakage reactance X_{al} and armature reaction mmf F_a. For an alternator z.p.f.c. is obtained as follows:

1. The synchronous machine is run at rated synchronous speed by the prime mover.
2. A purely inductive load (z.p.f. load) is connected across the armature terminals and field current is increased till full-load armature current is flowing.
3. The load is varied in steps and the field current at each step is adjusted to maintain armature current. The plot of armature terminal voltage and field current recorded at each step gives the zero-power factor characteristic at full-load armature current.



The triangle ABC shown above is known as Potier triangle. If the armature resistance is assumed zero and the armature current is kept constant, then the size of Potier triangle ABC remains constant and can be shifted parallel to itself with its corner remaining on the OCC and its corner A, tracing the z.p.f.c. Thus the z.p.f.c has the same shape as the O.C.C. and is shifted vertically down-ward by an amount equal to F_aX_{al} (i.e. leakage reactance drop) and horizontally to the right by an amount equal to the armature reaction mmf F_a or the field current equivalent to the armature reaction mmf, i.e. BC = I_aX_{al} and AB = F_a. For determining X_{al} and F_a experimentally, entire z.p.f.c. is not necessary, but only two points A and F′ are sufficient. The point A (PA = rated voltage) is obtained actually loading the over-excited alternator by an under-excited synchronous motor, so that rated armature current flows in the alternator. The point F′ on the z.p.f.c. corresponds to the zero terminal voltage and can, therefore, be obtained by performing short-circuit test. So here OF′ is the field current required to circulate short-circuit current equal to the armature current at which point A is determined in the zero power factor test.

Now draw a horizontal line AD, parallel and equal to F′O. Through point D, draw a straight line parallel to the air-gap line, intersecting the O.C.C. at C. Draw CB perpendicular to AD. Then from the Potier triangle ABC

$$BC = I_aX_{al} \qquad \text{and} \qquad AB = F_a$$

Since I_a at which point A is obtained is known, X_{al} can be calculated.

Voltage Regulation of an Alternator

It is defined as the 'rise in voltage when full-load is removed (field excitation and speed remaining the same)', expressed as a percentage (or p.u.) of the rated voltage.

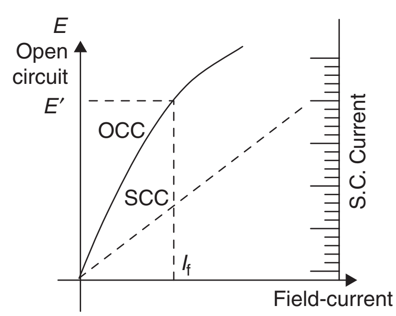
$$\therefore \text{ Voltage regulation} = \frac{E_f - V_t}{V_t} \text{ in p.u.}$$

$$= \frac{E_f - V_t}{V_t} \times 100 \text{ in percentage.}$$

The following are the methods to determine voltage regulation.

Synchronous Impedance or EMF Method

In this method, OCC and SCC of given alternator are obtained and are drawn on a common field current base.



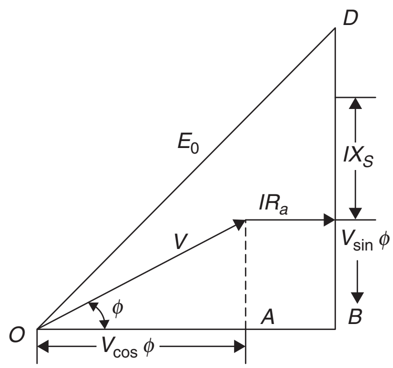
Consider a field current I_f. The OC voltage corresponding to this field current is E_1. When the armature winding is short-circuited, whole of this voltage E_1 is used to circulate the armature short-circuit current I_1, against the synchronous impedance Z_s

$$E_1 = I_1Z_s; \quad \therefore Z_s = \frac{E_1(\text{open-circuit})}{I_1(\text{short-circuit})}$$

After determining R_a, X_s can be calculated as

$$X_s = \sqrt{Z_s^2 - R_a^2}$$

Knowing R_a and X_s, the phasor diagram can be drawn for any load and any power factor.



$$OD = E_0$$

$$\therefore \quad E = \sqrt{OB^2 + BD^2}$$

$$E_0 = \sqrt{(V\cos\phi + IR_a)^2 + (V\sin\phi + IX_s)^2}$$

and % regulation $= \dfrac{E_0 - V}{V} \times 100$

For leading p.f, ϕ is taken –ve and +ve for lagging p.f.

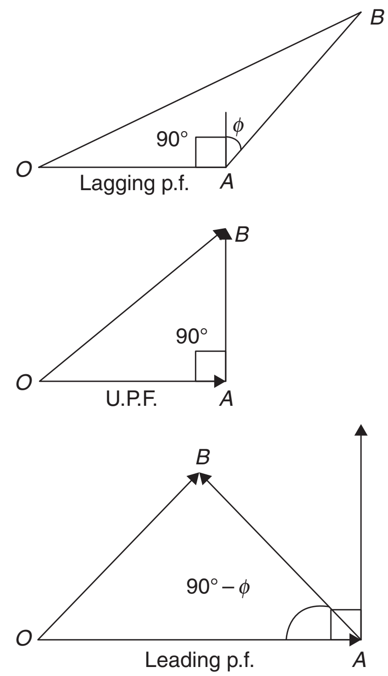
The synchronous impedance Z_s calculated by this method is higher than actual value. Hence the value of regulation so obtained is always more than that found from an actual test. That is why it is called pessimistic method.

Ampere-turn or MMF Method

- In this method, OC and SC data are used.
- The voltage is attributed entirely to armature reaction (i.e. armature leakage reaction drop, which is rather small, is clubbed with armature reaction). In other words, it is assumed that the change in terminal voltage on load is entirely due to armature reaction. Normally R_a is neglected.
- Since R_a is neglected and is small for the low voltage applied on short circuit, the p.f. may be assumed to be zero lagging.
- Therefore, the field mmf is used to overcome the demagnetizing effect of armature reaction.
- The excitation required to overcome the demagnetizing effect of armature reaction is determined on the unsaturated portion of the OCC.
- This method is optimistic since the regulation calculated by this method is less than the actual value.

Determination of Voltage Regulation, by MMF Method

1. The field current I_{f1} corresponding to rated voltage is obtained from the OCC.
2. The field current I_{f2}, to circulate rated armature current I_a, is obtained from the SCC.
3. $I_f \cos\phi$ is the load p.f., I_{f2} is added vectorially at an angle of $(90 \pm \phi)$ with I_{f1} to get the resultant field current I_f as shown in following figures.



$$OA = I_{f1},\ AB = I_{f2}$$

$$OB = I_f,\ \phi = \text{Power factor angle}$$

The emf E, corresponding to I_f is read from the OCC

$$\%\ \text{Regulation} = \frac{E - V}{V} \times 100$$

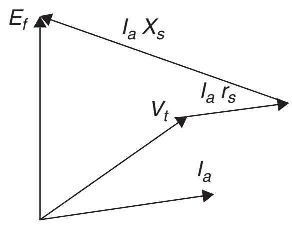
Zero Power Factor or Potier Triangle Method

In the EMF and MMF methods, the effects of armature leakage reactance and armature reaction are clubbed. ZPF method is based on the separation of armature leakage reactance drop and the armature reaction effects. Hence the regulation obtained by this method is more accurate. In addition to no-load curve, full-load ZPF curve is also required.

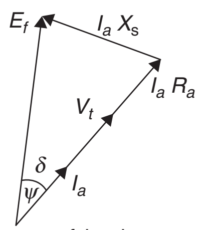
New A.S.A. (American Standard Association) Method

This method is essentially a modification of the MMF method and gives satisfactory results both for cylindrical and salient-pole machines. New A.S.A. methods require O.C.C. and z.p.f.c.

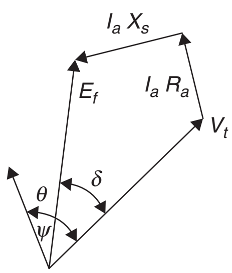
Voltage Phasor Diagram for an Alternator



Lagging p.f. load



u.p.f. load



Leading p.f. load

For lagging p.f. load

$$E = \sqrt{(V_t \cos\theta + I_a r_a)^2 + (V_t \sin\theta + I_a X_s)^2}$$

For u.p.f. load

$$E = \sqrt{(V_t + I_a r_a)^2 + (I_a X_s)^2}$$

For leading p.f. load

$$E = \sqrt{(V_t \cos\theta + I_a r_a)^2 + (V_t \sin\theta - I_a X_s)^2}$$

Example 3: A three-phase, Y-connected, 1000 kVA, 2000 V, 50 Hz alternator has the following readings:

I_F (A)	10	20	25	30	40	50
OC (V_{LL})	800	1500	1760	2000	2350	2600
SCI_a (A)		200	250	300		
OC V_P	462	866	1016	1155	1357	1501

$R_a = 0.2\ \Omega$ /phase

Find the full-load voltage regulation at 0.8 p.f. leading.

Solution: Full-load phase voltage $= \dfrac{2000}{\sqrt{3}} = 1155$ V

$$\text{KVA} = \frac{\sqrt{3}\, V_{LL} I_{fl}}{1000}$$

$$\Rightarrow 1000 \times 1000 = \sqrt{3} \times 2000 \times i_{fl}$$

$$\Rightarrow I_{fc} = 288.7 = I_a$$

at 0.8 leading

$$E = V_p + I_a R_a = 1155 + (288.7 \times 0.2 \angle\cos^{-1}(0.8))$$

$$= 1155 + 46.2 + j34.44 = 1201.7 \angle 1.6°$$

$$I_{FI} = I_F \angle(90 + \alpha) = 32 \angle(90 + 1.6°)$$

(Ampere-turns method)

$$= -0.89 + j\,31.98 \text{ A}$$

$$I_{f2} = 29 \angle(180 + 36.87°) = 29\angle 216.87° \text{A}$$

$$I_f = I_{f1} + I_{f2} = 28.15 \angle 131.18°$$

at this $I_{f'}$ $E = 1098$ V

$$\Rightarrow V_R = \frac{10998 - 1155}{1155}$$

$$= -5.02\%$$

Example 4: A 3-phase alternator delivers power to a balanced 3-phase load of power factor 0.8 lagging. It is observed that the open-circuit emf phasor leads the corresponding terminal voltage phasor by 15°. Neglecting the effect of harmonics, what is the angle between the axis of the main field mmf and the axis of the armature mmf?

Solution: Angle between E_f and $\phi_{ar} = \delta + \phi$

$$= 15 + \cos^{-1}(0.8) = 51.86°$$

[where δ is load angle and ϕ is power factor angle]

Example 5: A 3-phase, 400 V, delta-connected alternator has a synchronous impedance of (0 + j20) ohm per phase. If it delivers a load of 12 kVA at zero power factor leading, then what is the value of percentage voltage regulation.

Solution: Load = 12×10^3 VA = $\sqrt{3} \times V_L I_L$

$$\text{Line current } I_L = \frac{12 \times 10^3}{\sqrt{3} \times 400}$$

$$\text{Phase current} = \frac{I_L}{\sqrt{3}} = \frac{12 \times 10^3}{3 \times 400} = 10 \text{ A}$$

$$\% \text{ Regulation} = \frac{IR\cos\phi - I\,X\sin\phi}{V}$$

$$\because \theta = 90°$$

$$\% \text{ Regulation} = \frac{-I\,X\sin 90}{V}$$

$$= \frac{10 \times 20}{400} = -50\%$$

Example 6: A single-phase alternator has a synchronous reactance of 2 ohm and negligible resistance. If it supplies 15 A to a purely capacitive load at 200 V, then what is the value of generated emf?

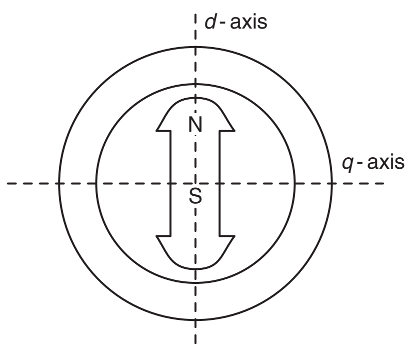
Solution: Generated emf $E_f = \overline{V_t} + \overline{I_a} X_s$

$$= 200 + (j15)(j2)$$
$$= 170 \text{ V}$$

Operation of a Salient-pole Synchronous Machine

Non-salient-pole synchronous machines have a uniform air-gap, because of which its reactance remains the same irrespective of the spatial position of rotor. However a synchronous machine with salient or projected poles has non-uniform air gap due to which its reactance varies with rotor position. A salient-pole machine possesses two-axes of geometric symmetry.

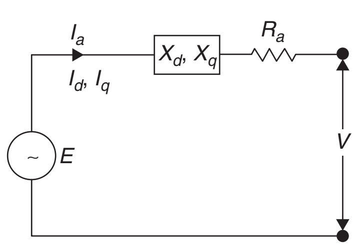
1. Fixed-pole axis called direct axis or d-axis
2. Axis passing through the centre of the inter polar space, called the quadratic axis or q-axis.



To analyse the operation of a salient-pole machine two-reaction theory is used, according to which the armature mmf, F_a is resolved into two sinusoidal components, one F_{ad} along the d-axis and the other F_{aq} along the q-axis. So two mmf act on the d-axis, i.e. field mmf and armature mmf (F_{ad}) whereas only one mmf armature mmf (F_{aq}) acts on the q-axis. The magnetic reluctance is low along the poles and high between the poles.

According to two-reaction theory,

1. armature current I_a can be resolved into two components, i.e. I_d perpendicular to E_0 and I_q along E as shown in figure.



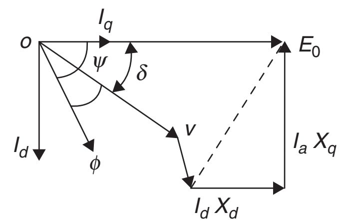


Figure 2 Phasor diagram for a salient-pole alternator

2. armature reactance has two components, i.e. q-axis armature reactance X_{ad} associated with I_d and d-axis armature reactance X_{aq} associated with I_q.

   If we include the armature leakage reactance X_l, which is the same on both axes, we get

   $$X_d = X_{ad} + X_l$$

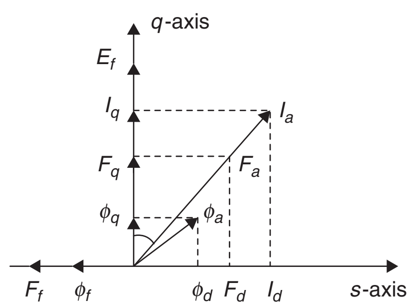
   and $X_q = X_{aq} + X_l$

   Since reluctance is higher on the q-axis, because of the large air-gap, we have

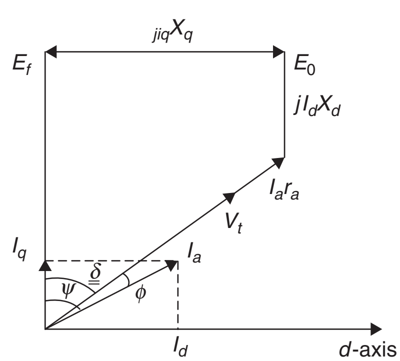
   $X_{aq} < X_{ad}$, $X_q < X_d$ or $X_d > X_q$

Two-reaction Theory

In a cylindrical rotor synchronous machine, the permeance offered to a mmf wave is Independent on rotor position of the wave axis with respect to field-pole axis. But in salient-pole synchronous the permeance offered is different because the rotor alignment is different therefore the mmf vector also different. The mmf vector and induced emf in salient-pole synchronous machine are as shown below. The reactance of direct and quadrature axis are X_d and X_q, respectively, generally $X_d > X_q$.



The phasor diagram of the generated voltage and terminal voltage of salient-pole synchronous machine is as shown in the following figure.



The direct and quadrature axis currents are

$$I_d = I_a \sin\Psi$$

$$I_q = I_a \cos\Psi$$

The generated emf in salient-pole synchronous machine is

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

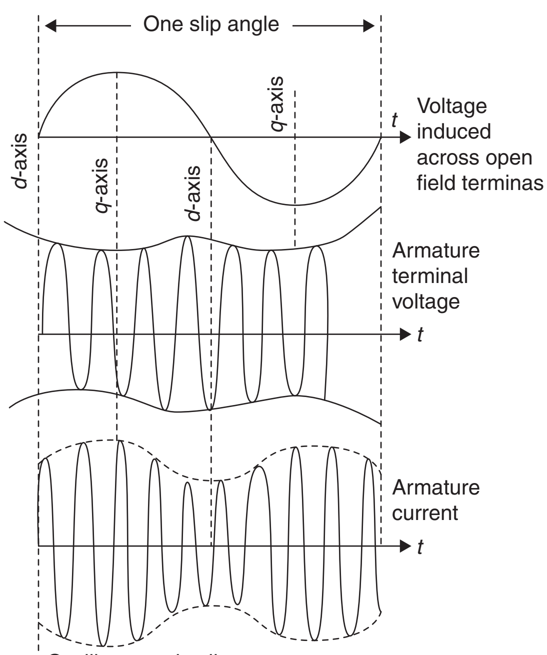
Slip Test

From this test X_d and X_q can be determined. The synchronous machine is driven by a separate prime-mover (or motor) at a speed slightly different from synchronous speed. The field winding is left open, and positive sequence balanced voltages of reduced magnitude (around 25% of rated value) and of rated frequency are impressed across the armature terminals. Under these conditions, the relative velocity between the field poles and the rotating armature mmf wave is equal to the difference between synchronous speed and the rotor speed, i.e. slip speed. A small AC voltage across the open field winding indicates that the field poles and rotating mmf wave are revolving in the same direction - and that is what is required in slip test. If field poles revolve in a direction opposite to the rotating mmf wave, negative sequence reactance would be measured.

The field winding is open-circuited and rotor is rotated at synchronous speed N_s. As the excitation is absent, armature would draw heavy current from terminals. Now, the armature current would vary form minimum (d-axis) and maximum (at the q-axis position).

It would vary at the rate of twice the corresponding slip frequency.

The voltage at the terminal would vary from minimum at (q-axis) to maximum (at d-axis). Oscillations of voltage and current are shown in following figure.



Oscillograms in slip test

$$= \frac{[\text{Maximum armature terminal voltage per phase}]}{[\text{Minimum armature current per phase}]}$$

and

$$X_q = \frac{[\text{Minimum armature terminal voltage per phase}]}{[\text{Maximum armature current per phase}]}$$

Power Developed by a Synchronous Generator

The per phase power developed by an alternator is given by

$$P_d = \frac{E_0 V}{X_d}\sin\delta + \frac{1}{2}V^2\left[\frac{1}{X_q} - \frac{1}{X_d}\right]\sin 2\delta$$

$$= \frac{E_0 V}{X_d}\sin\delta + \frac{V^2\left(X_d - X_q\right)}{2X_d X_q}\sin 2\delta$$

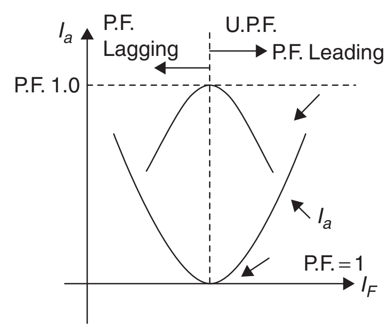
The above expression for P_d consists of two components, the first term represents the power due to field excitation and the second term gives the reluctance power, i.e. power due to saliency.

If $X_d = X_q$, i.e. the machine has a cylindrical rotor, then the reluctance power is zero and the power is given by the first term only. If on the other hand, the field has not excited, i.e. $E_0 = 0$, then the first term in the above expression becomes zero and the power developed is given by second term. The value of δ is positive for a generator and negative for a motor.

Power-factor Control of Alternators

An under excited alternator operates at a leading power factor and absorbs reactive power from infinite bus.

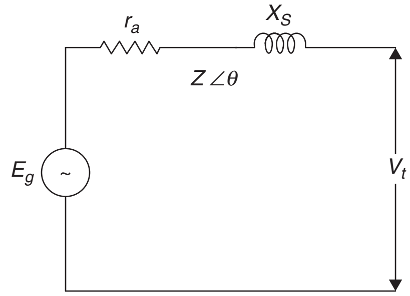
The over excited alternator operates at a lagging p.f. and delivers reactive power to infinite bus.



Effect of field current on an alternator connected to infinite bus is given by the V-curve and inverted V-curve shown in above figure.

Power Angle Characteristics of Synchronous Machine

The power flow in a cylindrical rotor synchronous generator is analysed by



In the above circuit E_g represent the generated voltage in generator and V_t represent the terminal voltage across the generator terminals after subtracting the armature and friction drop from the generated voltage. Therefore the power input (i.e., power developed) in generator

$$P_{in} = \frac{E_g V_t}{Z_s}\sin(\delta - \alpha) + \frac{E_g^2}{Z_s^2} r_a$$

δ – is the angle between generated voltage and terminal voltage.

$$\therefore \qquad \theta = \text{impedance angle} = \tan^{-1}\left(\frac{X}{R}\right)$$

$$\alpha = 90 - \theta$$

Maximum power input occurs at $\dfrac{dP_{in}}{d\delta} = 0$

$$\frac{E_g V_t}{Z_s}\cos(\delta - \alpha) = 0$$

$$\delta = 90 + \alpha = 180 - \theta$$

$\therefore$ Maximum input power is $P_{in}\,(\max) = \dfrac{E_g V_t}{Z_s} + \dfrac{E_g^2}{Z_s^2} r_a$

Power output equation of generator

$$P_{out} = \frac{E_g V_t}{Z_s}\sin(\delta + \alpha) - \frac{V_t^2}{Z_s^2} r_a$$

Maximum real power output obtained at $\dfrac{dP_{out}}{d\delta} = 0$

$$\frac{E_g V_t}{Z_s}\cos(\delta + \alpha) = 0$$

$$\delta + \alpha = 90^\circ$$

$$\delta = 90^\circ - \alpha = \theta$$

$\therefore$ The corresponding maximum output power is

$$P_{out(\max)} = \frac{E_g V_t}{Z_s} + \frac{V_t^2}{Z_s^2} r_a$$

Similarly Reactive power output at generator terminals

$$Q_{out} = V_t\left[\frac{E_g}{Z_s}\sin(\theta - \delta) - \frac{V_t}{Z_s}\sin\theta\right] \text{(or)}$$

$$Q_{out} = \frac{V_t E_g}{Z_s}\cos(\delta - \alpha) - \frac{V_t^2}{Z_s} X_s$$

Maximum output reactive power obtained at

$$\frac{dQ_{out}}{d\delta} = \frac{V_t E_g}{Z_s}\sin(\delta + \alpha) = 0$$

$$\Rightarrow \qquad \delta + \alpha = 0$$

$$\therefore Q_{out(\max)} = \frac{V_t}{Z_s}\left[E_g - \frac{V_t}{Z_s}\cdot X_s\right]$$

$$= \frac{V_t E_g}{Z_s} = \frac{V_t^2}{Z_s} X_s$$

If $r_a = 0$

$$Q_{out} = \frac{V_t E_g}{X_s}\cos\delta - \frac{V_t^2}{X_s}$$

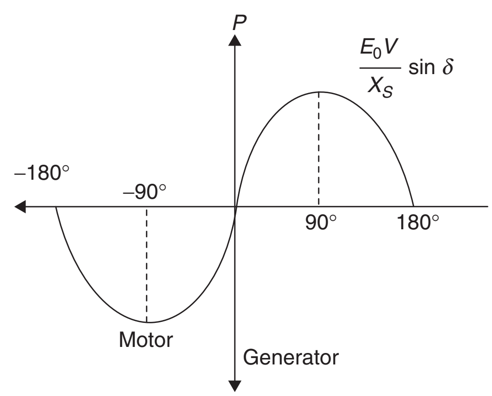
$$= \frac{V_t}{X_s}[E_g\cos\delta - V_t]$$

1. when $E_g \cos\delta > V_t$, then Q_{out} positive. Therefore the generator delivers the reactive power.
2. when $E_g \cos\delta = V_t$, then Q_{out} is zero. Therefore the generator neither absorbs nor delivers reactive power.
3. when $E_g \cos\delta < V_t$, then Q_{out} is negative therefore the generator absorbs the reactive power from bus bar.

For cylindrical rotor synchronous machine

$$P = \frac{E_0 V}{X_s}\sin\delta$$

The power vs. load angle curve has sinusoidal shape and is called power angle characteristic.



The Power-angle Curves of Synchronous Generator

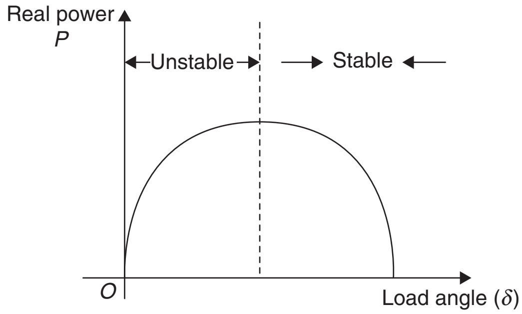


Figure 3 Real power versus load angle characteristic

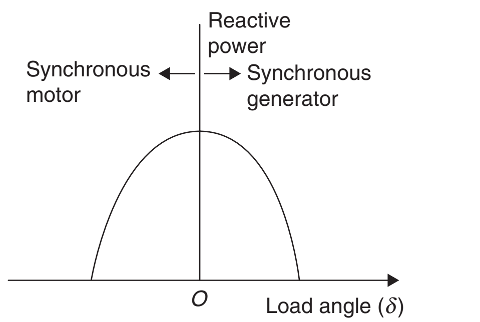
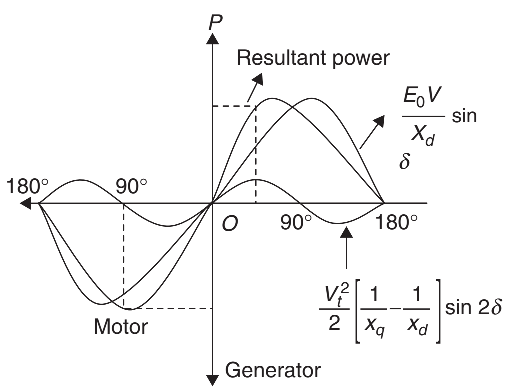


Figure 4 Reactive power versus load angle characteristic

For salient-pole synchronous machine

$$P = \underbrace{\frac{E_0 V}{X_d}\sin\delta}_{\text{Fundamental component}} + \underbrace{\frac{1}{2}V^2\left[\frac{1}{X_d} - \frac{1}{X_q}\right]\sin 2\delta}_{\text{Second harmonic component}}$$



Common data for Example 7:
A 400 V, 4-pole 3-ϕ 50 Hz, induction motor has a rotor resistance and reactance per phase of 0.02 Ω and 0.2 Ω, respectively. Stator-to-rotor turns ratio is 4.

Example 7: A synchronous generator with a synchronous reactance of 1.2 p.u. is connected to an infinite bus whose voltage is 1 p.u., through an equivalent reactance of 0.3 p.u. What should be the value of emf to give a maximum output of 1.2 p.u.?

Solution: $P = \frac{E_f V_t}{x}\sin\delta$

$$P_{\max} = \frac{E_f V_t}{X}$$

$$E_f = \frac{X P_{\max}}{V_t} = \frac{(1.2+0.3)\times 1.2}{1.0} = 1.8 \text{ p.u.}$$

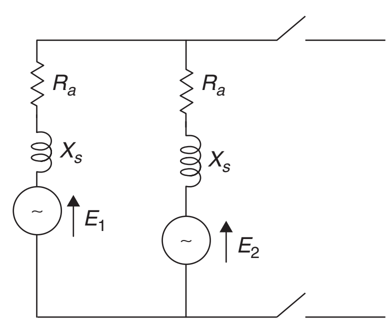
Parallel Operation of Alternators

Connecting an alternator in parallel with another alternator or with common bus-bars is known as synchronizing. Conditions to be satisfied for synchronization of alternators are:

1. The terminal voltage of the incoming alternator must be the same as bus-bar voltage
2. The speed of the incoming machine must be such that its frequency $\left(f = \frac{NP}{120}\right)$ equals bus-bar frequency
3. The phase of the alternators must be same as that of bus-bar voltage, it means that the synchronizing switch must be closed at (or very near) the instant the two voltages have correct phase relationship

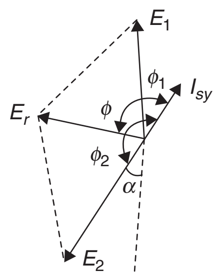
Synchronizing Current and Synchronizing Power

Once synchronized properly, two alternators continue to run in synchronism. Any tendency on the part of one to drop out of synchronism is immediately counteracted by the production of a synchronizing torque, which brings it back to synchronism.



When in exact synchronism, the two alternators have equal terminal voltages and are in exact phase opposition.

But now suppose that E_2 falls back by a phase angle of α electrical degrees as shown in following figure.



Neglecting the resistance R_a, then $\theta = 90°$ and

$$E_r = 2E\sin \alpha/2$$

since α is small (α is in electrical radians)

$$I_{sy} = \frac{E_r}{2X_s} = \frac{\alpha E}{2X_s}$$

From the above phasor diagram, it can be seen that machine no. 1 is generating and supplying synchronizing power whereas machine no. 2 acts a motor and receives the synchronizing power. Hence I_{sy} is generating current with respect to machine no. 1 and motoring current with respect to machine no. 2

$$P_{sy} = E_1 I_{sy} \cos \phi_1 = EI_{sy} \cos (90 - \theta)$$

$$= EI_{sy} \sin \theta = EI_{sy} \; (\because R_a \text{ is neglected and } \theta = 90°)$$

Substituting the value of I_{sy}

$$P_{sy} = E.\alpha E/2X_s$$

$$= \alpha E^2/2X_s \text{ per phase}$$

$$\left(\text{More accurately, } P_{sy} = \frac{\alpha E^2 \sin\theta}{2X_s}\right)$$

This is the value of the synchronizing power when two alternators are connected in parallel and are on no-load.

Alternators Connected to Infinite Bus-bars

In this case impedance (or reactance) of only one alternator has to be considered

$$\therefore \quad I_{sy} = \frac{\alpha E}{X_s}$$

$$P_{sy} = \frac{\alpha E^2}{X_s}$$

$$\left[\text{or } P_{sy} = \frac{\alpha E^2 \sin\theta}{X_s}\right]$$

Synchronizing torque (T_{sy}) can be calculated from the value of synchronizing power by using relation

$$\omega \times T_{sy} = P_{sy}$$

$$\text{i.e. } T_{sy} = \frac{P_{sy}}{\omega}$$

Synchronizing Power and Synchronizing Torque

The rate at which synchronous power, 'P' varies with δ is called the synchronizing-power coefficient P_{sy}. It is also known as stiffness of coupling, rigidity factor or stability factor.

The coefficient P_{sy} is equal to the slope of the power angle curve.

For a cylindrical rotor machine

$$P_{sy} = \frac{dP}{d\delta} = \frac{EV}{X_s}\cos\delta$$

$$P_{sy} = \frac{dP}{d\delta} = \frac{EV}{X_d}\cos\delta + V^2\left[\frac{1}{X_q} - \frac{1}{X_d}\right]\cos 2\delta$$

From the above equations it is obvious that P_{sy} is inversely proportional to X_s or X_d and is directly proportional to E, the excitation voltage.

Hence, an over excited synchronous machine is more rigidly coupled than the one which is under excited. Large air gap decreases the value of X_s or X_d, thus a synchronous machine with longer air gap is more stiffer than the one with smaller air-gap units of synchronizing power coefficient are watt per electrical radian.

The variation of synchronous power with the change of load angle is called the synchronizing power. It exists only during the transient state, i.e. whenever there is a sudden disturbance in load (or steady-state operating conditions). Once the steady-state is reached, the synchronizing power reduces to zero.

The synchronizing power flows from or to the bus in order to maintain the relative velocity between interacting stator and rotor field, zero, once the equality is reached, the synchronizing power vanishes.

Hunting

The operation of a synchronous machine is satisfactory, if the mechanical speed of the rotor is equal to the stator field speed i.e. if the relative speed between the rotor and stator field is zero. Any departure from these conditions gives rise to synchronizing forces which tend to maintain this equality. With a sudden change in the load, the rotor swings or oscillates first to one side and then to other side of the new equilibrium position of load angle. This phenomenon involving the oscillations of the rotor about its final equilibrium position, is called hunting. During the rotor oscillation or hunting, the orientation of phasor, E_f changes relative to terminal voltage, V_t and because of this reason, hunting is also called phase-swinging.

Common data for Example 8:

A 3-ϕ, star-connected 400 V, 50 Hz, 4-pole induction motor has the following per phase constants in ohm referred to stator and $N_r = 1440$ rpm.

$$R_1 = .15\ \Omega,\ x_1 = .45\ \Omega,\ r_2 = 0.12\ \Omega$$

$$x_2 = 0.45\ \Omega,\ x_m = 28.5\ \Omega$$

Example 8: A 3000 kVA, 6-pole star-connected alternator runs at 1000 rpm in parallel with other machines on 3300 V bus-bars. The synchronous reactance is 25%. Calculate the synchronizing power for 2° (mech) displacement and the corresponding synchronizing torque.

Solution: Alternator is working in parallel with many alternators, hence it may be considered to be connected to infinite bus-bars.

$$\text{Voltage/phase} = 3300/\sqrt{3} = 1905\text{ V}$$

Full-load current, $I = 3 \times 10^6 / \sqrt{3} \times 3300 = 525$ A

Now, $IX_S = 25\%$ of 1905

$\therefore$ $X_S = 0.25 \times 1905/525$

$= 0.9075\ \Omega$

$P_{Sy} = 3 \times \alpha E^2/Xs$

$$\alpha = 2°\text{ mech } \alpha_{elect} = 2\times\frac{6}{2} = 6°$$

$$\alpha = 6\times\frac{\pi}{180} = \frac{\pi}{30}\text{ elect rad}$$

$$\therefore \quad P_{SY} = \frac{3\times\pi\times1905^2}{30\times0.9075\times1000}$$

$= 314.2$ kW

$$T_{SY} = \frac{60\cdot P_{SY}}{2\pi N_S} = 9.55\frac{P_{SY}}{N_S}$$

$$= 9.55\times\frac{314.2\times10^3}{1000}$$

$= 3000$ Nm

Load Sharing of Alternators Connected in Parallel

(a) Effect of change in excitation: The change in excitation merely changes the p.f. at which the load is delivered without affecting the load so long as the input to prime mover remains unchanged, i.e. kVA component of its output is changed (indirect proportion with excitation) but not its kW output.

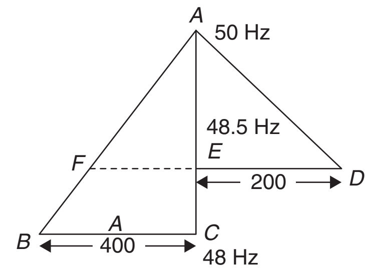
(b) Effect of change in the power input to prime mover: The amount of load taken up by an alternator running, in parallel with other machines, directly depends upon its driving torque or in other words upon the power input (or the angular advance of its rotor). The increase in the power input to prime mover does not disturb the division of reactive power.

Example 9: An alternator has a per unit impedance of 0.9 p.u. to a base of 20 MVA, 33 kV, find the p.u. impedance to the base of 50 MVA and 11 kV.

Solution: $Z_{new} = Z_{old}\dfrac{MVA_{new}}{MVA_{old}}\times\left(\dfrac{kV_{old}}{kV_{new}}\right)^2$

$$= 0.9\times\frac{50}{20}\times\left(\frac{33}{11}\right)^2 = 20.25$$

Example 10: An alternator of 400 kW is driven by a prime mover of speed regulation 4% and another alternator of 200 kW is driven by a prime mover of speed regulation 3%. Find the total load they can take, without over loading either of the machines



Solution: For getting maximum load, DE is extended to cut AB at F.

Max load = DF

$$\frac{FE}{BC} = \frac{AE}{AC}$$

$$\frac{FE}{400} = \frac{(50-48.5)}{(50-48)}$$

$$FE = \frac{400\times1.5}{2} = 300\text{ kW}$$

Maximum load FD = FE + ED

= 300 + 200 = 500 kW

Short-circuit Ratio (SCR)

- $$\text{SCR} = \frac{\text{Field current required to produce rated voltage on open circuit}}{\left(\text{Field current required to produce rated current on 3-}\phi\text{ short circuit}\right)}$$
- A lower value of SCR means a greater change in field current to maintain a constant terminal voltage and lower value of steady-state stability limit.
- Lesser the SCR, lesser is the size, weight and cost of machine.
- If there were no magnetic saturation, SCR is the reciprocal of the p.u. value of saturated synchronous reactance.
- Modern alternators have SCR between 0.5 and 1.5.

Synchronous Motors

A synchronous motor construction is identical with an alternator. It has following features.

1. It runs either at synchronous speed or not at all, i.e. while running it maintains a constant speed.

$$N_s = \frac{120f}{P}$$

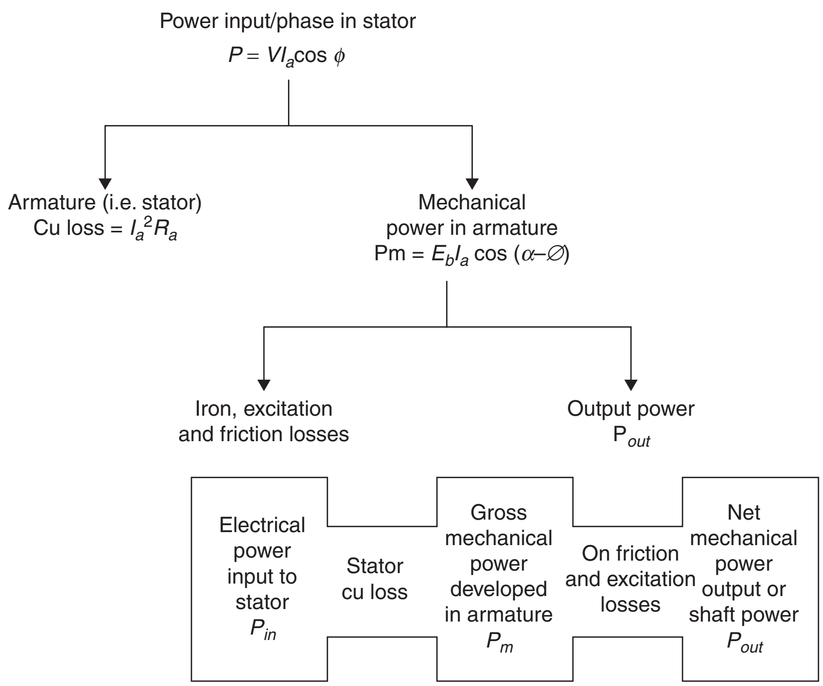
2. It is not inherently self-starting. It has to be run up to synchronous (or near synchronous) speed by some means (known as starting methods) before it is connected to the supply.
3. A synchronous motor can be operated under a wide range of power factors both lagging and leading. A range of zpf lag to zpf lead through unity can be obtained by adjusting the excitation. Hence it can be used for power factor improvement purposes, in addition to supplying driving torque to drive loads.

Principle of Operation

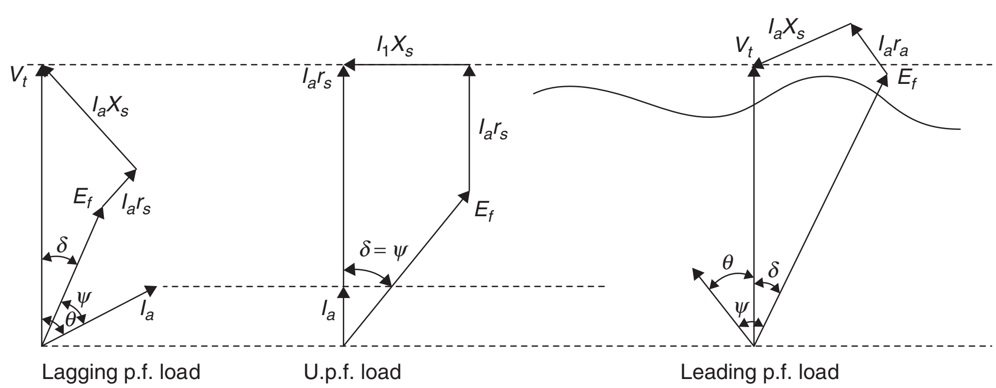
A synchronous motor works on the principle of magnetic locking between rotating air-gap flux and rotor poles.

Method of Starting

The rotor (which is as yet unexcited) is speeded up to synchronous/near synchronous speed by some arrangement and then field circuit is excited. The moment this synchronously (or near) rotating rotor is excited, and it is magnetically locked into position with the stator poles. A synchronous motor may be started with the help of auxiliary motor connected to the same shaft or by means of induction torque obtained by damper bars.

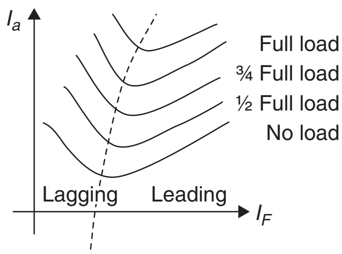


Synchronous Motor Phasor Diagram

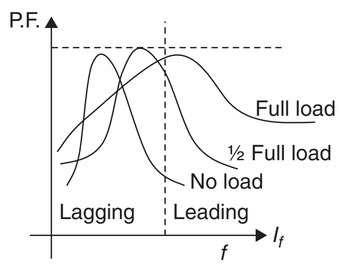


V- and Inverted V-curves

The V-curves of a synchronous motor show how armature current varies with its field current when motor input is kept constant and are so called because of their shape. Minimum armature current corresponds to unity power factor.



The inverted *V*-curves of a synchronous motor show how power factor varies with excitation (or I_f) when motor input is constant. The curve for p.f. looks like inverted '*V*' curve.



In case of synchronous motor

1. If armature current I_a lags the excitation emf, E_f 90°, the nature of armature MMF or armature reaction MMF F_a is magnetizing.
2. If armature current I_a leads E_f by 90°, the nature of armature MMF, or armature reaction MMF F_a is demagnetizing.

Effect of Increased Load with Constant Excitation

1. As load on the motor increases the armature current, I_a increases regardless of level of excitation (i.e. normal, under, or over-excited conditions)
2. For under-and over-excited motors p.f. tend to approach unity with increase in load
3. Both with under-and over-excited, change in p.f. is greater than in I_a with increase in load
4. For normal excited case, when load is increased, change in I_a is greater than in p.f. which tends to become increasingly lagging.

Effect of Changing Excitation on Constant Load

The variations in the excitation of a synchronous motor running with a given load produce variations in its load angle only. When excitation is decreased the load angle increases and vice-versa.

Example 11: A 3-phase, induction motor draws 1000 kVA at a p.f. of 0.8 lag. A synchronous condenser is connected in parallel to draw an additional 750 kVA at 0.6 p.f. lead. What is the p.f. of the total load supplied by the mains?

Solution: Reactive power drawn by induction motor

$$Q_m = 1000 \sin 36.86$$

$$j\,600 \text{ kVAR lagging}$$

Reactive power supplied by condenser

$$Q_C = 750 \sin(\cos^{-1} 0.6)$$

$$= -J\ 600 \text{ kVA lead}$$

Total reactive power $Q = Q_m + Q_c$

$$Q = j600 + -j600 = 0$$

Power factor of total load

$$\cos\left[\tan^{-1}\left[\frac{Q}{P}\right]\right] = 1$$

Example 12: A 2300 V, 3-phase synchronous motor driving a pump is provided with a line ammeter and a field rheostat. When the rheostat is adjusted such that the AC line current is minimum, the ammeter reads 8.8 A. What is the power being delivered to the pump, neglecting losses? How should the rheostat be adjusted so that the motor operates at 0.8 leading power factor? What is the reactive power supplied by the motor at this new power factor?

Solution: Line current will be minimum at unity power factor

$$\text{Power delivered} = \sqrt{3} \times 2300 \times 8.8 \times 1 = 35.05 \text{ kW}$$

For operating motor at 0.8 leading power factor field current should be increased.

As the load is unaltered $I \cos\phi$ remains same.

So $I_{a2} \cos\phi_2 = I_{a1} \cos\phi_1$

$$I_{a2} = \frac{8.8 \times 1}{0.8} = 11 \text{ A}$$

Leading kVAR supplied

$$= \frac{\sqrt{3} \times 2300 \times 11 \times 0.6}{1000} = 26.3$$

Power Developed by a Synchronous Motor

$$P_m = \frac{E_b V}{Z_s}\cos(\theta - \alpha) - \frac{E_b^{\,2}}{Z_s}\cos\theta$$

where α = Load angle

θ = Internal or Machine angle

Since R_a is generally negligible, $Z_s = X_s$ so that $\theta \cong 90°$. Hence, mechanical power developed,

$$P_m = \frac{E_b V}{X_s}\cos(90° - \alpha) = \frac{E_b V}{X_s}\sin\alpha$$

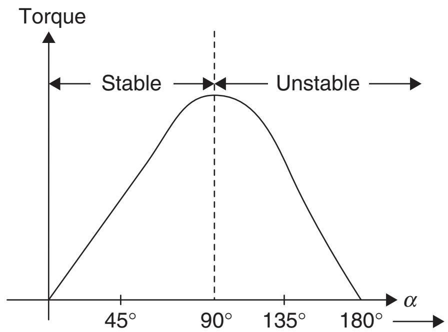
Condition for Maximum Power Developed

Maximum power can be developed when $\theta = \alpha$

$\therefore$ Value of maximum power $(P_m)_{\max}$

$$= \frac{E_b V}{Z_s} - \frac{E_b^2}{Z_s}\cos\alpha \text{ or } (P_m)_{\max} = \frac{E_b V}{Z_s} - \frac{E_b^2}{Z_s}\cos\theta$$

The above expression shows that maximum power and hence torque ($\because$ speed is constant) depends on V and E_b. Maximum value of θ (and hence α) is 90°. The variation of torque (or power) with load angle α is shown in following figure.



If R_a is neglected then $Z_s \cong X_s$ and $\theta = 90°$.

$\therefore \quad \cos\theta = 0$

$$(P_m)_{\max} = \frac{E_b V}{X_s}.$$

This corresponds to pull-out or maximum torque.

Special Motors

Servomotor

The motors that are used in automatic control systems are called servomotors. When the objective of the system is to control the position of an object, then the system is called servomechanism. The servomotors are used to convert an electrical signal (control voltage) applied to them into an angular displacement of the shaft. The suitability of a motor for a particular application depends on the characteristics of the system, the purpose of the system and its operating conditions.

A servomotor should have the following features.

1. Linear relationship between the speed and electric control signal
2. Steady-state stability
3. Wide range of speed control
4. Linearity of mechanical characteristics throughout the entire speed range
5. Low mechanical and electrical inertia and
6. Fast response.

A two-phase induction motor with certain special design features can be used as servomotors, they are

1. The rotor of servomotor is built with high resistance, so that its $\frac{X}{R}$ (Inductive reactance/resistance) ratio is small which results in linear speed-torque characteristics.
2. The excitation voltage applied to two stator windings should have a phase difference of 90°.

Stepper Motor

A stepper motor transforms electrical pulses into equal increments of rotor shaft motion called steps. A one-to-one correspondence exists between the electrical pulses and the motor steps. The number of teeth or poles on the rotor and the number of poles on the stator determine the size of the step.

$$\text{Step angle} = \frac{360}{\begin{bmatrix}\text{No. of rotor poles} \\ \text{or teeth}\end{bmatrix} \times \begin{bmatrix}\text{No. of stator pole} \\ \text{pairs}\end{bmatrix}}$$

The frequency and sequence of pulses given to the stator windings is controlled by switching devices. Stepper motors are used in computer peripherals, X-Y plotters, robots and machine tools.

Exercises

Practice Problems I

Directions for questions 1 to 26: Select the correct alternative from the given choices.

1. Per unit synchronous impedance of synchronous machine is 1.10. Its SCR is ________?
(A) 1.20 (B) 0.417
(C) 0.909 (D) 0.833

2. A synchronous generator with a synchronous reactance of 1.3 p.u. is connected to an infinite bus whose voltage is 1 p.u., through an equivalent reactance of 0.2 p.u., for maximum output of 1.2 p.u., the alternator emf must be
(A) 1.5 p.u. (B) 1.56 p.u.
(C) 1.8 p.u. (D) 2.5 p.u.

3. A single-phase alternator has a synchronous reactance of 2 Ω and negligible resistance. If it supplies 10 A to a purely capacitive load at 200 V, then the generated emf will be ________
(A) 240 V (B) 220 V
(C) 200 V (D) 180 V

4. An alternator has 18 slots/pole and the first coil lies in slots 1 and 16. What is the pitch factor for 5th harmonic ________?
(A) 0.96 (B) 0.259
(C) 0.289 (D) 0.829

5. An alternator on open circuit generates 400 V and 60 Hz. When the field current is 3.6 A. Neglecting saturation, determine the open-circuit emf. When the frequency is 40 Hz and the field current is 3 A ________

(A) 160 V (B) 200 V
(C) 220 V (D) 240 V

6. A salient-pole alternator has X_d = 1.0 p.u., X_q = 0.6 p.u. and r = 0. If this alternator delivers a power of 0.9 p.u. to an infinite bus at rated voltage and at p.f. 0.8 lag. Its load angle is ________

(A) 42.048° (B) 21.024°
(C) 60.234° (D) 36.06°

7. A synchronous generator is running over excited with E_f = 1.40 p.u. This machine with a synchronous reactance of 1.20 p.u. is delivering a synchronous power of 0.5 p.u. to the bus. If the prime mover torque is increased by 1%, by how much will the P and Q change?

(A) P increases by 1% but the Q decreases by 0.475%
(B) P decreases by 1% but the Q increases by 0.475%
(C) P and Q both increases by 1%
(D) P and Q both decreases by 1%

8. A 3-phase, 415 V, 6-pole, 50 Hz, star-connected synchronous motor develops a torque of 220 Nm and the stator winding has a synchronous reactance of 2 ohm/phase. Its load angle is _____. Its emf is 520 V (L – L)

(A) 24.66° (B) 36.80°
(C) 18.40° (D) 12.33°

9. A 4-pole, 3-phase, 50 Hz, star-connected alternator has 60 slots with 4 conductors per slot. Coils are short-pitched by 3 slots. If the phase spread is 60°, find the line voltage induced for a flux per pole of 0.943 Wb distributed in space.

(A) 7.613 kV (B) 5.234 kV
(C) 13.185 kV (D) 12.42 kV

10. A 3-ϕ, star-connected alternator supplies a load of 10 MW of P.F of 0.85 lag and at 11 kV, terminal voltages, its resistance is 0.1 ohm per/phase and synchronous reactance 0.66 ohm per phase. The line value of emf generated is ________

(A) 6.625 kV (B) 13.21 kV
(C) 7.22 kV (D) 11.4863 kV

11. A 3-phase star-connected alternator is rated at 1600 kVA, 13.5 kV. The armature resistance drop and synchronous reactance drops are 3% and 10%, respectively. Find the regulation of alternator on full load at a power factor of 0.8 leading?

(A) –2.1% (B) –3.1%
(C) +3.1% (D) 2.1%

Common Data for Questions 12 and 13:

A 3-ϕ star-connected 400 V synchronous motor takes a power input of 6 kW at rated voltage. Its synchronous reactance is 10 Ω per phase and resistance is negligible. If the excitation voltage is adjusted equal to the rated voltage of 400 V then

12. The load angle is ________

(A) 20.0° (B) 24.02°
(C) 22.02° (D) 29.82°

13. The armature current is _____

(A) 8.82 A (B) 7.86 A
(C) 6.43 A (D) 4.4 A

Common Data for Questions 14 and 15:

A 500 kVA, 11 KV, 3-ϕ star-connected alternator has the following data:

Friction and windage losses = 1000 W

core loss = 1500 W

Field winding resistance at 75°C is 180 Ω

Effective armature resistance per phase = 4 Ω

Field copper loss = 1000 W

For the above data

14. The load at which maximum efficiency occurs is _______.

(A) 65% of full load
(B) 58% of full load
(C) 70%of full load
(D) 80% of full load

15. The maximum efficiency at 0.8 p.f lagging is ______.

(A) 96. 85% (B) 86.89%
(C) 78.79% (D) 70.23%

16. List-I lists different applications and List-II lists motors for these applications. Match the application with the most suitable motor.

	List-I		List-II
A.	Escalator	1.	Single-phase induction motor
B.	Food mixer	2.	Three-phase induction motor
C.	Cassette tape recorder	3.	Permanent magnet DC motor
D.	Domestic water pump	4.	Universal motor
		5.	DC series motor
		6.	Stepper motor

	A	B	C	D
(A)	1	4	3	2
(B)	1	4	2	3
(C)	5	4	3	6
(D)	1	4	3	5

17. A rotating electrical machine having its self-inductance of both the stator and the rotor windings independent of the rotor position will be definitely not develop

(A) synchronizing torque.
(B) starting torque.
(C) reluctance torque.
(D) hysteresis torque.

18. A synchronous motor on load draws a current at a leading power factor angle ϕ. If the internal power factor angle which is the phase angle between the excitation emf and the current in time phasor diagram, is Ψ, then the air gap excitation m. m. f. lags the armature mmf by

(A) $\pi/2 + \Psi$ (B) Ψ

(C) $\Psi - \phi$. (D) $\frac{\pi}{2} - \Psi$

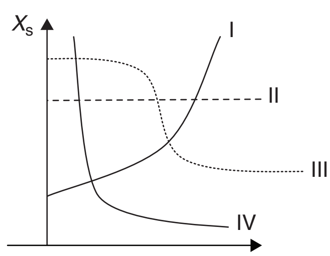
19. The developed electromagnetic force and/or torque in electro-mechanical energy conversion system act in a direction that tends

(A) to decrease the co-energy at constant mmf.
(B) to decrease the stored energy at constant mmf.
(C) to decrease the stored energy at constant flux.
(D) to increase the stored energy at constant mmf.

20. The following motor definitely has a permanent magnet rotor

(A) Brushless DC motor.
(B) DC commutator motor.
(C) Universal motor.
(D) Stepper motor.

21. In the figure the characteristic that corresponds to the variation of synchronous reactance of synchronous motor with field current is



(A) curve I (B) curve II
(C) curve III (D) curve IV

22. X_d, X_d' and X_d'' are steady-state *d*-axis synchronous reactance, transient *d*-axis reactance and sub-transient d-axis reactance of synchronous machine, respectively. Which of the following relation is true?

(A) $X_d'' > X_d' > X_d$
(B) $X_d' > X_d'' > X_d$
(C) $X_d > X_d' > X_d''$
(D) $X_d > X_d'' > X_d'$

23. An isolated engine driven synchronous generator is feeding a partly inductive load. A capacitor is now connected across the load to completely compensate the inductive current. For this operating condition

(A) the field current has to be increased and fuel input left unaltered.
(B) the field current has to be reduced and fuel input left unaltered.
(C) the field current and fuel input have to be reduced.
(D) the field current and fuel input have to be increased.

24. In relation to the synchronous machines, which one of the following statements is false?

(A) the damper bars help the synchronous motor self-start.
(B) in salient-pole machines, the quadrature axis synchronous reactance is less than the direct axis synchronous reactance.
(C) the V curve of a synchronous motor represents the variation in the armature current with field excitation, at a given output power.
(D) the short-circuit ratio is the ratio of the field current required to produce the rated voltage on open circuit to the rated armature current.

25. A three-phase synchronous motor connected to AC mains is running at full-load unity power factor. If the load is reduced by half, with excitation unaltered, its new power factor will be

(A) leading
(B) lagging
(C) unity
(D) dependent on machine parameters

26. A 4-pole, 3-phase, double layer winding is housed in a 36 slot stator for an AC machine with a phase spread of 60^o. The coil span is 7 slot pitches Number of slots in which top and bottom layers belonging to same phases is

(A) 12 (B) 14
(C) 24 (D) 28

Practice Problems 2

Directions for questions 1 to 100: Select the correct alternative from the given choices.

1. Two similar alternators are working in parallel. They have identical field excitations and supply a common load. Now the steam supply to one of the alternator is increased keeping the field excitation constant, its active power component

(A) remains the same, but the reactive power component will increase
(B) decreases while reactive power increases
(C) increases and reactive power also increases
(D) increases while reactive power contribution remains unchanged

2. Two mechanically coupled alternators deliver power at 50 Hz and 60 Hz, respectively. The highest speed of the alternator is

(A) 3000 rpm (B) 3600 rpm
(C) 500 rpm (D) 600 rpm

3. The phase groups of machines A and B are 60° and 120°, respectively. If the breadth factor of machine A is x times that of B, then value of x is
(A) 1 (B) <1
(C) >1 (D) None of these

4. For the same power rating an alternator at lower voltage will be
(A) larger in size (B) smaller in size
(C) less noisy (D) more efficient

5. When an alternator, designed for operation at 60 Hz is operated at 50 Hz
(A) kVA rating increases by 1.2
(B) operating voltage reduces by $\frac{5}{6}$
(C) operating voltage increases by 1.2
(D) operating voltage reduces by $\left(\frac{5}{6}\right)^2$

6. When a balanced 3-ϕ distributed type armature winding is carrying 3-ϕ balanced currents, the strength of rotating magnetic field is
(A) three times the amplitude of each constituent pulsating magnetic field
(B) equal to the amplitude of each constituent pulsating magnetic field
(C) half the amplitude of each pulsating magnetic field
(D) one and a half times the amplitude of each constituent pulsating magnetic field

7. The armature of a 1-ϕ alternator is completely wound with T single turn coils distributed uniformly, the induced voltage in each turn is 2 V (RMS). The emf of the whole winding is
(A) 2 T V (B) 1.27 T V
(C) 1.11 T V (D) 1.414 T V

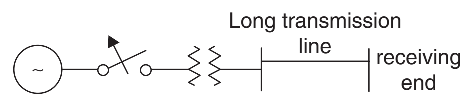
8. A 3-ϕ, 4-pole alternator has 48 stator slots carrying the 3-ϕ distributed winding. Each coil of the winding is short-circuited by one slot pitch. The winding factor is
(A) $\frac{1}{16}\cot 7.5°$ (B) $\frac{1}{8}\cot 7.5$
(C) $\frac{1}{16\sin 7.5°}$ (D) cos 7.5°

9. A 50 kW, 3-ϕ Y-connected, 50 Hz, 415 V cylindrical rotor synchronous generator operates at rated excitation with 0.8 p.f. leading. The motor efficiency excluding field and stator losses is 90% and $X_s = 2.5\ \Omega$. The power angle of the machine is approximately
(A) 27° (B) 54°
(C) –27° (D) –54°

10. A stationary alternator is connected across line bus bars. It
(A) will get short-circuited
(B) will run as a synchronous motor
(C) will decrease bus bar voltage through momentarily
(D) will distinct generated emf's of other alternators connected in parallel

11. Two alternators P and Q operate in parallel and supply a load of 20 MW at 0.8 p.f. lag. By adjusting the steam input of P its power output is adjusted to 12 MW and by changing its excitation its p.f. is adjusted to 0.9 lag. Find p.f. of alternator Q
(A) 0.557 lag (B) 0.657 lag
(C) 0.557 lead (D) 0.657 lead

12. A 50 Hz alternator is initially connected to a long lossless transmission line which is open circuited at the receiving end. With field voltage held constant, generator is disconnected from transmission line. Which of the following can be said about steady-state terminal voltage and field current of the generator?



(A) magnitude of terminal voltage decreases and magnitude of field current does not change
(B) magnitude of terminal voltage increases and field current does not change
(C) magnitude of terminal voltage increases and field current increases
(D) magnitude of terminal voltage does not change and field current decreases

13. A 250 MW, 21 kV, 50 Hz, 3-ϕ, 4-pole alternator having a rated p.f. = 0.8 has moment of inertia 30×10^3 kg m^2. The inertia constant H will be
(A) 1.18 s (B) 1.91 s
(C) 2.68 s (D) 4.82 s

14. A 80 kVA, 400 V, Y-connected synchronous machine generates rated open-circuit voltage of 400 V at a field current of 16 A. The short-circuit armature current at a field current of 10 A is equal to rated armature current. The per unit saturated synchronous reactance is
(A) 0.571 (B) 1.25
(C) 0.625 (D) 1.63

15. In relation to synchronous machines, which one of the following statements is false?
(A) In salient-pole machines, direct axis synchronous reactance is greater than quadrature axis synchronous reactance
(B) Damper winding helps synchronous motor self-start
(C) Short-circuit ratio is the ratio of field current required to produce, the rated voltage on O.C. to rated armature current
(D) The V curve of a synchronous motor represent variation in armature current with field excitation at a given output power

16. A 50 Hz, 6-pole, 100 MVA, 22 kV turbo generator is delivering rated MVA at 0.8 p.f. Suddenly a fault occurs reducing electric output by 30%. Neglect losses and assume constant power input to the shaft. The accelerating torque of generator in KNm at time of fault is

(A) 534.76 (B) 356.27
(C) 296.35 (D) 178.13

17. Two 3-ϕ, Y-connected alternators are to be paralleled to a set of common bus bars. The armature has a per phase synchronous reactance of 1.5 Ω and negligible armature resistance. The line voltage of first machine is adjusted to 3300 V and of second machine is 3200 V. The machine voltages are in phase at the instant they are paralleled. Under this condition, the synchronizing current per phase will be

(A) 19.1 A (B) 33.08 A
(C) 38.2 A (D) 66.16 A

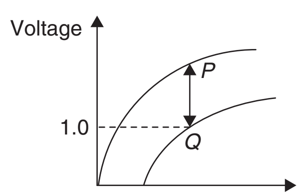
18. A 4-pole, 3-ϕ, double-layer winding is housed in a 36 slot stator for an **AC** machine with 60° phase speed. Coil span is 7 slot pitches. No. of slots in which top and bottom layers belong to different phases is

(A) 24 (B) 18
(C) 12 (D) 0

19. A standalone engine drives synchronous generator is feeding a partly inductive load. A capacitor is now connected across the load to completely nullify the inductive current. For this operating condition

(A) field current and fuel input has to be reduced
(B) field current and fuel input has to be increased
(C) field current has to be increased and fuel input left unaltered
(D) field current has to be reduced and fuel input left unaltered

20. Curves X and Y denote O.C. and full-load ZPF characteristics of a synchronous generator. Q is a point on ZPF characteristics at 1 p.u. voltage. The vertical distance PQ gives voltage drop across.



(A) synchronous reactance
(B) magnetizing reactance
(C) Potier reactance
(D) leakage reactance

21. A round rotor generator with internal voltage $E_1 = 2$ p.u. and $X = 0.9$ p.u. is connected to a round rotor synchronous motor with internal voltage. $E_2 = 1.2$ p.u. and $x = 1.1$ p.u. The reactance of line connecting generator and motor is 0.5 p.u. When generator supplies 0.4 p.u. power, rotor angle difference between machines is

(A) 30° (B) 24°
(C) 18° (D) 45°

22. The phase sequence of a 3-ϕ alternator can be reversed by

(A) reversing the field current and doubling the number of poles
(B) doubling the number of poles without reversing the field current
(C) reversing the field current keeping direction of rotation same
(D) reversing the direction of rotation keeping the field current same

23. A 5000 kVA, 10,000 V 1500 rpm, 50 Hz alternator is connected with infinite bus bar. Its synchronous reactance is 20%. The no-load synchronizing torque when there is a displacement of 0.5° mechanical is

(A) 672 kW (B) 772 kW
(C) 872 kW (D) 972 kW

24. The terminals of a 3-ϕ unloaded alternator is shorted. The role of damper windings here is to

(A) establish flux through the direct axis magnetic circuit of the machine
(B) repel the armature flux and confine it to leakage flux path in the air gap
(C) allow only partial linkage of armature flux with main field winding
(D) confine the armature flux to completely link the damper winding

25. Synchronous impedance method is used to calculate the regulation of a synchronous generator. This is

(A) lower than actual because of saturation of magnetic circuit
(B) higher than actual due to saturation of magnetic circuit
(C) nearly accurate as generator is normally operated with unsaturated magnetic circuit
(D) nearly accurate as it takes into account the magnetic saturation

26. The armature current of an alternator lags behind the excitation emf by an angle ϕ. The electrical angle between field axis and the axis of armature reaction field will be

(A) ϕ (B) 90°
(C) $90° - \phi$ (D) $90° + \phi$

27. In an alternator, the stator field,

(A) leads the rotor field and electromagnetic torque is developed in a direction opposite to direction of rotation of rotor
(B) leads the rotor field and electromagnetic torque is developed in the direction of rotation of rotor
(C) lags the rotor field and electromagnetic torque is developed opposite to direction of rotation of rotor
(D) lags the rotor field and electromagnetic torque is developed in same direction of rotation of rotor

28. A 50 Hz 4-pole turbo generator rated 100 MVA, 11 kV has been given a mechanical input of 80 MW suddenly for an electrical load of 40 MW, then speed of rotor after 10 cycles will be, if machine inertia constant is 8 μJ/MVA
(A) 1515 rpm (B) 1468 rpm
(C) 496 rpm (D) None of these

29. The maximum electrical output of a synchronous generator is
(A) $\frac{X_s}{V_t C_f}$ (B) $\frac{V_t^2}{X_s}$
(C) $\frac{C_f^{\ 2}}{X_s}$ (D) $\frac{V_t C_f}{X_s}$

30. An alternator is synchronized with the infinite bus bar. If the input to prime mover is cut off with field supply remaining constant
(A) it gets burnt
(B) it behaves as an induction motor but run in reverse direction
(C) it behaves as a synchronous motor and will rotate in same direction
(D) it behaves as a synchronous motor and rotate in reverse direction

31. High frequency on aircraft alternators is used to
(A) free system from external disturbance
(B) compensate for high speed
(C) compensate for high altitudes
(D) reduce bulk

Common Data for Questions 32 and 33:
A 4-pole, 50 Hz, synchronous generator has 36 slots in which a double layer winding is housed. Each coil has 10 turns and is short pitched by an angle of 30° electrical. The fundamental flux per pole is 0.025 Wb.

32. The line to line induced emf for a 3-ϕ Y connection is approximately
(A) 969 V (B) 869 V
(C) 1369 V (D) 1069 V

33. The line to line induced emf for a 2-ϕ connection is approximately
(A) 873 V (B) 973 V
(C) 1269 V (D) 1069 V

34. The fifth-harmonic component of phase emf for the 3-ϕ *Y* connection
(A) 0 (B) 269
(C) 281 (D) 808

Common Data for Questions 35 and 36:
A 500 kVA, 13.2 kV, 3-ϕ Y-connected cylindrical-pole synchronous generator has a synchronous reactance of 80 Ω. Neglect armature resistance and consider operation at full load and u.p.f.

35. The induced emf (line to line) is close to
(A) 11.24 kV (B) 13.54 kV
(C) 16.24 kV (D) 14.24 kV

36. The power or torque angle is close to
(A) 13.9° (B) 16.3°
(C) 12.9° (D) 30.3°

37. Distribution factor K_d is also known as
(A) Length factor
(B) Breadth factor
(C) Winding Factor
(D) None of the above

38. Which losses are reduced, by having laminated poles and pole shoes?
(A) Eddy current losses
(B) Hysteresis losses
(C) Iron losses
(D) Copper losses

39. Two 3-phase star-connected alternators, whose armature has a per phase synchronous reactance of 0.85 Ω and negligible armature resistance, are to be paralleled to a set of common bus bars. The line voltage of the first machine is adjusted to 330 V and that of second machine is adjusted to 320 V the synchronizing current per phase would be
(A) 16.97 A (B) 15.88 A
(C) 3.39 A (D) 1.697 A

40. Which among the following is not correct about distributed winding?
(A) Improves the waveform of induced emf
(B) Provides better utilization of core
(C) Enhances armature reaction
(D) Facilitates cooling

41. A 3.3 kV single-phase alternator delivering a current of 100 A at 0.8 p.f. lagging, produces a full-load current of 100 A on short circuit by a field excitation of 5 A and produces an emf of 250 V on open circuit by the same field current. The armature resistance is 0.65 Ω. The percentage regulation of the alternator is
(A) –6% (B) –8.9%
(C) +8.9% (D) +6%

42. For a uniformly distributed 3-phase winding the value of distribution factor would be
(A) 0.955 (B) 0.8
(C) 0.755 (D) 0.675

43. A 6.6 MVA, 3-phase star-connected, 6.6 kV, 2-pole turbo generator has a synchronous impedance of $(0.2 + j1.4)\Omega$ per phase. The generator losses are as given below
(a) S.C load loss = 110 kW
(b) O.C core loss at rated voltage = 45 kW
(c) Friction and windage losses = 25 kW
(d) Field winding resistance = 3 Ω
(e) Field current = 100 A

Neglecting the change in field current compute the efficiency at rated load 0.8 p.f. leading

(A) 94.65% (B) 95.46%
(C) 96% (D) 92%

44. The power angle at which a synchronous generator will develop maximum power will be

(A) $\delta = \theta$ and $\theta = \tan^{-1}\left(\frac{Xs}{\text{Re}}\right)$

(B) $\delta = \theta$ and $\theta = \tan^{-1}\left(\frac{\text{Re}}{Xs}\right)$

(C) $\delta = \theta$ only

(D) $\delta = \theta$ and $\theta = \tan^{-1}(\text{Xs})$

45. A 380 V, 100 kVA, 0.8 p.f. leading delta-connected, 60 Hz synchronous machine has a synchronous reactance of 2 Ω and negligible armature resistance. The friction and windage losses are 1 kW and the core loss is 1.6 kW. Calculate the power supplied to the load if the load is drawing a line current of 21 A at 0.8 p.f. leading

(A) 9 kW (B) 9.5 kW
(C) 8.5 kW (D) 11.785 kW

46. Given below are the test results that were conducted on an alternator for a field excitation of 20 A. Test Results

S.C. test: Armature current = 200 A

O.C. test: Terminal voltage = 1000 V

The magnitude of internal voltage drop within the machine for a load current of 25 A is

(A) 1000 V (B) 500 V
(C) 250 V (D) 125 V

47. A synchronous machine with large air gap has higher synchronizing power due to

(A) Larger air gap offers large reluctance to the path of flux produce by armature mmf
(B) Large air gap reduces the effect of armature reaction
(C) Large air gap results in small value of synchronous reactance
(D) All of the above

48. The methods employed to reduce hunting in alternators are by

(A) Employing heavy flywheels
(B) Putting dash-pots on the engine governors
(C) Using squirrel cage windings on the surface of the rotor
(D) All of the above

49. Synchronous generator with a synchronous reactance of 1.2 p.u. is connected to an infinite bus whose voltage is 1 p.u. through an equivalent reactance of 0.3 p.u. What should be the value of emf to give a maximum output of 1.2 p.u.?

(A) 0.8 p.u. (B) 1.8 p.u.
(C) 2.8 p.u. (D) 3.65 p.u.

50. Power angle δ depends upon which of the following factors:

(i) Supply voltage
(ii) Armature current
(iii) Power factor

(A) (i) and (ii) (B) (ii) and (iii)
(C) (i) and (iii) (D) (i), (ii) and (iii)

51. The increase in field current causes an increase in armature current in a synchronous motor, fed from an infinite bus and is delivering half full-load. Then the motor

(A) delivers reactive power to the bus an absorb active power from the bus
(B) Absorbs reactive power from the bus and delivers active power to the bus
(C) Absorbs active power and reactive power from the bus
(D) deliver reactive power and active power to the bus

52. The field current of a synchronous motor operating at 0.8 p.f. lag is continuously increased. Then

(A) the armature current increases up to a certain value of field current, and thereafter decreases
(B) the armature current decreases up to a certain value of field current and then increases
(C) the power factor increases up to a certain value of field current and then decreases
(D) the power factor decreases up to a certain value of field current and then increases

53. During hunting of synchronous motor

(A) negative phase sequence currents are generated
(B) harmonics are developed in the armature circuit
(C) damper bar develops torque
(D) field excitation increases

54. A 11 kV synchronous motor is connected to a load taking 0.8 p.f. lagging current. The armature reaction is

(A) cross-magnetizing (B) demagnetizing
(C) non-effective (D) magnetizing

55. A 3-ϕ synchronous motor connected to **AC** mains is running at full load and unity p.f. If the shaft load is reduced by half, with field current held constant, new power factor will be

(A) unity
(B) leading
(C) lagging
(D) dependent on m/c parameters

56. During hunting of a synchronous motor

(A) negative phase sequence current are generated
(B) harmonics are developed in armature circuit
(C) damper bar develops torque
(D) field excitation increases

57. A synchronous condenser is used to compensate a 2400 kVA 0.65 p.f. load so that the p.f. becomes unity. The kVA rating of condenser is

(A) 27 kVAr (B) 1560 kVAr
(C) 1825 kVAr (D) 840 kVAr

58. If the excitation of a salient-pole synchronous motor running under normal excitation is reduced to zero, then
(A) it becomes an induction motor
(B) it becomes a reluctance motor
(C) it remains a synchronous motor
(D) motor stops

59. Inverted V curves for a synchronous motor show variation of
(A) power factor and supply voltage when motor is hunting
(B) field current and supply voltage when excitation is constant
(C) power factor with **DC** field current when load on motor is constant
(D) None of these

60. A 3-ϕ synchronous motor is connected to an infinite bus. It is operating at half load with normal excitation. When load on the machine is suddenly increased
(A) speed decreases and then becomes synchronous
(B) speed first increases and then becomes synchronous
(C) speed will fluctuate around synchronous speed and then becomes
(D) speed remains unchanged

61. Damper windings are provided
(A) on pole faces
(B) on armature
(C) on rotor shaft
(D) on stator frame

62. The torque angle in a synchronous machine is the angle between
(A) rotating stator flux and rotor poles
(B) magnetizing current and back emf
(C) supply voltage and back emf
(D) none of the above

Common Data for Questions 63 and 64:
A synchronous motor connected to an infinite bus at 1 p.u. voltage draws 0.8 p.u. current at u.p.f. Its synchronous reactance is 0.9 p.u. and resistance is negligible.

63. The excitation voltage (E) and load angle δ will be
(A) 0.616 and 35.7 lag
(B) 0.616 and 35.7 lead
(C) 1.23 and 35.7 lag
(D) 1.23 and 35.7 lead

64. Keeping the excitation voltage same, the load on the motor is increased such that motor current increases by 20%. The operating power factor becomes
(A) 0.812 lag (B) 0.812 lead
(C) 0.749 lag (D) 0.749 lead

65. A synchronous motor runs at Ns rpm at full load. The speed of the synchronous motor at half full-load will be
(A) Half the rated rpm
(B) 1/4th the rated rpm
(C) Remains the same
(D) Double the rated rpm

66. A 3-phase synchronous motor driving a constant load torque draws power from infinite bus bar at leading power factor. With increase in excitation the power angle and power factor will
(A) Both power angle and p.f. decreases
(B) Power angle increases, p.f. decreases
(C) Power angle decreases, p.f. increases
(D) Both power angle and p.f. would increase

67. What should be the nature of excitation for a synchronous motor to operate as synchronous condenser?
(A) Under excited
(B) Over Excited
(C) Normally excited
(D) cannot be determined

68. The maximum value of torque that a motor can develop without losing synchronism is called
(A) Starting torque (B) Running torque
(C) Pull in torque (D) Pull out torque

69. For synchronous motors v-curves are plotted between the values of
(A) Armature current and power factor
(B) Armature current and Field current
(C) Field current and power factor
(D) Terminal voltage and Field current

70. A 1000 hp, 3.75 kV, 3-phase, star-connected synchronous motor has a synchronous impedance of $(5 + j12)$ Ω per phase. It is excited to develop an O.C emf of 2.5 kV. The ratio of current due to supply voltage and current due to induced emf is
(A) 1:2 (B) 2:3
(C) 3:2 (D) 2:1

71. Which of the following is false with regards to applications of a synchronous motor?
(A) Power factor correction equipment
(B) Voltage regulation equipments
(C) Constant speed drives
(D) Variable load drives

72. A synchronous motor is operated on no-load u.p.f. What should be done to the field current for the power factor to be leading?
(A) should not be changed
(B) should be increased
(C) should be decreased
(D) none of the above

73. If the excitation of a synchronous motor on infinite mains at no-load is increased, the current drawn by it will be of

(A) Unity p.f.
(B) Zero p.f. lagging
(C) It will not draw any current
(D) Zero p.f. leading

74. What would happen to load angle of a synchronous motor which is supplied power from a common bus bar and the bus voltage and frequency are reduced while field current and load torque are held constant?
(A) Load angle would decrease
(B) Load angle would increase
(C) Load angle would remain the same
(D) the motor will lose synchronism

75. If the phase angle between the excitation emf and current of a synchronous motor is given by θ_1. The synchronous motor on load draws a current at lagging p.f. θ_2. Then the armature mmf leads the excitation mmf by
(A) θ_2 (B) θ_1
(C) $\theta_1 - \theta_2$ (D) $\theta_1 + \theta_2$

76. What may be the causes if the synchronous motor fails to attain synchronous speed?
(A) Low supply voltage (B) Excessive load
(C) Field excited (D) All of the above

77. In what ways magnitude of armature current and power factor of a synchronous motor would vary if it is connected to an infinite bus, supplying constant torque, operating at u.p.f.
(A) Armature current will increase and p.f. will decrease
(B) Armature current will decrease and p.f. will increase
(C) Both armature current and p.f. will decrease
(D) Both armature current and p.f. will increase

78. A 440 V, 3-ϕ, 50 Hz circuit takes 10 A at 0.8 lagging p.f. A synchronous motor is used to raise the p.f. to unity. If the motor is driving a mechanical load of 10 kW and the motor has an efficiency of 80%, calculate the kVa input given to the motor and its p.f.
(A) 13.63, 0.64 lead
(B) 12.75, 0.875 lead
(C) 15.231, 0.75 lead
(D) 13.3, 0.94 lead

79. Which among the following is INCORRECT regarding a servomotor?
(A) They have non-linear relationship between the speed and electric control signal
(B) It has steady-state stability
(C) Wide range of speed control
(D) Low mechanical and electrical inertia

80. When a synchronous motor operates unexcited it is a
(A) AC series motor
(B) Universal motor
(C) Reluctance motor
(D) Repulsion motor

81. The maximum value of power developed in the synchronous motor is dependent on which of the following factors
(A) Maximum value of δ
(B) Rotor excitation
(C) Supply voltage
(D) All of the above

82. The purpose of damper winding in a synchronous motor is to
(A) reduce noise
(B) minimize circulating currents
(C) provide starting torque
(D) prevent hunting and provide starting torque.

83. Back emf set up in the stator of a synchronous motor will depend on
(A) Rotor speed, excitation and load angle
(B) Rotor excitation only
(C) Rotor speed only
(D) Rotor excitation and rotor speed

84. If the field windings of a synchronous motor are shorted on themselves and the motor is switched on then it will
(A) not start
(B) start and continue to run as an induction motor
(C) start as an induction motor and then run as synchronous motor
(D) Burn immediately

85. A 2300 V, 3-phase synchronous motor driving a pump is provided with a line ammeter and a field rheostat. When the rheostat is adjusted such that the AC line current is minimum, the ammeter reads 8.8 A. What is the reactive power supplied by the motor, if the motor was operating at 0.8 p.f. leading?
(A) 26.3 kVAR
(B) 36.3 kVAR
(C) 62.3 kVAR
(D) None of the above

86. A 3-ϕ star-connected 440 V, 20 A, 50 Hz, 500 rpm, develops an internal power of 6.7 kW. Calculate the effective resistance of the motor winding when operated at rated current and 0.8 leading p.f.?
(A) 1.5 Ω (B) 2.5 Ω
(C) 3.5 Ω (D) 4.5 Ω

87. A 3-ϕ, 2.3 kV, star-connected synchronous motor has an effective resistance and synchronous reactance of 0.45 Ω and 4.5 Ω, respectively. If 'θ' was the internal angle of the motor then what would happen to the value of θ if the value of R was increased by 0.9 Ω
(A) remain the same (B) 2θ
(C) 3θ (D) 4θ

88. A salient-pole synchronous motor has X_q = 0.35 p.u. and X_d = 0.55 p.u.. If the excitation is adjusted to 1.2 p.u. and the motor is connected to a bus bar of

1.0 p.u. voltage. The maximum power that the motor can deliver without loss of synchronism will be
(A) 0.958 p.u. (B) 1.58 p.u.
(C) 2.58 p.u. (D) 0.85 8 p.u.

89. The stepping angle of a stepper motor be increased by
(A) Decreasing the number of phases
(B) Reducing the number of poles
(C) Depends on the type of motor
(D) Both (A) and (B)

90. The number of stacks for a stepper motor of 6 poles and a stepping angle of 15° would be
(A) Single (B) Double
(C) Three (D) Four

91. Which of the following statements are true regarding servo motors
(i) The motor output torque is proportional to the voltage applied
(ii) The direction of torque developed depends on the instantaneous polarity of control voltage
(iii) The motor output torque is inversely proportional to the voltage applied
(iv) The direction of torque developed is independent of the polarity of control voltage
(A) (i) and (ii) (B) (ii) and (iii)
(C) (i) and (iv) (D) (iii) and (iv)

92. In a 3-phase synchronous motor the air gap flux will
(A) lag behind the armature mmf
(B) lead the armature mmf
(C) in phase with armature mmf
(D) either lead or lag based on load

93. For a 3-ϕ synchronous motor if
E_0 was O.C. emf/phase
V was Terminal voltage/phase
θ was the internal angle with lagging p.f. The relationship among the quantities will be
(A) $E_0 = \left[V^2 + E_R{}^2 + 2VE_R\cos(\theta+\phi)\right]^{\frac{1}{2}}$
(B) $E_0 = \left[V^2 + E_R{}^2 - 2VE_R\cos(\theta+\phi)\right]^{\frac{1}{2}}$
(C) $E_0 = \left[V^2 + E_R{}^2 + 2VE_R\cos(\theta-\phi)\right]^{\frac{1}{2}}$
(D) $E_0 = \left[V^2 + E_R{}^2 - 2VE_R\cos(\theta-\phi)\right]^{\frac{1}{2}}$

94. A 440 V, 1-ϕ synchronous motor gives a net output mechanical power of 6.5 kW and operates at 0.8 lagging p.f. If the effective resistance is 0.9 Ω and mechanical losses are 350 W then the estimated armature current is
(A) 15A (B) 25A
(C) 20 A (D) 30 A

95. The 'pull-out torque' of a synchronous motor is x times the 'full-load torque'. x can vary from
(A) 0.5 to 1.5
(B) 1.5 to 2.5
(C) 1.25 to 3.5
(D) It is a constant value 0.6

96. A 440 V, 50 Hz, 3-phase circuit takes a 10 A at lagging p.f. of 0.8 A synchronous motor is used to raise the p.f to unity. Calculate the efficiency of the motor when driving a mechanical load of 8.5 kW, supplied with an input of 13.63 kVa at a power factor of 0.6472
(A) 60% (B) 66%
(C) 71.25% (D) 76.66%

97. A 4-pole, 3-phase, 50 Hz, star-connected synchronous motor has a negligible armature resistance and armature reactance of 8 Ω/phase. The excitation is such as to give an E_{OC} of 13.2 kV. If the motor is connected to a 11.5 kV, 50 Hz supply. The maximum load that the motor can supply during synchronism is
(A) 18.97 kW
(B) 18.97 MW
(C) 17.89 kW
(D) 17.89 MW

98. Which among the following is the expression for maximum mechanical power developed by a synchronous motor if the synchronous impedance was purely reactive and armature resistance is negligible
(A) $(P_{\text{mech}})_{\max} = 3\left[\frac{EV}{Zs} - \frac{E^2}{Zs}\cos\theta\right]$
(B) $(P_{\text{mech}})_{\max} = \frac{3EV}{Zs}$
(C) $(P_{\text{mech}})_{\max} = 3\left[\frac{EV}{Zs} - \frac{E^2}{Z_s}\right]$
(D) None of the above

Common Data for Questions 99 and 100:
A 3-ϕ star-connected 400 V synchronous motor takes a power input of 6 kW at rated voltage. Its synchronous reactance is 10 Ω per phase and resistance is negligible. If the excitation voltage is adjusted equal to the rated voltage of 400 V, then

99. The load angle is ______
(A) 20° (B) 24.02°
(C) 22.02° (D) 29.82°

100. The armature current is ______
(A) 8.82 A (B) 7.80 A
(C) 6.43 A (D) 4.4 A

Previous Years' Questions

1. For a 1.8°, 2-phase bipolar stepper motor, the stepping rate is 100 steps/second. The rotational speed of the motor in rpm is **[2004]**

(A) 15 (B) 30
(C) 60 (D) 90

2. A 400 V, 50 kVA, 0.8 p.f. leading Δ-connected, 50 Hz synchronous machine has a synchronous reactance of 2 Ω and negligible armature resistance. The friction and windage losses are 2 kW and the core loss is 0.8 kW. The shaft is supplying 9 kW load at a power factor of 0.8 leading. The line current drawn is **[2004]**

(A) 12.29 A (B) 16.24 A
(C) 21.29 A (D) 36.88 A

3. A 500 MW 3-phase Y-connected synchronous generator has a rated voltage of 21.5 kV at 0.85 p.f. The line current when operating at full-load rated conditions will be **[2004]**

(A) 13.43 kA (B) 15.79 kA
(C) 23.25 kA (D) 27.36 kA

Common Data for Questions 4a and 4b:

A 1000 kVA, 6.6 kV, 3-phase star-connected cylindrical-pole synchronous generator has a synchronous reactance of 20 Ω. Neglect the armature resistance and consider operation at full load and unity power factor.

4. (a) The induced emf (line-to-line) is close to **[2005]**

(A) 5.5 kV (B) 7.2 kV
(C) 9.6 kV (D) 12.5 kV

(b) The power (or torque) angle to close to

(A) 13.9° (B) 18.3°
(C) 24.6° (D) 33.0°

5. In relation to the synchronous machines, which one of the following statements is false? **[2005]**

(A) In salient-pole machines, the direct-axis synchronous reactance is greater than the quadrature-axis synchronous reactance
(B) The damper bars help the synchronous motor self-start
(C) Short-circuit ratio is the ratio of the field current required to produce the rated voltage on open circuit to the rated armature current
(D) The V-curve of a synchronous motor represents the variation in the armature current with field excitation, at a given output power

6. A synchronous generator is feeding a zero power factor (lagging) load at rated current. The armature reaction is **[2006]**

(A) magnetizing
(B) demagnetizing
(C) cross-magnetizing
(D) ineffective

7. A 3-phase, 400 V, 5 kW, star-connected synchronous motor having an internal reactance of 10 Ω is operating at 50% load, unity p.f. Now, the excitation is increased by 1%. What will be the new load in per cent, if the power factor is to be kept same? Neglect all losses and consider linear magnetic circuit. **[2006]**

(A) 67.9% (B) 56.9%
(C) 51% (D) 50%

Common Data for Questions 8 to 10:

A 4-pole, 50 Hz, synchronous generator has 48 slots in which a double layer winding is housed. Each coil has 10 turns and is short pitched by an angle to 36° electrical. The fundamental flux per pole is 0.025 Wb.

8. The line-to-line induced emf (in volts), for a three-phase star connection is approximately **[2006]**

(A) 808 (B) 888
(C) 1400 (D) 1538

9. The line-to-line induced emf (in volts), for a three-phase connection is approximately **[2006]**

(A) 1143 (B) 1332
(C) 1617 (D) 1791

10. The fifth harmonic component of phase emf (in volts), for a three-phase star connection is **[2006]**

(A) 0 (B) 269
(C) 281 (D) 808

11. A three-phase synchronous motor connected to AC mains is running at full load and unity power factor. If its shaft load is reduced by half, with field current held constant, its new power factor will be **[2007]**

(A) unity
(B) leading
(C) lagging
(D) dependent on machine parameters

12. A 100 kVA, 415 V (line), star-connected synchronous machine generates rated open-circuit voltage of 415 V at a field current of 15 A. The short-circuit armature current at a field current of 10 A is equal to the rated armature current. The per unit saturated synchronous reactance is **[2007]**

(A) 1.731 (B) 1.5
(C) 0.666 (D) 0.577

13. A three-phase, three-stack, variable reluctance step motor has 20 poles on each rotor and stator stack. The step angle of this step motor is **[2007]**

(A) 3° (B) 6°
(C) 9° (D) 18°

14. In a stepper motor, the detent torque means **[2008]**

(A) minimum of the static torque with the phase winding excited.

(B) maximum of the static torque with the phase winding excited.
(C) minimum of the static torque with the phase winding unexcited.
(D) maximum of the static torque with the phase winding unexcited.

Common Data for Questions 15 and 16:
A synchronous motor is connected to an infinite bus at 1.0 p.u. voltage and draws 0.6 p.u. current at unity power factor. Its synchronous reactance is 1.0 p.u. and resistance is negligible.

15. The excitation voltage (E) and load angle (δ) will, respectively, be **[2008]**
(A) 0.8 p.u. and 36.86° lag
(B) 0.8 p.u. and 36.86° lead
(C) 1.17 p.u. and 30.96° lead
(D) 1.17 p.u. and 30.96° lag

16. Keeping the excitation voltage same, load on the motor is increased such that the motor current increases by 20%. The operating power factor will become **[2008]**
(A) 0.995 lagging (B) 0.995 leading
(C) 0.791 lagging (D) 0.848 leading

17. A field excitation of 20 A in a certain alternator results in an armature current of 400 A in short circuit and a terminal voltage of 2000 V on open circuit. The magnitude of the internal voltage drop within the machine at a load current of 200 A is **[2009]**
(A) 1 V (B) 10 V
(C) 100 V (D) 1000 V

18. The direct axis and quadrature axis reactances of a salient-pole alternator are 1.2 p.u. and 1.0, respectively. The armature resistance is negligible. If this alternator is delivering rated kVA at u.p.f. and at rated voltage then its power angle is. **[2011]**
(A) 30° (B) 45°
(C) 60° (D) 90°

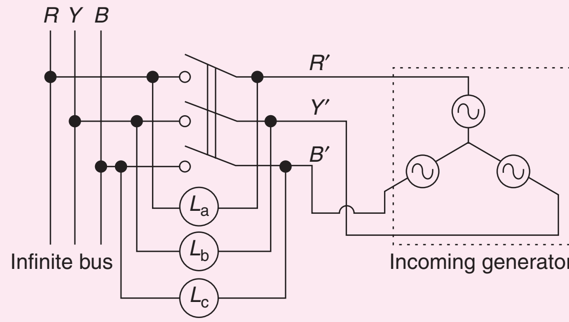
19. A star-connected 400 V, 50 Hz, 4-pole synchronous machine gave the following open-and short-circuit test results:

Open-circuit test: V_{oc} = 400 V (RMS, line-to-line) at field current, I_f = 2.3 A

Short-circuit test: I_{sc} = 10 A (RMS, phase) at field current, I_f = 1.5 A

The value of per phase synchronous impedance in Ω at rated voltage is ______. **[2014]**

20. A three-phase synchronous generator is to be connected to the infinite bus. The lamps are connected as shown in the figure for the synchronization. The phase sequence of bus voltage is R-Y-B and that of incoming generator voltage is R'-Y'-B'.



It was found that the lamps are becoming dark in the sequence L_a-L_b-L_c. It means that the phase sequence of incoming generator is **[2014]**
(A) opposite to infinite bus and its frequency is more than infinite bus
(B) opposite to infinite bus but its frequency is less than infinite bus
(C) same as infinite bus and its frequency is more than infinite bus
(D) same as infinite bus and its frequency is less than infinite bus

21. A 20-pole alternator is having 180 identical stator slots with 6 conductors in each slot. All the coils of a phase are in series. If the coils are connected to realize single-phase winding, the generated voltage is V_1. If the coils are reconnected to realize three-phase star-connected winding, the generated phase voltage is V_2. Assuming full pitch, single-layer winding, the ratio V_1/V_2 is **[2014]**
(A) $\frac{1}{\sqrt{3}}$ (B) $\frac{1}{2}$
(C) $\sqrt{3}$ (D) 2

22. In a synchronous machine, hunting is predominantly damped by **[2014]**
(A) mechanical losses in the rotor
(B) iron losses in the rotor
(C) copper losses in the stator
(D) copper losses in the rotor

23. A non-salient-pole synchronous generator having synchronous reactance of 0.8 p.u. is supplying 1 p.u. power to a unity power factor load at a terminal voltage of 1.1 p.u. Neglecting the armature resistance, the angle of the voltage behind the synchronous reactance with respect to the angle of the terminal voltage in degrees is ___________. **[2014]**

24. A three-phase, salient-pole synchronous motor is connected to an infinite bus. It is operated at no load at normal excitation. The field excitation of the motor is first reduced to zero and then increased in the reverse direction gradually. Then the armature current.
(A) increases continuously
(B) first increases and then decreases steeply

(C) first decreases and then increases steeply
(D) remains constant

25. A three-phase, 11 kV, 50 Hz, 2 pole, stars connected, cylindrical rotor synchronous motor is connected to an 11 kV, 50 Hz source, Its synchronous reactance is 50 Ω per phase, and its stator resistance is negligible. The motor has a constant field excitation. At a particular load torque, its stator current is 100 A at unity power factor. If the load torque is increased so that the stator current is 120 A, then the load angle (in degrees) at this load is ________. **[2015]**

26. Consider a system consisting of a synchronous generator working at a lagging power factor, a synchronous motor working at an overexcited condition and a directly grid-connected induction generator. Consider capacitive VAr to be a source and inductive VAr to be a sink of reactive power. Which one of the following statements is TRUE? **[2016]**

(A) Synchronous motor and synchronous generator are sources and induction generator is a sink of reactive power.
(B) Synchronous motor and induction generator are sources and synchronous generator is a sink of reactive power.
(C) Synchronous motor is a source and induction generator and synchronous generator are sinks of reactive power.
(D) All are sources of reactive power.

27. A three-phase, 50 Hz salient-pole synchronous motor has a per-phase direct-axis reactance (X_d) of 0.8 pu and a per-phase quadrature-axis reactance (X_q) of 0.6 pu. Resistance of the machine is negligible. It is drawing full-load current at 0.8 pf (leading). When the terminal voltage is 1 pu, per-phase induced voltage, in pu, is ________. **[2016]**

Answer Keys

Exercises

Practice Problems 1

1. C	**2.** C	**3.** D	**4.** B	**5.** B	**6.** B	**7.** A	**8.** D	**9.** C	**10.** D
11. B	**12.** C	**13.** A	**14.** A	**15.** C	**16.** A	**17.** C	**18.** D	**19.** C	**20.** A
21. C	**22.** C	**23.** B	**24.** D	**25.** B	**26.** A				

Practice Problems 2

1. D	**2.** D	**3.** B	**4.** A	**5.** B	**6.** D	**7.** B	**8.** B	**9.** C	**10.** A
11. B	**12.** D	**13.** A	**14.** C	**15.** C	**16.** A	**17.** A	**18.** C	**19.** D	**20.** D
21. A	**22.** D	**23.** C	**24.** B	**25.** B	**26.** C	**27.** C	**28.** A	**29.** D	**30.** C
31. D	**32.** D	**33.** A	**34.** A	**35.** B	**36.** C	**37.** B	**38.** A	**39.** C	**40.** C
41. D	**42.** A	**43.** C	**44.** A	**45.** C	**46.** D	**47.** D	**48.** D	**49.** B	**50.** D
51. A	**52.** B	**53.** C	**54.** D	**55.** B	**56.** C	**57.** C	**58.** B	**59.** C	**60.** C
61. A	**62.** A	**63.** D	**64.** D	**65.** C	**66.** A	**67.** B	**68.** D	**69.** B	**70.** C
71. D	**72.** B	**73.** D	**74.** B	**75.** C	**76.** B	**77.** A	**78.** D	**79.** A	**80.** C
81. D	**82.** D	**83.** B	**84.** C	**85.** A	**86.** D	**87.** C	**88.** A	**89.** D	**90.** D
91. A	**92.** A	**93.** B	**94.** C	**95.** C	**96.** B	**97.** B	**98.** B	**99.** C	**100.** A

Previous Years' Questions

1. B	**2.** C	**3.** B	**4.** (a) B (b) C		**5.** C	**6.** B	**7.** A	**8.** C	**9.** C
10. A	**11.** B	**12.** C	**13.** B	**14.** D	**15.** D	**16.** A	**17.** D	**18.** B	**19.** 15.06
20. A	**21.** D	**22.** D	**23.** 33.61	**24.** B	**25.** –48 to –46°		**26.** A	**27.** 1.606	

Test
Electrical Machines

Ref: ELE1431435 **Time: 60 min.**

Directions for questions 1 to 25: Select the correct alternative from the given choices.

1. An auto transformer supplies a load of 3 KW at 150 V at a unity power factor.

   If the applied voltage is 230 V. The power transferred to the load inductively is

   (A) 1.043 KW (B) 1.956 KW
   (C) 3 KW (D) 1.5 KW

2. Neglecting the effects of armature reaction, if the excitation of a synchronous motor running with a constant load is decreased from its normal value it leads to

   (A) increase in p.f.
   (B) increase in I_a
   (C) decrease in p.f.
   (D) increase in I_a and decrease in p.f.

3. No load test on a 3-phase induction motor was conducted at different supply voltage and a plot of input power versus voltage was drawn. This curve is extrapolated to intersect the Y axis. This intersection point yields

   (A) friction and windage loss
   (B) core loss
   (C) stator copper loss
   (D) stray load loss

4. In a 3-phase delta/star transformer, the phase displacement of secondary line voltage with respect to corresponding primary line voltages will be _______.

   (A) zero (B) 30°lag
   (C) 30° lead (D) 180°

5. If a 230 V d.c. series motor is connected to a 230 V a.c. supply,

   (A) the motor will vibrate violently.
   (B) the motor will run with less efficiency and more sparking.
   (C) the motor will not run.
   (D) the fuse will be blown.

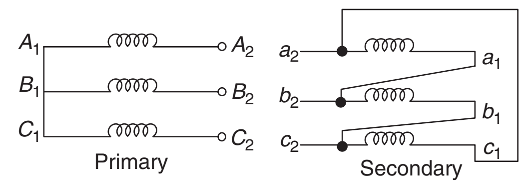
6. A 3-phase 20-pole, synchronous generator has 180 stator slots with single-layer full pitch coils. There are 6 conductors per slot and all coils per phase are connected in series. The rotor is driven at 300 rpm and the flux pole (sinusoidally distributed) is 25 mWb. The voltage induced per phase is nearest to

   (A) 500 V
   (B) 1000 V
   (C) 1500 V
   (D) 2000 V

7. The phase sequence of an alternator reverses if

   (A) The field current is reversed keeping the direction of rotation same
   (B) The field current remains the same but the direction of rotation is reversed
   (C) Field current is reversed and number of poles doubled
   (D) Number of poles doubled and field current remain same

8. Three single phase transformer are connected to form a 3 phase transformer bank. The transformer are connected as in figure. The transformer connection will be represented by



   (A) Yd0 (B) Yd1 (C) Yd6 (D) Yd11

9. The primary current in a current transformer is dictated by

   (A) The secondary burden
   (B) The core of the transformer
   (C) The load current
   (D) None of these

10. A 100 MVA synchronous generator operates on full load UPF at a frequency of 50 Hz. The load is suddenly reduced to 50 MW. Due to time lag in governor system, the system valve begins to close after 0.4 seconds. The frequency at the end of 0.4 seconds is _____. (Given H = 5 KW – seconds/KVA of generator capacity)

    (A) 51 Hz (B) 52 Hz (C) 53 Hz (D) 49 Hz

11. Which of the following conditions are necessary for parallel operation of alternators?

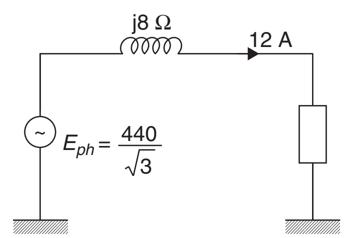
    1. Equal terminal voltage
    2. Same frequency
    3. Same phase sequence
    4. Same KVA rating
    5. Same $\frac{X}{R}$ ratio

    (A) 1, 2 and 3 (B) 2, 3 and 5
    (C) 1, 2 and 4 (D) 2, 3 and 4

12. A 400 V, 20 kW, 4 pole, 50 Hz Y-connected induction motor has full load slip of 3.4%. The output torque of the machine at full load is

    (A) 250 Nm (B) 141 Nm (C) 120 Nm (D) 131.8 Nm

13. The per phase synchronous reactance of a star connected 440 V, 50 Hz alternator is 8 Ω. It supplies a balanced capacitive load current of 12 A, as shown in figure. If zero voltage regulation is desirable, the load power factor should be



    (A) 0.923 (B) 0.783 (C) 0.85 (D) 0.65

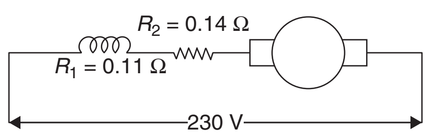
14. If the applied voltage of a certain transformer is increased by 50% and the frequency is reduced to 50% (assuming that the magnetic circuit remains unsaturated), the maximum core flux density will ______.

(A) change to three times the original value
(B) change to 1.5 times the original value
(C) change to 0.5 times as the original value
(D) remain the same as the original value.

15. A 20 kVA 400V/200V single phase transformer with a percentage resistance of 4% and percentage reactance of 8% is supplying a current of 80 A to a resistive load. The value of load voltage is

(A) 193.6 V (B) 387.2 V
(C) 190.4 V (D) 197.8 V

16. A DC series motor is rated 230 V, 1000 rpm, 80 A. The series field resistance is 0.11 Ω and the armature resistance is 0.14 Ω. If the flux at an armature current of 20 A is 0.4 times of that under rated condition, calculate the speed at the reduced armature current of 20 A.



(A) 2168 rpm
(B) 876 rmp
(C) 2678 rpm
(D) 1980 rpm

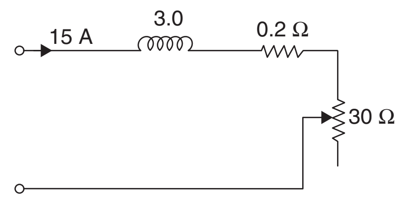
17. A separately excited dc machine, having an armature resistance of 2 ohms was working on a 220 V supply and drawing 10 A armature current from the source. When the supply voltage suddenly dropped to 200 V, assuming that the field circuit source voltage remained unaffected, how will the armature current of the machine react to the change?

(A) It will initially rise to 11 A and then settle down to 10 A.
(B) It will fall momentarily to 9.09 A and then slowly attain 10 A.
(C) It will reduce to zero first and then settle back to 10 A.
(D) It will remain unaffected by the change and continue to be 10 A.

18. A 50 KW synchronous motor is tested by driving it by another motor. When the excitation is not switched on, diving motor takes 800 W. When the armature is short circuited and rated armature current of 10 A is passed through it, the driving motor requires 2500 W. On open circuiting the armature with rated excitation, driving motor takes 1800 W. Neglecting the losses in the driving motor, the efficiency of the synchronous motor is

(A) 87.71%
(B) 91.83%
(C) 83.05%
(D) 85.32%

19. A 3 ϕ, 50 Hz, 6 pole induction motor has an equivalent diagram as shown in the figure. The torque developed in the motor is



(A) 113.4 Nm
(B) 92.8 Nm
(C) 185.6 Nm
(D) 193.4 Nm

20. Two transformers having equal voltage ratio are connected in parallel. They have equal impedance and equal $\frac{X}{R}$ ratio. The ratio of full load KVA delivered to the sum of their individual KVA ratings is

(A) 0.5 (B) 1 (C) 0.6 (D) 0.75

21. A 400 V, 50 Hz, 100 KVA, 0.9 pf leading, delta connected synchronous machine has synchronous reactance of 3 Ω. The armature resistance can be neglected. The core loss of the machine is 1.2 KW and the friction and windage losses are 2.8 KW. If the shaft is supplying 20 KW at 0.9 leading, then the line current drawn is

(A) 36.88 A
(B) 52.16 A
(C) 18.44 A
(D) 26.08 A

22. A 200 V dc series motor runs at 500 rpm when taking a current of 25 A. The resistance of the armature is 0.5 Ω and that of field is 0.3 Ω. If the current remains constant, the resistance necessary to reduce the speed to 250 rpm is

(A) 1.8 Ω (B) 3.6 Ω (C) 5.4 Ω (D) 7.2 Ω

23. A 3 – ϕ squirrel cage induction motor has a starting torque of 140% and a maximum torque of 280% with respect to rated torque at rated voltage and rated frequency. Neglect the stator resistance and rotor losses. The value of slip for maximum torque is

(A) 300%
(B) 26.79%
(C) 2.67%
(D) 267.9%

Common Data for Questions 24 and 25:

A 250 V separately excited DC motor has armature resistance of 2.5 ohm. When driving a load at 600 rpm with constant torque, the armature takes 20 A. The motor is controlled by a DC chopper operating with a frequency of 400 Hz and an input voltage of 250 V D.C.

24. What should be the value of duty ratio, if it is desired to reduce the speed from 600 rpm to 400 rpm?
(A) 0.63 (B) 0.55
(C) 0.73 (D) 0.85

25. The motor speed at rated current and a duty ratio of 0.5, if the motor is regenerating is?
(A) 225 rpm (B) 525 rpm
(C) 325 rpm (D) 425 rpm

Answer Keys

1. A	**2.** D	**3.** A	**4.** C	**5.** B	**6.** B	**7.** B	**8.** B	**9.** C	**10.** A
11. A	**12.** D	**13.** A	**14.** A	**15.** A	**16.** C	**17.** C	**18.** B	**19.** D	**20.** B
21. A	**22.** B	**23.** B	**24.** C	**25.** B					