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Popular Publications

EXAMINATION GUIDE

[Solved 10 Years MAKAUT Questions]

B. TECH

ELECTRICAL ENGINEERING

5th (FIFTH) SEMESTER

Popular Publications

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Published By:
Popular Publications
231/A, Chittaranjan Avenue
Kolkata – 700 006

Printed By:
Graafika
36C, Aurobindo Sarani,
Kolkata – 700 006

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1st Edition 2010
2nd Revised Edition 2011
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4th Revised Edition 2013
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10th Revised Edition 2019
11th Revised Edition 2022

Price: Rs. 880.00

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ELECTRICAL MACHINE-II

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FUNDAMENTALS OF AC MACHINE WINDINGS

Multiple Choice Type Questions

1. For a P-pole machine, the relation between electrical and mechanical degrees is given by [WBUT 2012, 2013, 2016]

a) $\theta_{elec} = \frac{2}{P}\theta_{mech}$ b) $\theta_{elec} = \frac{4}{P}\theta_{mech}$ c) $\theta_{mech} = \frac{P}{2}\theta_{elec}$ d) $\theta_{elec} = \frac{P}{2}\theta_{mech}$

Answer: (d)

2. For eliminating n^{th} harmonic from the *emf* generated in the phase of a 3-phase alternator, the chording angle should be [WBUT 2012]

a) $n \times$ full-pitch b) $\frac{1}{n} \times$ full-pitch c) $\frac{2}{n} \times$ full-pitch d) $\frac{3}{n} \times$ full-pitch

Answer: (b)

3. Skew is used in induction motor in order to reduce [WBUT 2014]

a) Time harmonics
b) Space harmonics
c) Slot harmonics
d) None

Answer: (d)

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4. For eliminating *n*th harmonic from the EMF generated in the phase voltage of a 3-phase generator, the chording angle should be [WBUT 2018]

a) $n \times$ full pitch b) $\frac{1}{n} \times$ full pitch c) $\frac{2}{n} \times$ full pitch d) $\frac{3}{n} \times$ full pitch

Answer: (b)

5. In concentrated winding, the umber of slots in equal to the number of [MODEL QUESTION]

a) coil sides b) poles c) conductors d) coils

Answer: (b)

6. Concentrated winding has [MODEL QUESTION]

a) one coil per phase
b) two coils per phase
c) one coil per pair of poles per phase
d) one coil side per pole pair per phase

Answer: (c)

7. For a two layer winding the number of stator slots is equal to the number of [MODEL QUESTION]

a) poles b) conductors c) coil sides d) coils

Answer: (d)

8. Distributed winding has the advantage(s) of [MODEL QUESTION]
   a) better utilization of core as a number small slots evenly spaced are used
   b) improved waveforms as harmonic emfs are reduced
   c) diminished armature reactance and armature reaction
   d) efficient cooling
   e) all of these

Answer: (e)

9. For a full pitch winding, the induced emf in both coil sides are [MODEL QUESTION]
   a) additive b) subtractive c) in quadrature d) none of these

Answer: (a)

10. Smooth cylindrical rotors are usually designed for [MODEL QUESTION]
   a) 2 or 4 poles b) 8 poles c) 12 poles d) 24 poles

Answer: (a)

11. Armature winding in ac machines [MODEL QUESTION]
   a) is always closed one
   b) is always open one
   c) may be either closed one giving delta connections or open one giving star connections
   d) none of these

Answer: (c)

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12. A pole-pitch in electrical machines is equal to [MODEL QUESTION]
   a) 180 electrical degrees b) 90 electrical degrees
   c) 120 electrical degrees d) 360 electrical degrees

Answer: (a)

13. The amount of portion of cylindrical rotor is wound [MODEL QUESTION]
   a) one third b) two third c) one half d) whole

Answer: (b)

14. The minimum number of coils needed in single phase winding is [MODEL QUESTION]
   a) one b) two c) four d) six

Answer: (a)

15. The minimum number of windings required for producing a polyphase field is [MODEL QUESTION]
   a) one b) two c) three d) none of these

Answer: (b)

16. The mmf produced by single phase winding is [MODEL QUESTION]
   a) pulsating and rotating with constant speed
   b) pulsating and stationary
   c) constant in amplitude and stationary
   d) constant in amplitude and rotating

Answer: (b)

Short Answer Type Questions

1. What are the advantages of distributing winding in rotating electric machine?

Show that $k_d = \dfrac{\sin\frac{q\gamma}{2}}{q\sin\frac{\gamma}{2}}$, where k_d = distribution factor, q = slots per pole per phase, γ = slot pitch in electrical radian. [WBUT 2012, 2013]

OR,

What are the advantages of distributed winding in rotating electrical machine?

Show that $K_d = \dfrac{\sin\left(\frac{m\alpha}{2}\right)}{m\sin\left(\frac{\alpha}{2}\right)}$ where K_d = distribution factor, m = number of slots per pole per phase and α = angular slot pitch. [WBUT 2016]

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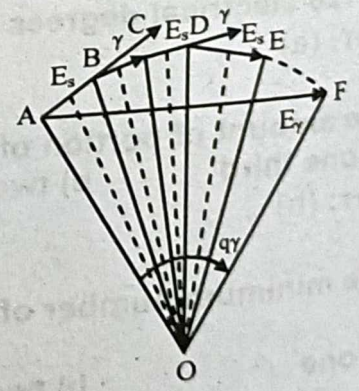
Answer:

The advantages of distributing winding in rotating electric machine are:

(i) improve wave form of induced emf.
(ii) provide better utilisation of core.
(iii) diminishes armature reaction.
(iv) facilitate cooling.



Let n = number of slots

q = number of slots / pole / phase.

E_s = induced emf in each coil side.

γ = angular displacement between the slots $= \dfrac{180°}{n}$.

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

EMF induced in each coil side, $E_s = AB = 2OA\sin\frac{\gamma}{2}$

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

The resultant emf, $E_\gamma = AF = 2 \times OA\sin\frac{AOF}{2} = 2 \times OA\sin\left(\frac{q\gamma}{2}\right)$

Distribution factor, $k_d = \frac{\text{Vector sum}}{\text{arithmetic sum}} = \frac{2 \times OA\sin\left(\frac{q\gamma}{2}\right)}{q \times 2 \times OA\sin\frac{\gamma}{2}} = \frac{\sin\left(\frac{q\gamma}{2}\right)}{q\sin\frac{\gamma}{2}}$

Hence distribution factor, $k_d = \frac{\sin\left(\frac{q\gamma}{2}\right)}{q\sin\left(\frac{\gamma}{2}\right)}$ (Proved).

2. Define:
Pitch factor **[WBUT 2014]**
OR,
i) Pitch Factor (Kp) **[MODEL QUESTION]**
ii) Winding Factor **[MODEL QUESTION]**

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Answer:
i) Pitch Factor (Kp)
It is defined as the ratio of resultant e.m.f. of a chorded coil to the resultant e.m.f. had the same coil been full-pitched. Thus

$$K_p = \frac{\text{Resultant e.m.f. of a chorded coil}}{\text{Resultant e.m.f. of a full pitched coil}} = \frac{2E\cos\frac{\varepsilon}{2}}{2E} = \cos\frac{\varepsilon}{2}$$

The chording angle is $\varepsilon°$ for fundamental flux wave and for nth space field harmonic, the chording angle becomes $n\varepsilon°$ electrical. Therefore, the pitch factor for nth harmonic is:-

$$K_{pn} = \cos\frac{n\varepsilon}{2}$$

The advantages of using fractional pitch winding are:
i) reduction in the copper for overhung. This result is less cost of the machine.
ii) reduction of harmonics in the generated e.m.f. wave, there by rendering the output e.m.f. wave almost a sine wave.

It may therefore be noted that the use chorded coil is quite justified as the advantage of reducing the higher order of harmonics in the e.m.f. wave is much more important than the disadvantage of higher initial cost.

ii) Winding Factor

The product of distribution factor K_d and the pitch factor K_p is referred to as the winding factor and may be denoted as K_w.

3. Why closed type slots are often used for small induction motor? **[MODEL QUESTION]**

Answer:

Use of closed slots make the reluctance more uniform reduced magnetising current, better power factor, low tooth pulsation loss and quiet operation.

4. What is done to reduce tooth pulsation loss in an induction motor? **[MODEL QUESTION]**

Answer:

The slots should be so proportioned that minimum variation in the airgap reluctance is achieved. This is possible by using large number of narrow slots.

5. What types of winding used in the stator of induction motor? **[MODEL QUESTION]**

Answer:

Two most common types of winding used induction motors are, the single layer mush winding and double layer lap winding.

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6. How stator phases can be formed in case of large motors or those for high voltage? **[MODEL QUESTION]**

Answer:

For large motors or those for high voltage the stator phases may be formed by single layer concentric coils.

7. What are the advantages of short pitch winding? **[MODEL QUESTION]**

Answer:

The advantages are:

i) Increased mechanical strength.
ii) Reduced tooth ripples s fractional number of slots per pole can be used.
iii) Saving in copper requirement in the coil ends due to shorter span.

8. What is done to reduce tooth pulsation los in an induction motor? **[MODEL QUESTION]**

Answer:

The slots should be so proportioned that minimum variation in the airgap reluctance is achieved. This is possible by using large number of narrow slots.

9. Why fractional pitch winding is used? **[MODEL QUESTION]**

Answer:

a) Results in reduced leakage reactance

b) Results in reduced axial length of the machine and makes it stiffer.

10. Why stator and rotor slots are not made equal in an induction motor?
[MODEL QUESTION]

Answer:
When numbers of stator and rotor slots are made equal, harmonics of every order will try to exert synchronous torques and the machine will refuse to start.

Long Answer Type Questions

1. Write short note on EMF Polygon. **[WBUT 2017]**

Answer:
With the help of emf polygon the expressions for distribution and pitch factors can be derived.
The Fig. 1(a) shown below has 12 conductors housed in 12 slots in which emf has induced in the conductors and Fig. 1(b) represents emf polygon.

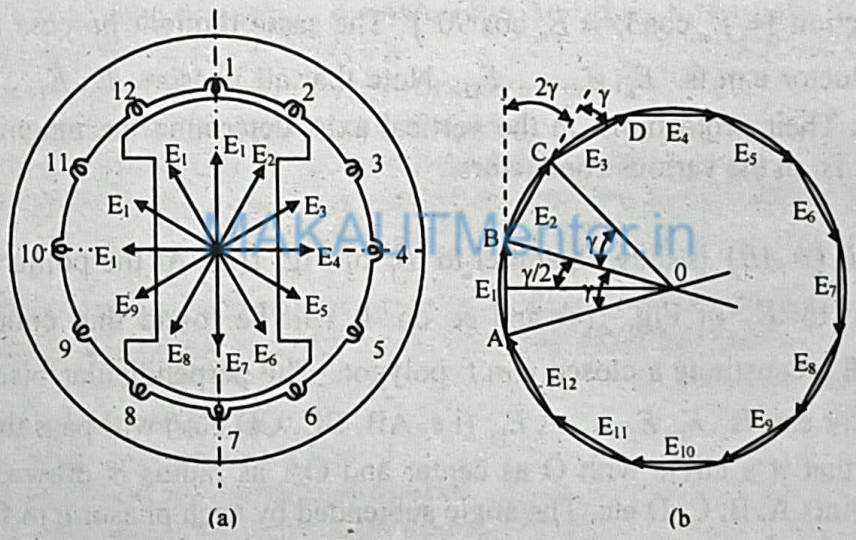

Fig: 1(a) E.m.f. induced in various conductors (b) e.m.f.

The field current produces two poles on the rotor and the field flux is assumed to be sine-distributed in space. At the instant shown in Fig. 1(a), the conductor 1 is being cut by the maximum flux, say ϕ_m, therefore, the e.m.f. induced in it is also maximum, say E_m. This e.m.f. can be represented by a phasor whose projection on the vertical axis must be equal to the r.m.s. value of the e.m.f. generated in conductor 1. This is shown in Fig. 1(a) by a phasor $\overline{E}_1 = E_m/\sqrt{2}$ along the vertical axis. Conductor 2 is being cut by a flux $(=\phi_m \cos\gamma)$ less than ϕ_m, accordingly the magnitude of generated e.m.f. is less than E_m. This e.m.f. in conductor 2 is indicated by phasor $\overline{E}_2 (=\overline{E}_1)$ whose vertical component $E_2 \cos\gamma$ is equal to the r.m.s. generated e.m.f. in conductor 2. Note that E_2 is displaced

from E_1 by an angle γ, equal to the angle between adjacent slots. This angle γ is usually called the angular slot pitch and is given by

$$\gamma = \frac{\pi P}{\text{Total number of slots}}$$

$$= \frac{180P}{\text{Total number of slots}} = \frac{180}{\text{Slots per pole}} \text{ Elect. degrees.}$$

In Fig. 1(a), γ is equal to 30°. The e.m.f. generated in conductor 3 can similarly be represented in Fig. 1(a) by phasor $\bar{E}_3 \left(= \bar{E}_1\right)$ whose vertical component $E_3 \cos 2\gamma$ is equal to the r.m.s. generated e.m.f. in conductor 3. Note that $\bar{E}_3$ is displaced from E_1 by 2γ and from $\bar{E}_2$ by γ. At the instant shown in Fig. 1(a), it may be seen that conductor 4 is not cutting any magnetic flux; therefore, e.m.f. phasor $\bar{E}_4 \left(= \bar{E}_1\right)$ must have a zero vertical projection $\left(= E_m \cos 3\gamma = E_m \cos 90°\right)$. The same thought process can further be used for conductor e.m.fs. $E_5, E_6 \ldots\ldots E_{12}$. Note that all phasors $E_1, E_2, \ldots\ldots E_{12}$ are of equal lengths. Their projections on the vertical axis, determine the magnitude of r.m.s. generated e.m.fs. in the various conductors.

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In Fig. 1(a), $E_1 (= AB)$ is drawn parallel to $\bar{E}_1$ of Fig. 1(a). At the point $B, BC = E_2$ is drawn parallel to E_2 of Fig. 1(a) and so on. It will be found that conductor e.m.fs. $E_1, E_2, \ldots\ldots, E_{12}$ constitute a closed e.m.f. polygon. The perpendicular bisectors of each of the conductor e.m.fs. $E_1, E_2, \ldots\ldots, E_{12}$ (i.e. AB, BC, CD etc.) will pass through a point O, indicating that if a circle with O as center and OA as radius is drawn, it must pass through the points A, B, C, D etc. The angle subtended by each phasor e.m.f. at the center O is seen to be equal to the slot-angular pitch ν.

Starting from the front end of conductor 1, join the back end of conductors 1 and 2 in Fig. 1(a). Further joint conductor 2 and 3 by a connection at the front and 3 and 4 at the back and so on. The resultant e.m.f. appearing between starting end of conductor 1 and the finishing end of conductor 12 (i.e., after having gone through all the conductors once), will be found to be zero. This is evident from Fig. 1(b) by the phasor addition of e.m.f. phasors $E_1, E_2, \ldots\ldots, E_{12}$.

PULSATING AND REVOLVING MAGNETIC FIELDS

Multiple Choice Type Questions

1. Three phase voltages are applied to the three windings of an electrical machine. If any two supply terminals are interchanged, then the rotating MMF wave [MODEL QUESTION]

a) direction reverses, amplitude alters
b) direction reverses, amplitude unaltered
c) direction remains same, amplitude alters
d) direction remains same, amplitude unaltered

Answer: (b)

2. A 3 phase star connected winding is fed from symmetrical 3 phase supply with their neutrals connected together. If one of the 3 supply lines gets disconnected, then the revolving MMF wave will have a [MODEL QUESTION]

a) constant amplitude but sub synchronous speed
b) varying amplitude but synchronous speed
c) constant amplitude but super synchronous speed
d) varying speed and a speed fluctuating around the synchronous speed

Answer: (d)

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3. In case of the 3 phase winding with delta or star connection without neutral, if one of the supply lines gets disconnected, then the MMF becomes [MODEL QUESTION]

a) stationary and pulsating
b) rotating with synchronous speed
c) rotating with sub synchronous speed
d) rotating with super synchronous speed

Answer: (a)

4. When a single-phase winding is excited by an alternating current, then which of the following statements are correct? [MODEL QUESTION]

a) It produces one stationary MMF wave
b) Produced MMF wave pulsates along its magnetic axis
c) It doesn't produce two counter rotating MMF wave
d) All of the mentioned

Answer: (d)

5. In the adjacent figure, what kind of voltage is generated by linear movement of a horizontally or vertically loop in or counter to the direction of magnetic field? [MODEL QUESTION]

a) A D.C. voltage
b) An A.C. voltage
c) No voltage
d) Pulse voltage

Answer: (c)

6. What kind of voltage is induced in a loop conductor rotating in an homogeneous magnetic field? [MODEL QUESTION]

a) A.C. b) D.C. c) No voltage d) Pulse voltage

Answer: (b)

7. If a loop conductor is rotated in the magnetic field, a voltage is induced in it. This voltage increases only with the [MODEL QUESTION]

a) density of the magnetic lines of force
b) active length of conductor in exciting field
c) velocity of the loop
d) length of conductor, velocity and flux density

Answer: (d)

8. A loop conductor is rotated in a homogeneous magnetic field the magnetic flux [MODEL QUESTION]

a) changes its intensity constantly
b) changes its direction with constant density
c) changes in intensity with its direction periodically
d) changes its intensity with its direction randomly

Answer: (c)

Short Answer Type Questions

1. What is a rotating electromagnet called? [MODEL QUESTION]

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Answer:

The permanent magnets are on the outside, and they stay fixed in place. The electromagnets are in the rotor, and they turn. The rotating part of the motor, including the electromagnets, is called the armature.

2. What is meant by rotating magnetic field? [MODEL QUESTION]

Answer:

A rotating magnetic field is the resultant magnetic field produced by a system of coils symmetrically placed and supplied with polyphase currents. Rotating magnetic fields are often utilized for electromechanical applications, such as induction motors, electric generators and induction regulators.

3. What is pulsating magnetic field? [MODEL QUESTION]

Answer:

A pulsating magnetic field is produced, when the stator winding of the single-phase induction motor shown below is energised by a single phase supply. The word Pulsating means that the field builds up in one direction falls to zero and then builds up in the opposite direction.

SINGLE PHASE INDUCTION MOTORS

Multiple Choice Type Questions

1. A 3-phase Induction Motor, while supplying a constant load, has the fuse of one line suddenly blown off. The motor will run as a single phase Induction Motor with line current nearly increased to [WBUT 2006, 2010, 2016]

a) $\sqrt{3}$ times b) 3 times c) 5 times d) 6 times

Answer: (a)

2. Usually the starting torques available in various split phase Induction motors are in the following ascending order; [WBUT 2006, 2014]

a) Capacitor split, Resistor-reactor split, Resistor split
b) Resistor split, Resistor-reactor split, Capacitor Split
c) Resistor-reactor split, Resistor split, Capacitor split
d) Resistor split, Capacitor split, Resistor-reactor split

Answer: (b)

3. A compensating winding in an A. C. Commutator motor [WBUT 2006, 2008]

a) reduces reactance drop and improves commutation
b) reduces reactance drop
c) reduces reactance drop but retards commutation
d) improves commutation only

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Answer: (a)

4. The direction of rotation of a single-phase induction motor can be reversed by [WBUT 2007, 2009, 2010, 2014, 2016]

a) reversing the leads of main winding
b) reversing the leads of auxiliary winding
c) reversing the supply leads
d) either (a) or (b)

Answer: (d)

5. The function of compensating winding in a single phase series motor is to [WBUT 2007, 2015]

a) improve the commutation
b) reduce the reactance drop and degrade the commutation
c) reduce the reactance drop and improve commutation
d) none of these

Answer: (a)

6. A capacitor selected for capacitor-start induction motor should be rated for [WBUT 2007]

a) peak voltage b) r.m.s voltage
c) average voltage d) none of these

Answer: (b)

7. Capacitor start and run induction motor is basically a [WBUT 2008, 2010, 2014, 2015]
   a) single phase induction motor
   b) two-phase induction motor
   c) three-phase induction motor
   d) single phase reluctance motor

Answer: (a)

8. In a double revolving field theory, the slip of the forward motor is S, then the slip of the backward motor is [WBUT 2009, 2018]
   a) 2
   b) S
   c) 2–S
   d) S–2

Answer: (c)

9. In a shaded pole motor, shading coils are used to [WBUT 2009, 2016]
   a) Reduce winding losses
   b) Reduce friction losses
   c) Produce rotating magnetic field
   d) Protect against sparking

Answer: (c)

10. A capacitor start and capacitor run induction motor is supplied from [WBUT 2009, 2018]
   a) single-phase supply
   b) 2-phase supply
   c) 3-phase supply
   d) none of these

Answer: (a)

11. When the main winding of a 1-phase induction motor is connected to 220 V, 50 Hz source, it takes a current of 50 ∠ – 60°A at standstill. Neglecting stator leakage impedance and magnetizing current, the rotor circuit parameters r_2 and x_2 in ohms are respectively [WBUT 2011]
   a) 2, 3.464
   b) 3.464, 2
   c) 4, 6.928
   d) 6.928, 4

Answer: (a)

12. The backward rotor slip in a single-phase induction motor is equal to [WBUT 2011]
   a) $1-s$
   b) s
   c) $2-s$
   d) $s/2$

Answer: (c)

13. A 230 V *dc* series motor is connected to a 230 V *ac* supply. [WBUT 2011, 2016]
   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

Answer: (b)

14. In a poly-phase A.C. machine "short-pitching" of coils leads to [WBUT 2011]
   a) high terminal voltage
   b) higher efficiency
   c) higher power factor
   d) better induced *emf*

Answer: (d)

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15. In capacitor start single phase induction motor, a capacitor is connected [WBUT 2012]

a) in series with the main winding
b) in parallel with the main winding
c) in series with the auxiliary winding
d) in parallel with the auxiliary winding

Answer: (a)

16. A ceiling fan uses [WBUT 2012]

a) split phase motor
b) capacitor start capacitor run motor
c) universal motor
d) capacitor start motor

Answer: (d)

17. In a single phase induction motor [WBUT 2013]

a) two rotating fields rotating at synchronous speed in opposite direction
b) two rotating fields rotating at synchronous speed in the same direction
c) one rotating field
d) none of these

Answer: (a)

18. In the resistance split phase motor, [WBUT 2013]

a) the motor employs an auxiliary winding with R/X ratio higher than that of the main winding
b) the motor employs an auxiliary winding with R/X ratio lower than that of the main winding
c) the motor employs an auxiliary winding with R/X ratio equal to that of the main winding
d) the motor employs an auxiliary winding with R/X ratio which is none of the above

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Answer: (a)

19. A compensating winding in a single-phase series motor [WBUT 2013, 2014]

a) reduces reactance drop and improves commutation
b) reduces reactance only
c) reduces reactance drop but retards commutation
d) improves commutation only

Answer: (d)

20. Which one of the statements is true regarding speed and power factor of a single phase ac series motor? [WBUT 2014]

a) both increase with increase in load torque
b) both decrease with increase in load torque
c) the former increases and the latter decreases with increase in load torque
d) the former decreases and the latter increases with increase in load torque

Answer: (b)

21. In a double revolving field theory, the slip of the forward motor is S, then the slip of the backward motor is [WBUT 2015]
a) 2S b) S c) 2 – S d) S – 2
Answer: (c)

22. A capacitor start and run motor is supplied from [WBUT 2016]
a) single phase supply b) 3 phase supply
c) 2 phase supply d) none of these
Answer: (a)

23. A universal motor is one [WBUT 2017]
a) which can run on any value of supply voltage
b) which has infinitely varying speed
c) which can operate on ac as well as dc voltage
d) which can work as single phase or three phase motor
Answer: (c)

24. Fro ceiling fans generally the single phase motor used is [WBUT 2017]
a) split phase type b) capacitor start type
c) capacitor start and run type d) permanent capacitor type
Answer: (c)

25. Capacitor in a single phase induction motor is for [WBUT 2019]
a) improving the power factor b) improving the starting torque
c) starting the motor d) reducing the harmonics
Answer: (b)

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26. The direction of rotation of a capacitor start single phase induction motor can be reversed by interchanging terminals of [WBUT 2019]
a) capacitor b) supply
c) centrifugal switch d) starting winding
Answer: (d)

27. Shaded pole single phase induction motor can be used for [WBUT 2019]
a) grinders b) food mixture
c) tape recorders d) personal computer as cooling fan
Answer: (d)

28. A ceiling fan uses [WBUT 2019]
a) permanent capacitor motor
b) capacitor start and capacitor run motor
c) capacitor motor
d) universal motor
Answer: (b)

Short Answer Type Questions

1. A pure single-phase induction motor does not have starting torque but has running torque. **[WBUT 2006, 2009, 2018]**

OR,

Explain why a 1-phase single winding induction motor produce no starting torque. **[WBUT 2017]**

Answer:

When the stator winding of a single-phase induction motor is connected to single-phase A.C. supply, a magnetic field is developed, whose axis is always along the axis of stator coils. The magnetic field produced by the stator coils is pulsating, varying sinusoidally with time. Currents are induced in the rotor conductors by transformer action, these currents being in such a direction as to oppose the stator mmf. Then the axis of the rotor mmf wave coincides with that of the stator field, the torque angle is, therefore, zero and no torque is developed on starting. As such the single-phase does not have starting torque. However, if the rotor is given a push by hand or by other means in either direction, it will pick up the speed and continue to rotate in the same direction developing running or operating torque. This behaviour can be explained either by double revolving field theory or cross-field theory.

2. For a 'universal' motor, the performance of the machine is better under d.c. operation than under a.c. operation. – Justify. **[WBUT 2006, 2008, 2009, 2015]**

OR,

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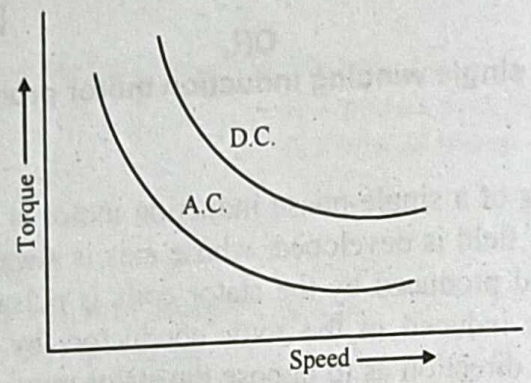
Explain why in a universal motor, the performance of the machine is better under d.c. than in a.c. operation. **[WBUT 2017]**

Answer:

It is known that if the polarity of the line terminals of a d.c. series motor is reversed, the motor will continue to run in the same direction. Thus it might be expected that a d.c. series motor would operate on alternating current also. Since the same current flows through the field and armature windings, it follows that a.c. reversals from positive to negative or from negative to positive, will simultaneously affect both the field flux polarity and the current direction through the armature. This means that the direction of the developed torque will remain positive and rotation will continue in the same direction. The nature of the torque will be pulsating and the frequency will be twice the line frequency. Universal motor is single-phase series motor of commutator type and can operate both on a.c. and d.c. supply. But the performance of the machine is better under d.c. than in a.c. operation because if it is used on single-phase a.c. supply:

1. Its efficiency will be low due to hysteresis and eddy current losses.
2. The power factor is low due to the large reactance of the field and the armature windings.
3. The sparking at the brushes will be excessive.
4. Less torque will be developed.

The universal motor will develop higher torque when operated on D.C. supply than when working from an equivalent A.C. supply resulting better torque and speed control. The torque speed characteristics in both the cases are shown below:



The presence of reactance voltage in the armature winding will be minimized thereby improving the commutation problem.

3. A single-phase induction motor when excited by a single-phase supply produces two equal and opposite revolving fields. Justify the statement. **[WBUT 2008, 2016]**

Answer:

A single-phase induction motor with its only main winding, can be represented schematically as below. With the rotor at standstill, the conditions are similarly to those in a transformer with its secondary short-circuited. An alternating current in the main winding produces a stator mmf wave which is stationary in space but pulsating in magnitude. As a result of it, the stator field ϕ_s induces large rotor currents which for any instant, are as shown in the figure above. For the assumed direction of pulsating stator flux ϕ_s, the direction of induced rotor currents is indicated by crosses and dots. These rotor currents set up rotor mmf which opposes the stator mmf at all instants of time. Since the stator and rotor mmf waves are along the same axis, the torque angle between ϕ_s and ϕ_r is 180° and no starting torque is developed. These all lead to conclude that a single-phase supply produces two equal and opposite revolving field resulting net torque zero and make the motor not inherently self starting.

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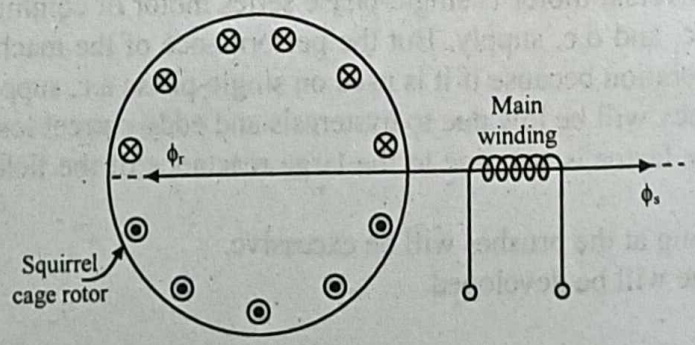


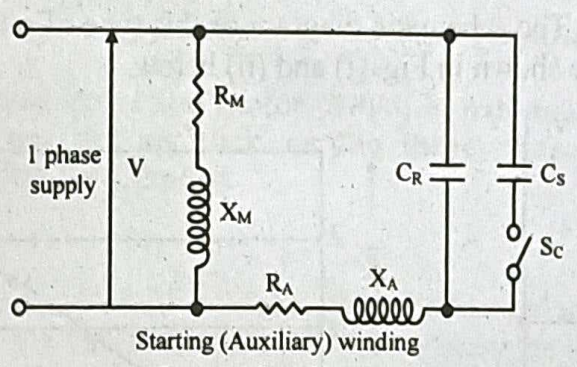
4. What are the methods adopted to start a single phase induction motor? Explain with the help of connection diagram and phasor diagram, the principle of operation of capacitor start and capacitor run motor. [WBUT 2010, 2014]

Answer:

For the purpose of starting a single phase induction motor, the following methods are broadly classified:

i) split phase starting
ii) shaded pole starting
iii) repulsion motor starting
iv) reluctance starting.

In order to explain the principle of operation of capacitor start and capacitor run motor, the connection diagram and phasor diagram are shown below:



Connection diagram

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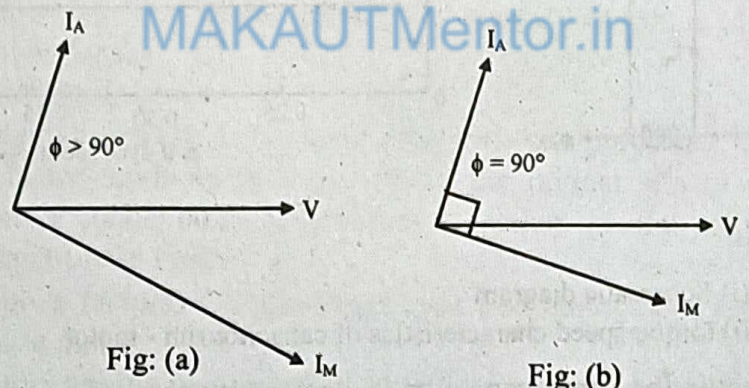

Phasor diagram

The motor uses two capacitors C_S (Starting Capacitor) and C_R (Running Capacitor) which are connected in parallel at starting. In order to obtain a high starting torque, a large current is required. For this purpose, the capacitive reactance X in the starting winding should be low. Since $X_R = \frac{1}{2\pi f C_R}$, the value of C_R should be small. As the motor approaches synchronous speed, the capacitor C_S is disconnected by a centrifugal switch S_C. The capacitor C_R is permanently connected in the circuit. It is usually oil filled paper construction and long time rated for continuous running. Since one capacitor C_S is used only at starting and other C_R for continuous running, this motor is called

capacitor start capacitor run motor. If the phasor diagrams are referred to it may be seen that at starting both the capacitors are in circuit and $\phi > 90°$ [Fig. (a)]. When the capacitor C_S in disconnected ϕ be comes 90° (electrical) as shown in Fig. (b).

5. What are the methods adopted to start a single phase induction motor? Explain with the help of connection diagram the principle of operation of a capacitor run motor. **[WBUT 2012]**

Answer:

Refer to Question No. 4 of Short Answer Type Questions.

Capacitor – run motors:

The capacitor run motors are also called permanent split capacitor (PSC) motor or single value capacitor motor. The schematic diagram of this type of motor along with its torque speed characteristic are shown in Fig. (i) and (ii) below.

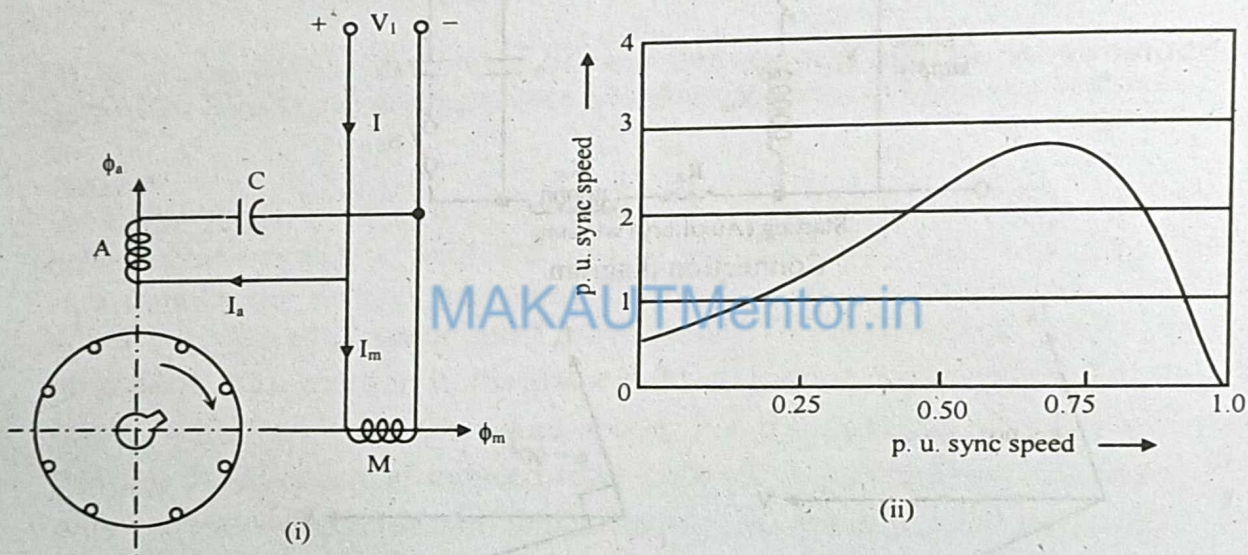

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Fig: (i) Schematic diagram
(ii) torque-speed characteristics of capacitor run - motor

In this type of motor the same capacitor is kept permanently in series with auxiliary winding both at starting and under running condition without using any centrifugal switch. At a particular desired load the capacitor and auxiliary winding can be so designed as to result in 90° time phase displacement between the two winding currents. In such a case, the motor should operate as a balanced two-phase induction motor, backward rotating field would therefore be absent and this results in a quiet motor and the motor would have improved efficiency.

Advantages:

i) It has higher pull out torque
ii) higher efficiency and higher power factor because of permanently connected capacitor
iii) No centrifugal switch is required.

Limitations:

i) It has a low starting torque

ii) since electrolytic capacitors cannot be used for continuous running, paper – spaced oil filled type capacitors are to be used. Paper capacitors of equivalent rating are larger in size and more costly.

Applications:

These motors are used for ceiling fans and blowers in heaters and also for air conditioner etc.

6. Why the rotating field is not developed in a single-phase IM when the stator is provided with a single phase ac supply? [WBUT 2013]

Answer: ***Refer to Question No. 7 of Long Answer Type Questions.***

7. Explain why single phase induction motor (SPIM) is extensively used although its performance figures are not as good as the three phase induction motor. Explain the double revolving field theory. [WBUT 2014]

Answer:

1st Part:

- The performance characteristics of a single phase induction motor are somewhat inferior to that of a 3-phase induction motor due to the presence of backward rotating field.
  - A single phase induction motor has a lower breakdown torque at larger slip and increased power losses.
  - Greater power input.
  - The speed regulation tends to be poorer than that for a polyphase motor.
  - The power factor tends to be lower (since the normal slip of a single phase induction motor under load conditions is rather greater than that of the corresponding 3-phase motor).
- In view of the above factors, a single phase induction motor has a larger frame size than that of 3-phase motor.
- Single phase motors tend to be somewhat noisier than 3-phase motors which have no such pulsating torque.

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2nd Part: ***Refer to Question No. 7 of Long Answer Type Questions.***

8. What methods are adopted to start a single phase induction motor? Explain with the help of connection diagram and phasor diagram, the principle of operation of capacitor start & run motor. [WBUT 2016]

Answer:

1st Part: ***Refer to Question No. 4 of Short Answer Type Questions.***

2nd Part: ***Refer to Question No. 10 (b) of Long Answer Type Questions.***

9. Explain the principle of operation of capacitor-start capacitor-run type single-phase induction motor with necessary diagrams and phasor. [WBUT 2018]

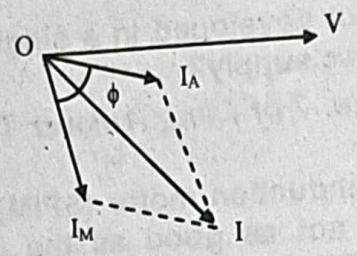
Answer:

Refer to Question No. 4 of Short Answer Type Questions.

10. How is the current phase shift accomplished in the auxiliary winding of a spilt phase induction motor? [WBUT 2019]

Answer:

The phasor diagram of the Split Phase Induction Motor is shown below:



The current in the main winding (I_M) lag behind the supply voltage V almost by the 90° angle. The current in the auxiliary winding I_A is approximately in phase with the line voltage. Thus, there exists the time difference between the currents of the two windings. The time phase difference ϕ is not 90°, but of the order of 30°. This phase difference is enough to produce a rotating magnetic field.

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Long Answer Type Questions

1. Develop the equivalent circuit of a 1-phase induction motor with two revolving field theory. [WBUT 2006]

OR,

Draw the equivalent circuit of a single phase induction motor during no load and blocked rotor condition with the help of double revolving field theory. [WBUT 2013]

Answer:

The equivalent circuit of a single-phase induction motor can be developed on the basis of two revolving field theory. For developing the equivalent circuit it is first imperative to consider stand still or blocked rotor conditions. Under blocked rotor condition, it will act like a transformer with its secondary short-circuited and its equivalent circuit will be as shown in Fig. (a) below, E_m being emf induced in the stator.

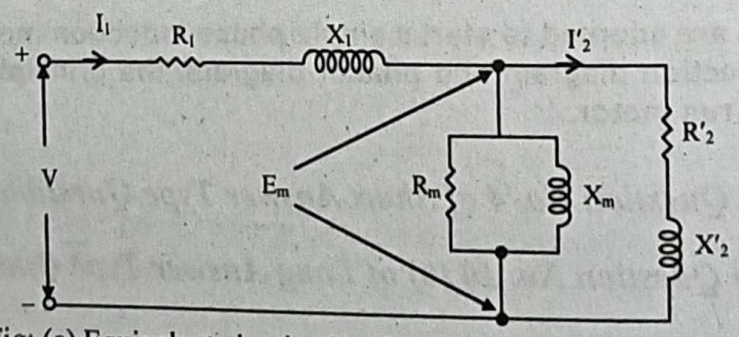

Fig: (a) Equivalent circuit of a 1ϕ induction motor at stand still

- Fig. (b) as shown below is the equivalent circuit of a single-phase induction motor at stand still on the basis of two revolving field theory. The phasor sum of

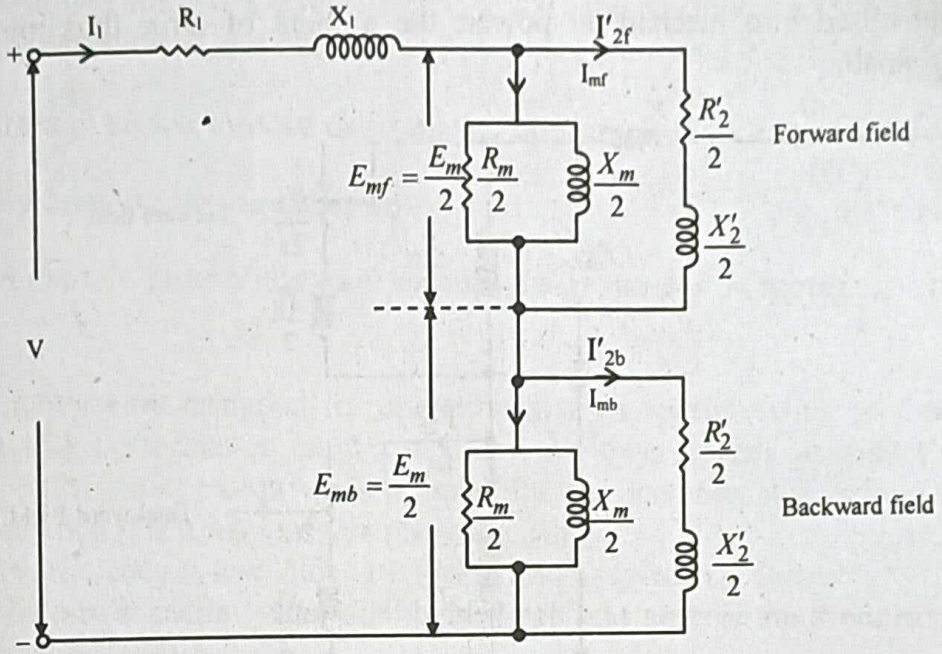

Fig: (b) Equivalent circuit of 1ϕ induction motor at standstill on the basis of two revolving field theory

E_{mf} and E_{mb} equals the applied voltage V (less the voltage drops is stator resistance R_1 and leakage reactance X_1).

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When the rotor runs at speed N with respect to forward field, the slip is 's' with respect to forward field and (2 – s) w.r.t backward field and the equivalent circuit becomes as shown in Fig. (c) below:

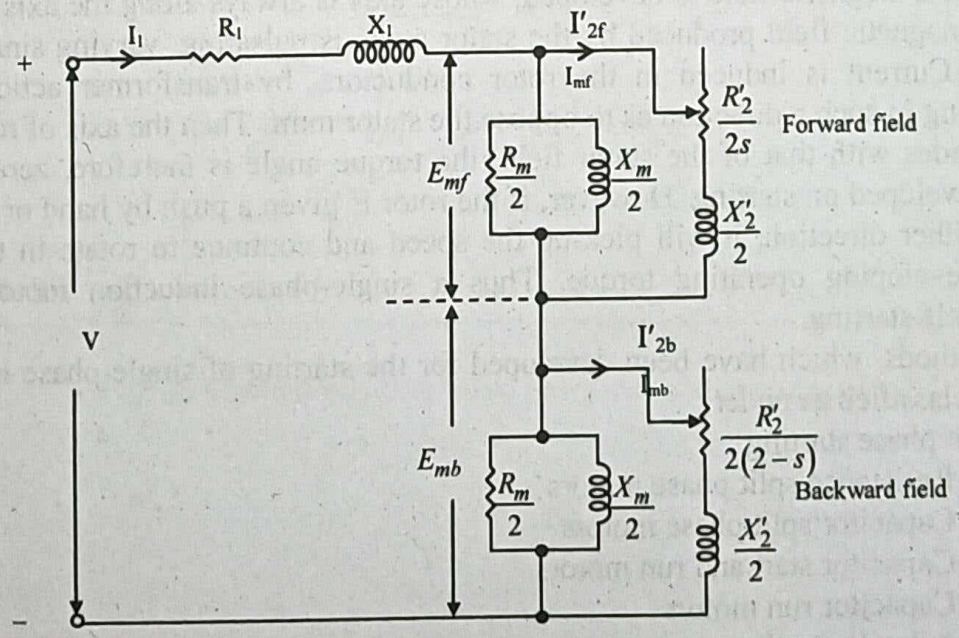

Fig: (c) Equivalent circuit of 1ϕ induction motor under normal operating condition

- If the core losses are neglected the equivalent circuit is modified as shown in Fig. (d) below. The core losses, here, are handled as rotational losses and subtracted from the power converted into mechanical power; the amount of error thus introduced is relatively small.

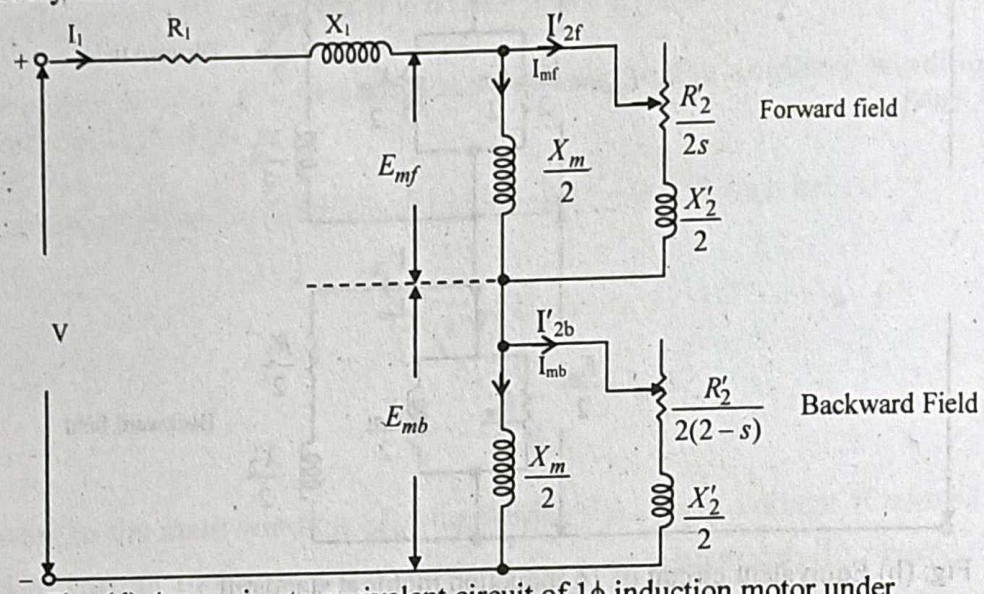

Fig: (d) Approximate equivalent circuit of 1ϕ induction motor under normal operating condition

2. Why is a single-phase induction motor not self starting? Name the various methods of starting and mention which mode of starting will provide high starting as well as running torque. **[WBUT 2007, 2015]**

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Answer:

When the stator winding of a single-phase induction motor is connected to single phase A.C. supply, a magnetic field is developed, whose axis is always along the axis of stator coils. The magnetic field produced by the stator coils, is pulsating, varying sinusoidally with time. Current is induced in the rotor conductors, by transformer action, those currents being in such a direction as to oppose the stator mmf. Then the axis of rotor mmf wave coincides with that of the stator field, the torque angle is therefore, zero and no torque is developed on starting. However, if the rotor is given a push by hand or by other means in either direction, it will pick-up the speed and continue to rotate in the same direction developing operating torque. Thus a single-phase induction motor is not inherently self-starting.

Various methods, which have been developed for the starting of single-phase induction motors are classified as under:

a) Split phase starting
   i) Resistance split phase motors
   ii) Capacitor split phase motors
   iii) Capacitor start and run motors
   iv) Capacitor run motors
b) Shaded pole starting
c) Repulsion motor starting and

d) Reluctance starting

Out of the above mode of starting, capacitor start and run motor will provide best starting with a high capacitance and best running performance with a low capacitance.

3. Why are a.c. series motors designed to operate at higher speeds? **[WBUT 2007, 2016]**

Explain by drawing phasor diagram. **[WBUT 2007, 2016]**

OR,

Draw and explain phasor diagram of a single-phase series motor. **[WBUT 2009]**

Answer:

1st Part:

A series motors are designed for operation at high speeds owing to the difficulty in obtaining like performance on d.c. and a.c. at lower speeds as also to have better operating p.f. A series motor which is meant for d.c. operation suffers from the following drawbacks when it is used on single phase a.c. supply:

a. Its efficiency is low due to hysteresis and eddy-current losses.
b. The power factor is low due to the large reactance of the field and the armature windings.
c. The sparking at the brushes is excessive.

2nd Part:

The phasor diagram of a conductively coupled single-phase ac series motor is shown in Fig. (a) along with schematic diagram of conductively coupled series motor in Fig. (b).

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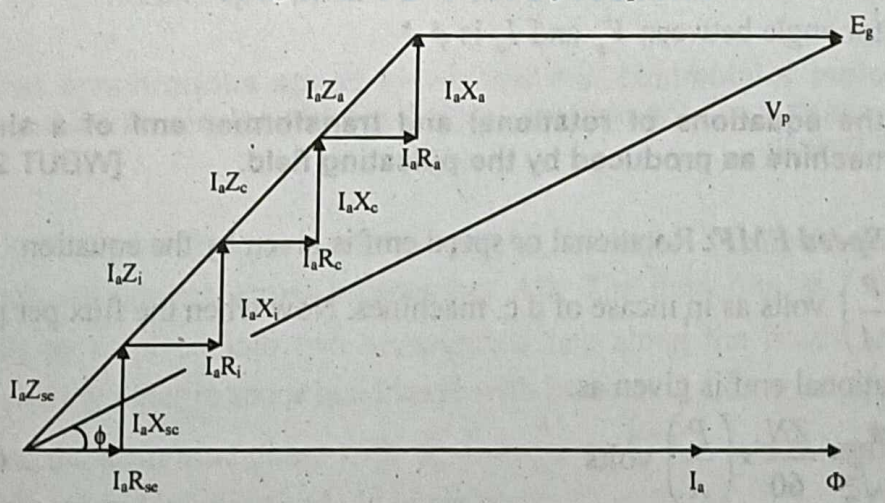

Fig: (a) Conductively coupled ac series motor-phasor diagram

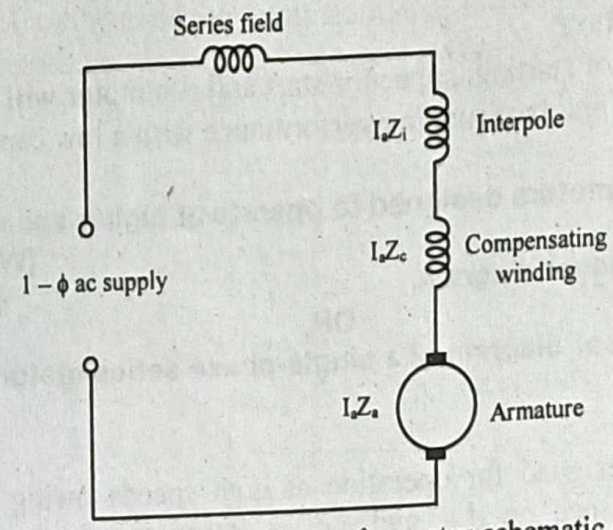

Fig: (b) Conductively coupled ac series motor-schematic diagram

The resistance drops $I_aR_{Sc}, I_aR_i, I_aR_c$ and I_aR_a due to resistances of series field, inter pole winding, compensating winding and of armature respectively are in phase with armature current I_a. The reactance drops $I_aX_{Sc}, I_aX_i, I_aX_c$ and I_aX_a due to reactance of series field, interpole winding, compensating winding and of armature respectively lead current I_a by $90°$. The generated armature counter emf is E_g. The terminal phase voltage V_p is equal to the phasor sum of E_g and all the impedance drops in series.

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$$V_p = E_g + I_aZ_{Sc} + I_aZ_i + I_aZ_c + I_aZ_a$$

The power factor angle between V_p and I_a is ϕ.

4. a) Derive the equations of rotational and transformer emf of a single phase commutator machine as produced by the pulsating field. **[WBUT 2007, 2008]**

Answer:

***Rotational or Speed EMF*:** Rotational or speed emf is given by the equation $E = \frac{\phi Z N}{60} \times \left(\frac{P}{A}\right)$ volts as in incase of d.c. machines. Now when the flux per pole is alternating rotational emf is given as:

$$E_r = \frac{\phi_{max}}{\sqrt{2}} \cdot \frac{ZN}{60} \times \left(\frac{P}{A}\right) \text{ volts} \qquad \text{.... (1)}$$

Now putting $2f_r = \frac{PN}{60} \left(\therefore f = \frac{PN}{120}\right)$ in Eqn. (1), E_r becomes

$$E_r = \sqrt{2}\, \phi_{max} \frac{Z}{A} \cdot f_r \qquad \text{.... (2)}$$

The frequency of rotational emf E_r is the same as the frequency of ϕ.

Transformer EMF: The cross – flux ϕ' in the neutral or brush axis produces alternating emf due to transformer action. If the cross flux ϕ' is sinusoidally distributed having peak value ϕ'_{max} and the winding is full pitched, winding being commutator winding, the magnitude of induced emf is given by

$$E_{t_{avg}} = \frac{d_\phi}{dt} = \frac{\phi'_{max}}{1/4f} = 4f\phi'_{max}\frac{T}{A} = 4f\phi'_{max} \times \frac{Z}{2A}$$

Introducing distribution factor K_d, the rms value of the induced emf across the brushes due to transformer action is given as

$$E_{t_{rms}} = K_f \cdot E_{avg} K_d = \frac{\pi}{2\sqrt{2}} \times 4f\phi'_{max}\frac{Z}{2A} \cdot K_d = \sqrt{2}\pi f \phi'_{max} K_d \frac{Z}{2A} \quad \text{.... (3)}$$

where $\frac{Z}{2A}$ is the number of turns per parallel paths and K_d is the distribution factor given as:

$$K_d = \frac{\sin n\frac{\alpha}{2}}{n\sin\frac{\alpha}{2}} = \frac{2}{\pi}, \text{ since the winding is uniformly distributed.}$$

So, $$E_t = \sqrt{2}\pi f \phi'_{max} \times \frac{2}{\pi} \times \frac{Z}{2A} = \sqrt{2}\phi'_{max}\frac{Z}{A} f \text{ volts.}$$

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The frequency of transformer emf E_t is the same as that of cross flux ϕ'.

b) Show that at synchronous speed show that a.c. commutator motor with a.c. input voltage and brush displaced from neutral position acts as a phase shifter.
[WBUT 2007, 2008]

Answer:

If brush axis is displaced from the neutral axis by an angle 'α', both rotational and transformer emfs are present across brushes say AB. The field flux ϕ_m, alternating at frequency f can be resolved into two components one along the brush axis AB, i.e., $\phi_t = \phi_m \sin\alpha$ and the other in space quadrature with brush axis, i.e., $\phi_r = \phi_m \cos\alpha$.

The flux component ϕ_t in time phase with ϕ_m induces emf 'E_t' across brushes AB, due to transformer action and its magnitude in given by: -

$$E_t = \sqrt{2} \cdot f \cdot \phi_m \frac{z}{a} \sin\alpha$$

The other flux component ϕ_r, in time phase with ϕ_m will cause rotational emf E_r which will appear across brushes AB whose magnitude will be given by $E_r = \sqrt{2}\, f_r \phi_m \frac{z}{a} \cos\alpha$

where z = number of conductors
a = number of parallel paths

The resultant E_R across brushes AB will be given by: -

$$E_R = \sqrt{E_t^2 + E_r^2} = \sqrt{2} \cdot \phi_m \cdot \frac{z}{a} \sqrt{f^2 \sin^2 \alpha + f_r^2 \cos^2 \alpha}$$

or, $$E_R = 2\sqrt{2}\, \phi_m \frac{N}{a} \sqrt{f^2 \sin^2 \alpha + f_r^2 \cos^2 \alpha}$$

where N = number of turns in armature

The time phase angle θ between E_R and ϕ_m is $\tan\theta = \frac{E_f}{E_r} = \frac{f}{f_r} \tan\alpha$

If the armature runs at synchronous speed, then $f_r = f$

and $E_R = \sqrt{2}\, \phi_m \frac{z}{a} f = 2\sqrt{2}\, \phi_m f \frac{N}{a}$ and time phase angle θ = space angle α.

Thus, an a.c. commutator machine at synchronous speed act as a phase shifter with the magnitude of E_R remaining constant at synchronous speed.

5. a) A 240 V, single phase induction motor gave the following test results:
Blocked rotor test : 120 V, 9.6 A, 460 W
No-load test : 220V, 4.6 A, 125W.
The stator winding resistance is 1.5 Ω and during the block rotor test, the starting winding is open. Find equivalent circuit parameters. Also find the core friction and windage losses. **[WBUT 2007, 2017]**

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Answer:

From blocked rotor test we get

$$V_{sc} = 120\text{ V},\ I_{sc} = 9.6\text{ A},\ P_{sc} = 460\text{ W}$$

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} = \frac{120}{9.6} = 12.5\Omega$$

$$R_c = \frac{P_{sc}}{I_{sc}^2} = \frac{460}{(9.6)^2} = 4.99\,\Omega$$

$$\therefore \quad X_c = \sqrt{Z_c^2 - R_c^2} = \sqrt{(12.5)^2 - (4.99)^2} = 11.46\,\Omega$$

$$X_{1m} = X_2' = \frac{1}{2} X_e = \frac{1}{2} \times 11.46 = 5.73\,\Omega$$

$$R_{1m} = 1.55\,\Omega$$

$$R_c = R_{1m} + R_2'$$

$$R_2' = R_c - R_{1m} = 4.99 - 1.55 = 3.49\,\Omega$$

From no load test we get

$$V_o = 220\text{ V},\ I_o = 4.6\text{ A},\ P_o = 125\text{ W}$$

No load power-factor

$$\cos\phi_o = \frac{P_o}{V_o I_o} = \frac{125}{220\times 4.6} = 0.1235$$

$$\therefore \quad \sin\phi_o = 0.9923$$

$$z_o = \frac{V_o}{I_o} = \frac{220}{4.6} = 47.83\,\Omega$$

$$\therefore \quad X_o = Z_o \sin\phi_o = 47.83\times 0.9923 = 47.46\,\Omega$$

core, friction and windage losses

= Power input to motor at no load – no load copper loss

$$= P_o - I_o^2(R_{1m} + \frac{R_2'}{4}) = 125 - (4.6)^2\left(1.5 + \frac{3.49}{4}\right) = 74.8 \text{ watts.}$$

b) Show with the help of phasor diagrams that a compensated series motor possesses better speed-torque characteristics, better power factor and improved commutation as compared to an uncompensated series motor.

[WBUT 2007, 2009, 2013]

Answer:

In small a.c. series motors, the commutating difficulties are not of much importance, since other motors operate at lower currents. In addition, these motors run at high speeds, and therefore, their operating p.f. is relatively good. In view of this, small a.c. series motors are usually un-compensated.

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But for larger series motors, a compensating winding is necessary to get better p.f., better speed torque characteristics and improved commutation. When the compensating winding is disconnected from the main circuit on short circuited on itself, it is called an inductively compensated machine. In this case, the compensating winding acts as the short circuited secondary of a transformer, the armature winding acting as the primary.

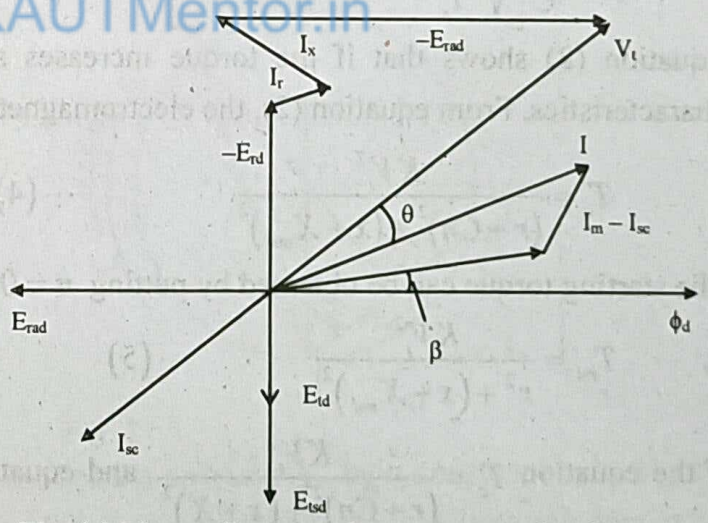

Fig: (a) Phasor diagram of a compensated A.C. motor

For a compensated series motor, if ϕ_q (armature q axis flux) is completely neutralized, then transformer emf E_{taq} becomes zero. Further, zero value of ϕ_q suppresses the rotational emf E_{rq} across the commutated coils, with zero values of E_{tq} and E_{rq}, the pattern of phasor diagram as shown in Fig. (a):

It may be noted that emf across the commutated coil is now only E_{td} and this emf alone set up I_{sc}. In the phasor diagram of Fig. (a), the resistance and leakage reactances of the compensating winding is taken into consideration. For the inductively compensated motor, resistance r_c and leakage reactance x_c has to be referred to the armature as in a transformer. The simplified phasor diagram of the compensated series motor is drawn in Fig. (b).

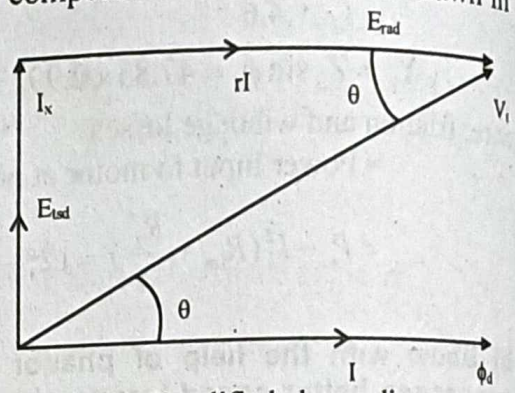

Fig: (b) Simplified phasor diagram of a compensated a.c series motor

If $\quad r = r_a + r_f + r_c$

And $\quad x = x_a + x_f + x_c$

Then from Fig. (b),

$$\bar{V}_t = \bar{I}(r + jx) + \bar{E}_{rad} + \bar{E}_{tsd}$$

Now $\quad \bar{E}_{rad} = C\bar{I}_n$ and $\bar{E}_{td} = jIX_{md}$

$$\bar{V}_t = \bar{I}(r + Cn) + j\bar{I}(x + X_{md}) \quad \cdots(1)$$

$$n = \frac{1}{C}\left[\sqrt{\left(\frac{V_t}{I}\right)^2 - (x + X_{md})^2} - r\right] \quad \cdots(2)$$

It is known, $T_e = KI^2$

$$n = \frac{1}{C}\left[\sqrt{\frac{KV_t^2}{T_e} - (x + X_{md})^2} - r\right] \quad \cdots(3)$$

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Equation (3) shows that if the torque increases speed decreases giving again series characteristics. From equation (2), the electromagnetic torque (T_c) is given by:

$$T_c = \frac{KV_t^2}{(r + Cn)^2 + (x + X_{md})^2} \quad \cdots(4)$$

The starting torque can be obtained by putting $n = 0$ in equation (4)

$$\therefore \quad T_{est} = \frac{KV_t^2}{r^2 + (x + X_{md})^2} \quad \cdots(5)$$

If the equation $T_c = \dfrac{KV_t^2}{(r + Cn)^2 + (x + X)^2}$ and equation (5) are examined it may be seen that for a given V_t and speed n, torque for a compensated series motor is higher $(\therefore X_{md} < X)$, thus giving better speed torque characteristics.

Again from equation (5) it is seen that starting is higher for a compensated series motor as in uncompensated series motor, starting torque is given by the equation

$$T_c = \frac{KV_t^2}{(r + Cn)^2 + (x + X)^2}$$

Again from Fig. (b), $\sin\theta = \dfrac{I(x+X_{md})}{V_t}$

$\therefore$ P.f. of compensated motor, $\cos\theta = \sqrt{1-\left[\dfrac{I(x+X_{md})}{V_t}\right]^2}$ here as

P.f. of uncompensated motor $= \sqrt{1-\left(\dfrac{I(x+X)^2}{V_t}\right)^2}$.

If these two are compared, it may be total that for a given speed, compensated motor has better p.f. because X_{md} is less than X.

6. a) For a single phase induction motor, derive the condition for maximum starting torque during capacitive starting. **[WBUT 2008, 2010, 2015, 2017]**

OR,

For single phase induction motor, derive the condition for maximum starting torque during resistor split phase motor. **[WBUT 2016]**

Answer:

The circuit diagram of a capacitor split phase motor and its phasor diagram under maximum starting torque conditions are shown in Fig. 1(i) and Fig. 1(ii) to below:

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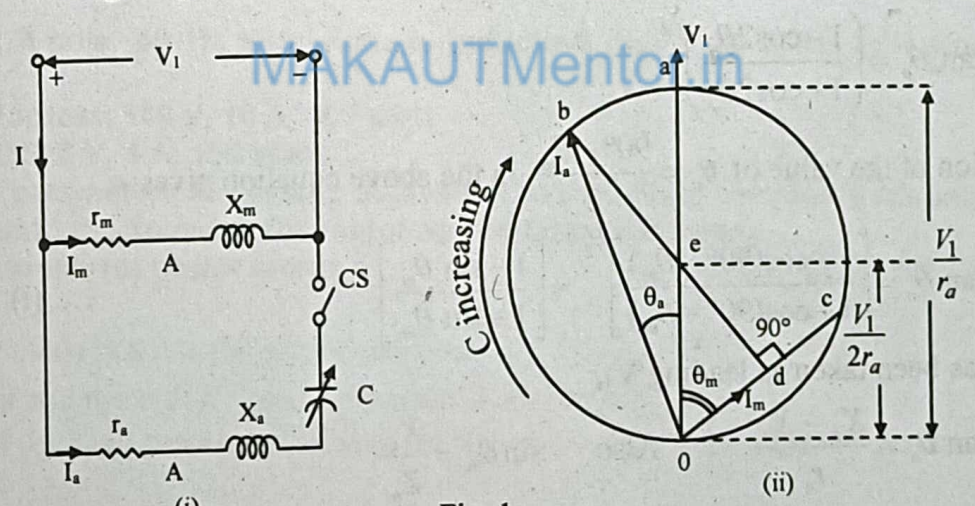

Fig: 1

Here also main winding current I_m is constant and lags V_1 by a constant angle θ_m. It is assumed that starting capacitor C, which is in series with the auxiliary winding is loss less. Now when $C=0, X_C = \dfrac{1}{2\pi fC} = \infty$ and, therefore, I_a is zero giving the operating point 0 in Fig. 1(ii). When $C=\infty, X_C = 0$ and $I_a = \dfrac{V_1}{Z_a}$ and when capacitive reactance $x_c =$ inductive reactance X_a, I_a is given by $\dfrac{V_1}{r_a} = oa$. When C is increased from zero,

x_c starts becoming less than infinity and as x_c is more than X_a, I_a leads V_1. The locus of the tip of phasor I_a is therefore, a circle as shown in Fig. 1(ii). For same value of C, I_a leads V_1 by some angle θ_c. The extension of phasor I_m, lagging V_1 by θ_m, meets the circle at point c.

When a perpendicular is drawn from center e of the circular locus, on to the extended phasor I_m, the point b is obtained. The line joining b with 0, then gives the required starting current I_a in the auxiliary winding so that maximum starting torque is obtained.

Since oe = eb = radius of the circle, $\angle e\,o\,b = \angle e\,b\,o = \theta_a$

in the right angled triangle o d b, $\angle d\,o\,b + \angle o\,b\,d = 90°$

or, $(\theta_a + \theta_m) + \theta_a = 90°$ or, $\theta_a = \dfrac{90° - \theta_m}{2}$

Now $\tan\theta_a = \dfrac{\sin\theta_a}{\cos\theta_a}$

Use of the trigonometric relations $\sin\theta_a = \sqrt{\dfrac{1-\cos 2\theta_a}{2}}$

and $\cos\theta_a = \sqrt{\dfrac{1+\cos 2\theta_a}{2}}$

given $\tan\theta_a = \left(\dfrac{1-\cos 2\theta_a}{1+\cos 2\theta_a}\right)^{1/2}$

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Substitution of the value of $\theta_a = \dfrac{90° - \theta_m}{2}$ in the above equation gives:-

$$\tan\theta_a = \left[\frac{1-\cos(90° - \theta_m)}{1+\cos(90° - \theta_m)}\right]^{1/2} = \left[\frac{1-\sin\theta_m}{1+\sin\theta_m}\right]^{1/2} \quad \text{.... (i)}$$

Since I_a has been taken as leading V_1,

$$\tan\theta_a = \frac{X_c - X_a}{r_a} \qquad \text{Also} \qquad \sin\theta_m = \frac{X_m}{Z_m}$$

Substitution of $\tan\theta_a$ and $\sin\theta_m$ in Eqn. (i) gives

$$\frac{X_c - X_a}{r_a} = \left[\frac{Z_m - X_m}{Z_m + X_m}\right]^{1/2} \quad \text{.... (ii)}$$

Now $Z_m^2 = r_m^2 + X_m^2$

or, $Z_m^2 - X_m^2 = r_m^2$

or, $Z_m - X_m = \dfrac{r_m^2}{Z_m + X_m}$

Substitution of the value of $(Z_m - X_m)$ in Eqn. (ii) gives:

$$\frac{X_c - X_a}{r_a} = \left[\frac{Z_m - X_m}{Z_m + X_m}\right]^{1/2} \quad \text{.... (iii)}$$

Now $Z_m^2 = r_m^2 + X_m^2$

or, $Z_m^2 - X_m^2 = r_m^2$ or, $Z_m - X_m = \dfrac{r_m^2}{Z_m + X_m}$

Substitution of the value of $(Z_m - X_m)$ in Eqn. (iii) gives:

$$\frac{X_c - X_a}{r_a} = \left[\frac{r_m^2}{(Z_m + X_m)^{1/2}}\right]^{1/2} = \frac{r_m}{Z_m + X_m}$$

$$X_c = X_a + \frac{r_a r_m}{Z_m + X_m} \quad \text{.... (iv)}$$

The value of capacitance to be inserted in series with the auxiliary winding for obtaining maximum torque at starting is given by $C = \dfrac{1}{\omega X_C}$ where ω is the angular frequency of supply voltage.

b) A 220 V, 4-pole, 50 Hz single-phase induction motor gave the following test results:

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Blocked Rotor test: 110 V, 10 A, 400 Watt

No-load test: 220 V, 4 A, 100 Watt.

i) Find the parameters to develop equivalent circuit. State necessary assumption.

ii) Considering the speed of the motor as 1440 rpm, determine

(a) line current, (b) power factor. **[WBUT 2008, 2010, 2015]**

Answer:

Assumptions made to solve the above questions:

1) Stator and rotor I^2R losses at standstill are equal.
2) Rotor leakage reactance referred to the stator and stator leakage reactance are equal.

From Locked Rotor test

Equivalent impedance of motor winding, $Z_{eq} = \dfrac{\text{Voltage applied}}{\text{curent drawn}} = \dfrac{110}{10} = 11\Omega$

Equivalent resistance of motor windings: $R_{eq} = Z_{eq}\cos\phi = 11 \times \dfrac{400}{110 \times 10} = 3.96\Omega$

Equivalent reactance of motor windings: $X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2} = \sqrt{11^2 - (3.96)^2} = 10.26\Omega$

Rotor winding resistance referred to stator = stator winding resistance

$$= \frac{R_{eq}}{2} = \frac{3.96}{2} = 1.98\Omega$$

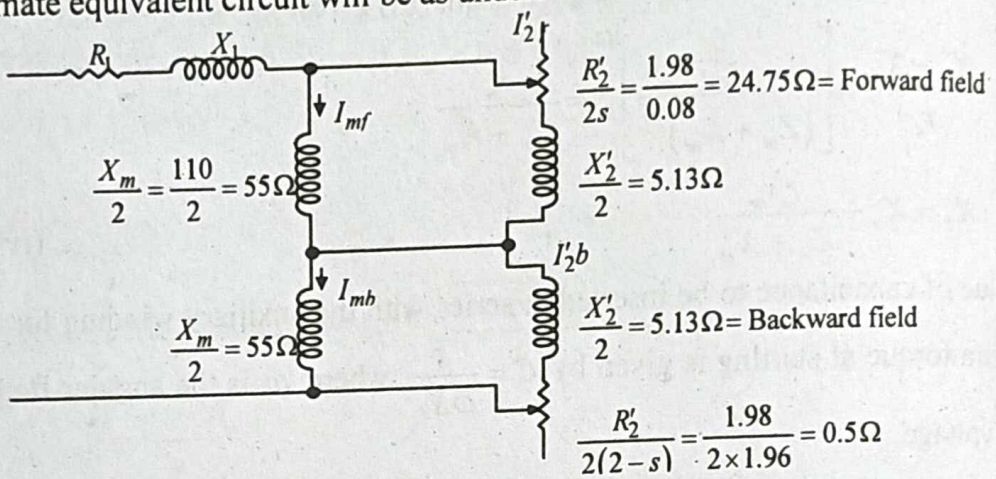
(Since the stator and rotor I^2R losses at standstill are equal).
Rotor winding reactance referred to stator = stator winding reactance

$$= \frac{X_{eq}}{2} = \frac{10.26}{2} = 5.13\Omega$$

Assuming that magnetizing reactance is same in both cross and main axes.

$$X_m = \frac{2 \times \text{No load voltage}}{\text{No load current}} = \frac{2 \times 200}{4} = 110\Omega$$

Approximate equivalent circuit will be as under:



Now $$Z_f = \frac{jX_m\left(\frac{r_2}{s}\right) + jX_2}{\frac{r_2}{s} + j(X_2 + X_m)} = X_m = \frac{X_m \frac{r_2}{s} \cdot X_m + j\left[\left(\frac{r_2}{s}\right)^2 + X_2X_0\right]}{\left(\frac{r_2}{s}\right)^2 + X_0^2} \quad [X_0 = X_m + X_2]$$

$$= \frac{110}{2} \cdot \frac{\frac{1.98}{0.04} \times 55 + j\left[\left(\frac{1.98}{0.04}\right)^2 + 5.13 \times 60.13\right]}{\left(\frac{1.98}{0.04}\right)^2 + (55 + 5.13)^2}$$

$$= 55 \cdot \frac{49.5 \times 55 + j[2450.25 + 308.46]}{2450.25 + 3615.6} = 55 \cdot \frac{2722.5 + j2758.71}{6065.85}$$

$$= 24.68 + j25.01 \quad = 35.1369\angle 45.38°\Omega$$

$$Z_b = \frac{jX_m\left(\frac{r_2}{2-s} + jX_2\right)}{\frac{r_2}{2-s} + j(X_2 + X_m)} = X_m \frac{\frac{r_2}{2-s}X_m + j\left[\left(\frac{r_2}{2-s}\right)^2 + X_2X_0\right]}{\left(\frac{r_2}{2-s}\right)^2 + X_0^2} \quad X_0 = X$$

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$$=\frac{110}{2}\cdot\frac{\frac{1.98}{2-0.04}\cdot 55+j\left[\left(\frac{1.98}{1.96}\right)^2+308.46\right]}{\left(\frac{1.98}{1.96}\right)^2+3615.6}$$

$$=55\cdot\frac{1.01\times 55+j\left[1.01^2+308.46\right]}{1.01^2+3615.6}=55\cdot\frac{55.56+j(1.0201+308.46)}{1.0201+3615.6}$$

$$=55\cdot\frac{55.56+j309.4801}{3616.6}=0.844+j4.706\ =4.7818\angle 79.8^\circ\Omega$$

Equivalent impedance

$$Z'=Z_1+Z_f+Z_0=1.98+j5.13+24.68+j25.01+0.844+j4.706$$

$$=(1.98+24.68+0.844)+j(25.01+4.706+5.13)$$

$$=27.504+j34.8\ =44.35\angle 51.67^\circ\Omega$$

Current $I'=\frac{V}{Z'}=\frac{220}{44.35}=4.96$ Amp

Power factor, $3VI\cos\phi=100$

$\Rightarrow$ $\cos\phi=0.03$ lag.

7. Explain the double revolving field theory as applied to a single-phase motor. **[WBUT 2009]**

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OR,

Explain double revolving field theory of 1-phase I/M. **[WBUT 2018]**

OR,

How is induced torque developed in a single-phase induction motor according to the double revolving-field theory? **[WBUT 2019]**

Answer:

This theory is based on the principle that any alternating quantity can be represented by means of two components of half the magnitude and revolving in the opposite directions. Hence the stator flux ϕ_m of 1ϕ induction motor can be resolved into two components ϕ_1 and ϕ_2 of magnitude $\frac{\phi_m}{2}$ with ϕ_1 revolving in clockwise direction and ϕ_2 revolving in anti clockwise direction at synchronous speed. At any angle θ, the resultant flux ϕ_r is produced by parallelogram law of forces, $\phi_r=\sqrt{\phi_1^2+\phi_2^2+2\phi_1\phi_2\cos 2\theta}$

It is known that $\phi_1=\phi_2=\frac{\phi_m}{2}$

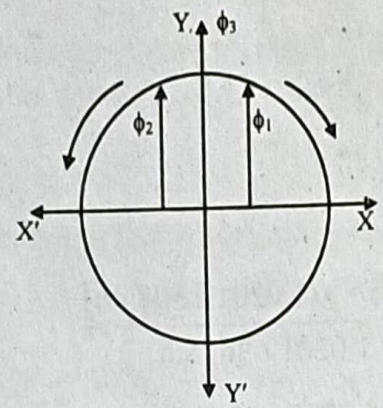
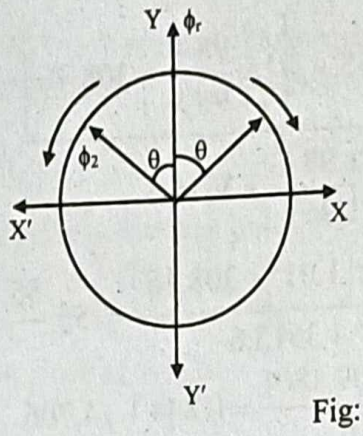


Fig: 1



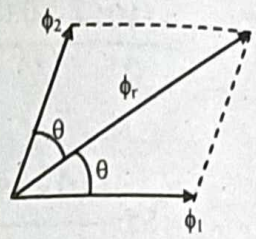


Fig: 2

Hence, $\phi_r = \sqrt{2.\left(\frac{\phi_m}{2}\right)^2 + 2\left(\frac{\phi_m}{2}\right)^2 \cos 2\theta} = \sqrt{2}\left(\frac{\phi_m}{2}\right)\sqrt{1+\cos 2\theta}$

$$= \sqrt{2}\left(\frac{\phi_m}{2}\right)\sqrt{2\cos^2\theta} = \sqrt{2} \times \frac{\phi_m}{2}\sqrt{2\cos^2\theta}$$

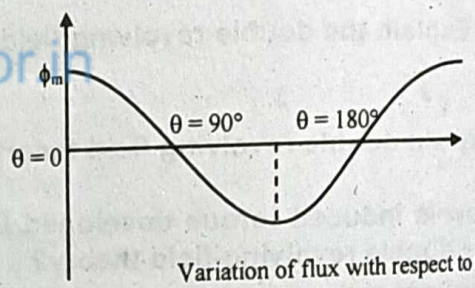
$$\phi_r = \phi_m \cos\theta$$

when $\theta = 0, \phi_r = \phi_m$, $\theta = 90°$, $\phi_r = 0$ $\theta = 180°$, $\phi_r = -\phi_m$

Here ϕ_1 is the forward flux rotating at the speed of N_S and ϕ_2 is the backward flux rotating at the speed of N_S.

The slip of the rotor with respect to forward flux

$s_f = \frac{N_S - N}{N_S} = s$ where N is rotor speed. The slip of rotor with respect to back ward flux,



Variation of flux with respect to θ

Fig: 3

$$s_b = \frac{N_S - (-N)}{N_S} = \frac{2N_S - (N_S - N)}{N_S} = 2 - s.$$

The forward flux produces a torque, which is called forward torque and the backward flux produces a torque, which is called backward torque.

The forward torque versus slip and backward torque versus slip curves are shown in Fig. 4 and Fig. 5.

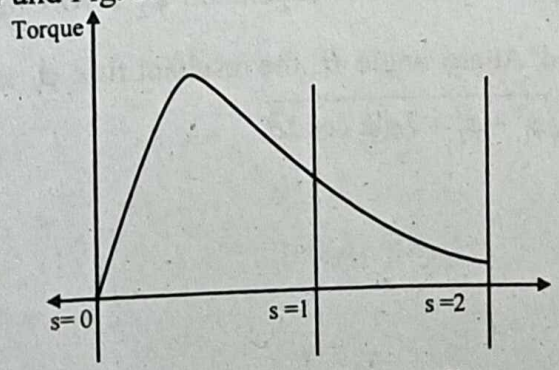


Fig: 4 Forward torque vs. slip

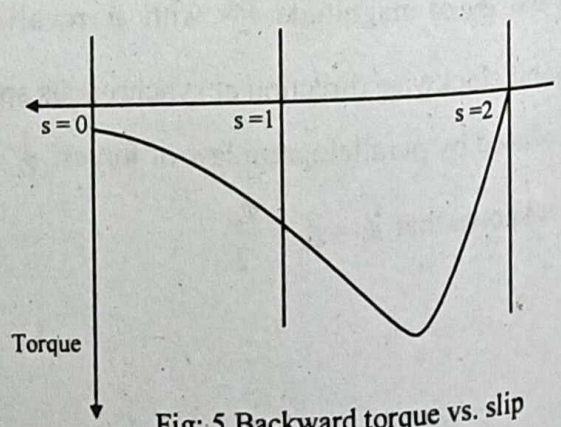


Fig: 5 Backward torque vs. slip

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The net torque or resultant torque will be the algebraic sum of the forward and backward torques and the net torque versus slip curve is shown below in Fig. (6). It may be seen from Fig. (6) that the net torque is zero at stand still i.e. at $s = 1$. This is because that the magnitude of forward and backward torques are equal and are of opposite directions, hence they cancel each other. Since the net torque at stand still is zero, the single-phase induction motor is not self-starting. But if the rotor is rotated by any external means in any direction (either in forward or in backward) the torque in that direction increases where as the reverse torque decreases and therefore the motor starts rotating in the direction in which it is rotated externally.

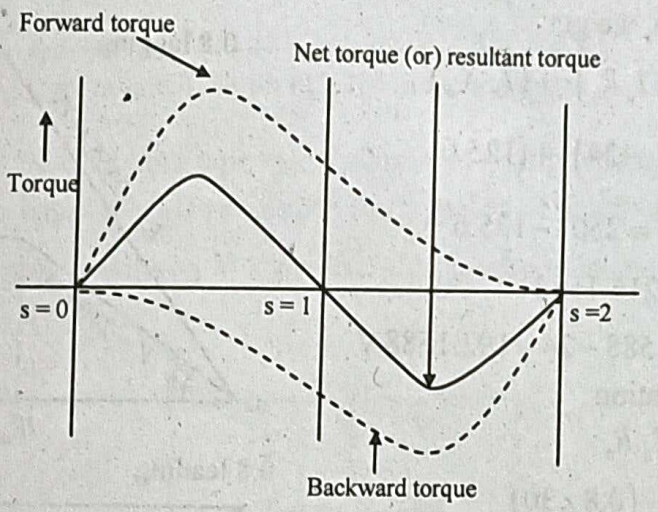

Fig: 6 Torque slip curve

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8. The resistance and total inductance of a single-phase fractional horse power series motor are 30 Ω and 0.5 H respectively. It draws 0.8 A current and runs at 2000 r.p.m. when connected to a 250 V d.c. supply. Calculate the speed and power factor when connected to a 250 V, 50 Hz supply and takes the same load current. How much voltage is required for getting 2000 r.p.m. with a.c. supply? Assume resistance and reactance remains constant. [WBUT 2009, 2016]

Answer:

$R_a = 30\Omega \qquad L = 0.5\text{H} \qquad I_a = 0.8\text{A}$

$E_{b\cdot ac} = ?\, E_{b\cdot dc} = ?\text{V} \qquad V = 250\text{V}$

For A.C. operation

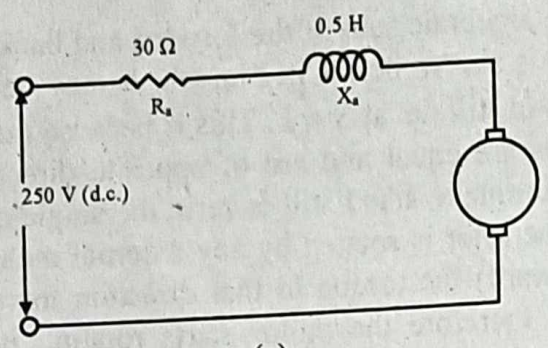
$X_a = 2\pi \times 50 \times 0.5 = 157\Omega$

$R_a = 30\Omega$

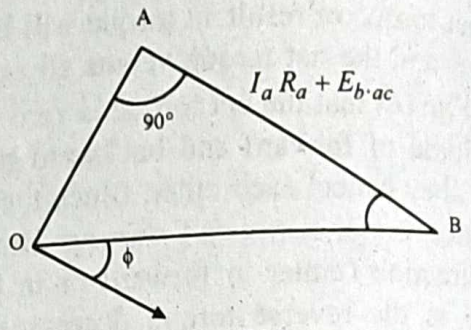
$I_a R_a = 0.8 \times 30 = 24\text{V}$

$I_a X_a = 0.8 \times 157 = 125.6\text{V}$

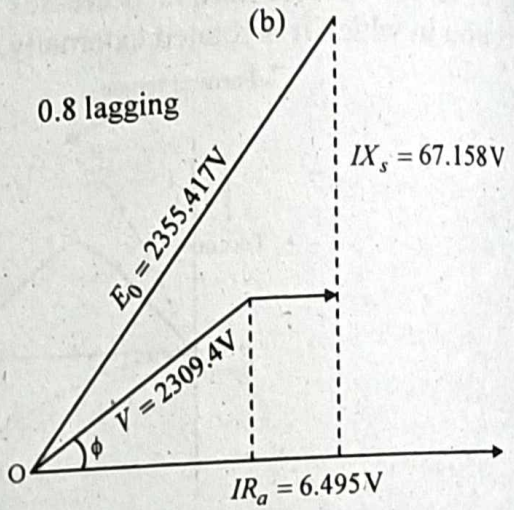
The phasor diagram is shown in Fig. (b)

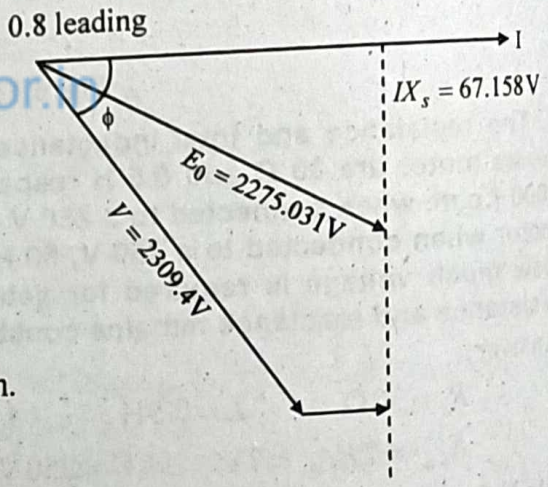


(a)



(b)





From phasor diagram, we get

$$V^2 = \left(E_{b\cdot ac} + I_a R_a\right)^2 + \left(I_a X_a\right)^2$$

or, $$250^2 = \left(E_{b\cdot ac} + 24\right)^2 + \left(125.6\right)^2$$

or, $$\left(E_{b\cdot ac} + 24\right)^2 = 250^2 - 125.6^2$$

or, $$E_{b\cdot ac} + 24 = 216.1588$$

or, $$E_{bac} = 216.1588 - 24 = 192.1588\,\text{V}$$

In case of D.C. operation

$$E_{b\cdot dc} = V - I_a R_a$$

$$E_{b\cdot dc} = 250 - (0.8 \times 30)$$

$$= 250 - 24 = 226\,\text{V}.$$

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Now, $$\frac{E_{b\cdot ac}}{E_{b\cdot dc}} = \frac{N_{ac}}{N_{dc}}$$

or, $$\frac{192.1588}{226} = \frac{N_{ac}}{2000}$$

or, $$N_{ac} = \frac{2000 \times 192.1588}{226} = 1700.52 \text{ r.p.m.}$$

$$\cos\phi = \frac{E_{b\cdot ac} + I_a R_a}{V}$$

$$= \frac{192.1588 + 24}{250} = \frac{216.1588}{250} = 0.8646 \text{ lag.}$$

9. a) Starting from the expression of sinusoidal supply current, mathematically derive the two revolving field theory model and the equivalent circuit of a single phase induction motor. [WBUT 2011]

Answer:

Refer to Question No. 7 of Long Answer Type Questions.

Equivalent Circuit

- The equivalent circuit of a single-phase induction motor can be developed on the basis of two revolving field theory. For developing the equivalent circuit it is first

imperative to consider stand still or blocked rotor conditions. Under blocked rotor condition, it will act like a transformer with its secondary short-circuited and its equivalent circuit will be as shown in Fig. (1) below, E_m being emf induced in the stator.

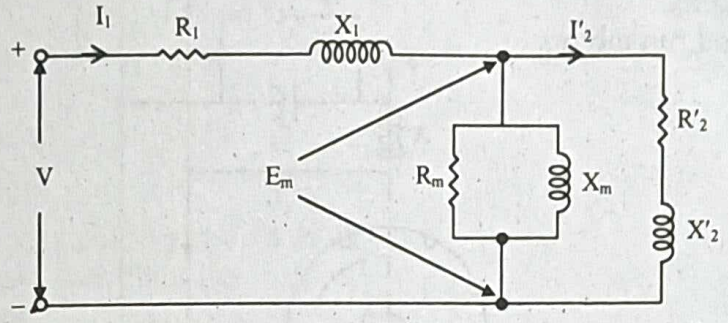

Fig: 1 Equivalent circuit of a 1-ϕ induction motor at stand still

- Fig. (2) as shown below is the equivalent circuit of a single-phase induction motor at stand still on the basis of two revolving field theory. The phasor sum of E_{mf} and E_{mb} equals the applied voltage V (less the voltage drops is stator resistance R_1 and leakage reactance X_1).

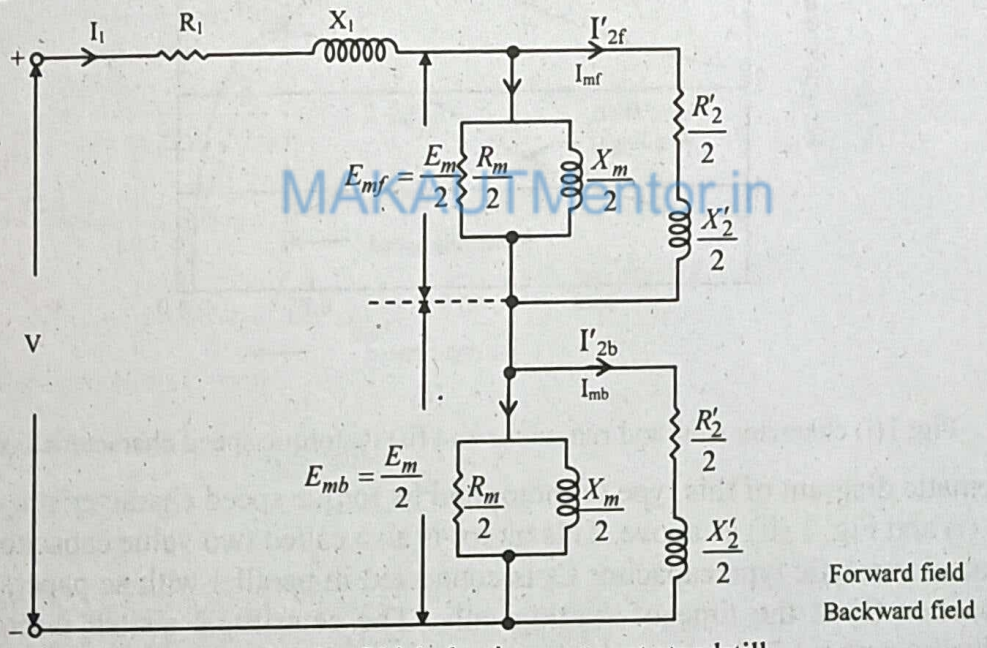

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Fig: 2 Equivalent circuit of 1ϕ induction motor at standstill on the basis of two revolving field theory

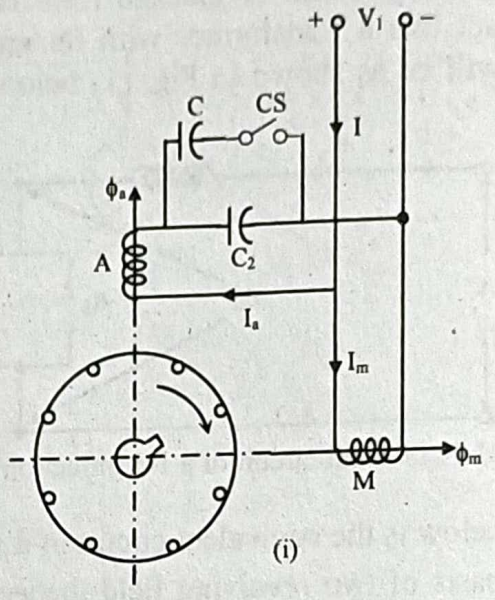
b) What are the different methods of starting a single phase induction motor? With the help of appropriate circuit diagram and phasor diagram, explain the principle of capacitor start-capacitor run 1-phase induction motor. Briefly indicate how to design the value of capacitor to be used. [WBUT 2011]

Answer:

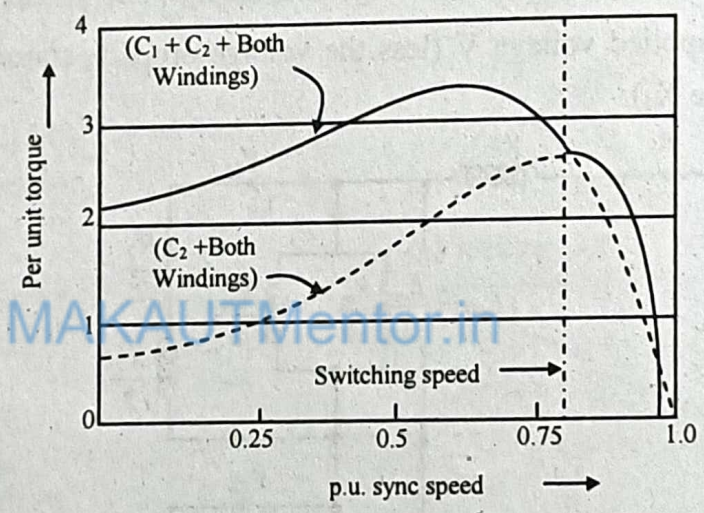
A single-phase induction motor is commonly known by the method employed for its starting. Different methods which have been developed for the starting of single phase induction motors may therefore be broadly classified into four ways viz.

1) split phase starting
2) shaded pole starting
3) repulsion motor starting and
4) reluctance starting

Capacitor start and run motors



(i)



(ii)

Fig: 1(i) character start and run motor and (ii) its torque speed characteristics

The schematic diagram of this type of motor and its torque speed characteristic are shown in Fig. 1.(i) and Fig. 1.(ii) as above. This motor is also called two value capacitor motor. A large ac electrolytic type capacitor C_1 is connected in parallel with ac paper, foil or oil type capacitor C_2 at the time of starting only. The centrifugal switch disconnects C_1 automatically at about 75% of synchronous speed; leaving behind C_2 a small capacitance in series with the auxiliary winding. Thus best starting with a high capacitance (C_1) and best running performance with low capacitance (C_2) can be achieved. For optimum operating conditions both at starting and running, C_2 should be less than $\frac{1}{2}(C_1 + C_2)$. In this case torque pulsations are reduced. Power factor and efficiency are also improved.

c) What may happen if one of the 3-lines of a 3-phase cage rotor induction motor suddenly gets disconnected? Justify your answer. **[WBUT 2011]**

Answer:
Still the motor will rotate. The reason is to have rotating magnetic field, 2-phase supply will create revolving magnetic field which will rotate in synchronous speed.

10. A 230 V 50 Hz, 4 pole, single phase induction motor has the following circuit parameters:

$R_{1m}=2.2\Omega$ $R_{2'}=4.5\Omega$ $X_{1m}=3.1\Omega$

$X_{2'}=2.6\Omega$ $R_M=80\Omega$ **[WBUT 2012]**

Friction, windage and core loss = 40 W.
For a slip of 0.03 pu, calculate its:
(i) Input current
(ii) Power factor
(iii) Developed power
(iv) Output power
(v) Efficiency.

Answer:
From the given data

$$\frac{R_2'}{2s}=\frac{4.5}{2\times 0.03}=75\Omega$$

$$\frac{R_2'}{2(2-s)}=\frac{4.5}{2(2-0.03)}=1.142\Omega$$

$$\frac{1}{2}X_2'=\frac{1}{2}\times 2.6=1.3\Omega$$

$$\frac{1}{2}X_M=\frac{1}{2}\times 80=40\Omega$$

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For the forward field circuit:

$$Z_f=R_f+jX_f=\frac{\left(R_2'/2s+j\frac{X_2'}{2}\right)\left(j\frac{X_M}{2}\right)}{\frac{R_2'}{2s}+j\frac{X_2'}{2}+j\frac{X_M}{2}}$$

$$=\frac{(75+j1.3)(j40)}{75+j1.3+j40}=\frac{(75.011\angle 0.993)\,(40\angle 90°)}{85.619\angle 28.84°}$$

$$=35.04\angle 62.15°\ \Omega=16.37+j30.98\Omega$$

For the backward field:

$$Z_b=R_b+jX_b=\frac{\left[\frac{R_2'}{2(2-s)}+j\frac{X_2'}{2}\right]\left(j\frac{X_m}{2}\right)}{\frac{R_2'}{2(2-s)}+j\frac{X_2'}{2}+j\frac{X_M}{2}}$$

$$= \frac{(1.42+j1.3)(j40)}{1.142+j1.3+j40} \frac{(1.73\angle 48.7°(40\angle 90°)}{41.316\angle 88.4°} = 1.675\angle 50.3° = 1.07 + j1.29\Omega$$

$$Z_{1m} = R_{1m} + jX_{1m} = 2.2 + j3.1$$

The total series impedance

$$Z_C = Z_{1m} + Z_f + Z_6$$
$$= 2.2 + j3.1 + 16.37 + j30.98 + 1.07 + j1.29$$
$$= 19.64 + j35.37 = 40.457 \ \angle 60.96°\Omega$$

a) Input current,

$$I_m = \frac{V_m}{Z_e} = \frac{230\ \angle 0°}{40.457\ \angle 60.96°} = 5.683\ \angle -60.96° A$$

b) Power factor = $\cos(-60.96°) = 0.4856$ lagging

c) Developed Power $P_d = I^2_m (R_f - R_b)(1-s)$

$$= (5.685)^2 (16.37 - 1.07)(1 - 0.03) = 479.65\text{W}$$

d) Output Power = $P_d - P_{rot} = 479.65 - 40 = 439.65W$

Input Power = $VI_m \cos\phi = 230 \times 5.685 \times 0.4856$

$= 634.9\text{W}$

e) Efficiency = $\frac{\text{Output}}{\text{Input}} = \frac{439.65}{634.9} = 0.692 pu.$

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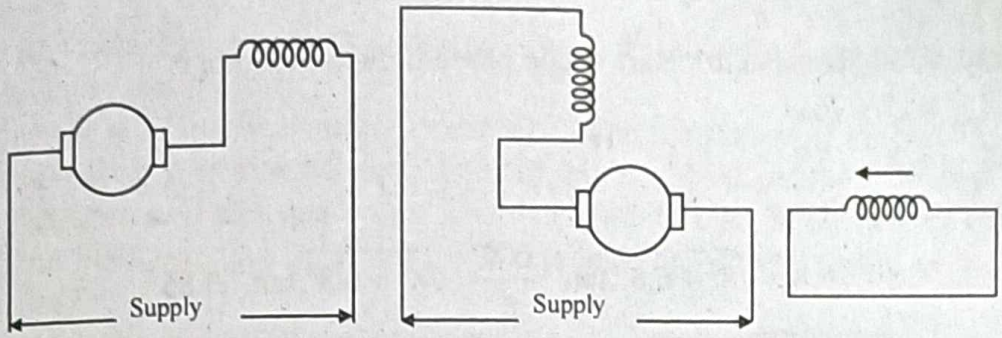
11. What are the modifications should be done in a dc series motor so that it will run satisfactory with ac supply? **[WBUT 2013]**

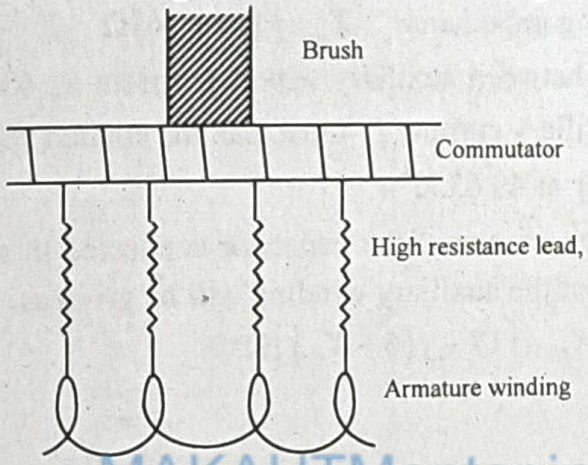
Answer:

If an alternating current is passed through an ordinary D.C. series motor, the field and armature currents reverse simultaneously every half cycle, so that a unidirectional torque is produced and the armature rotates. The motor has to be considerably modified for running it with alternating currents. The various operational difficulties and the required design modifications are given below:

1. While operating on alternating currents the eddy current loss increases considerably. Hence in addition to the armature, the field structure has to be laminated.
2. The D.C. series motor when connected to A. C. supply has a much greater tendency to produce sparking. Also its power factor is very low. Both excessive sparking and poor power factor are prevented by compensating the motor, the aim of which is to neutralize the effect of self-induction. The armature is compensated by employing coils carrying the armature current and placed on such a way as to neutralize the armature flux. The compensating coil can be connected in series with the main field or can be short-circuited on itself as shown in the figure below –



3. Sparking at the brushes is further reduced by using leads of high resistance between the windings and the commutator segments as shown in the figure below -



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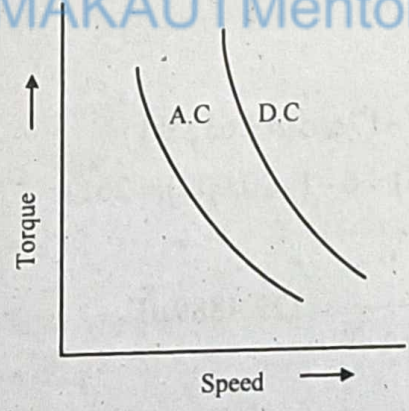

4. The air gap is kept small because of the weak main field. The number of turns in the field winding has to be kept low to reduce the reactance of the field winding.
5. Because of commutation difficulties the operation of large A.C. motor is confined to low frequencies as 16 2/3 and 25 Hz.

12. A 400 W, 230 V, 50 Hz capacitor starts single-phase induction motor has the following standstill constants for Main and Auxiliary winding:

Auxiliary winding: $Z_{aux} = 17 + j6\Omega$

Main winding: $Z_{main} = 8 + j6.8$

Find the value of starting capacitance that will place the main and auxiliary winding current in quadrature at starting. **[WBUT 2013]**

Answer:

400 W, 230 V, 50 Hz capacitor start single phase induction motor

$$Z_{aux} = 17 + j6\Omega$$

$$Z_{main} = 8 + j6.8$$

Main winding impedance

$$Z_{main} = 8 + j6.8 = \sqrt{8^2 + 6.8^2}\tan^{-1}\frac{6.8}{8} = \sqrt{8^2 + 6.8^2}\tan^{-1}0.85$$

$$= \sqrt{64 + 46.24}\angle 40.3645° = 110.24\angle 40.3645°.$$

It shows that the main winding current I_m (or I_f) lags the applied by 40.3645°.

Auxiliary starting winding impedance $Z_{aux} = (17 + j6)\Omega$

Since, time phase angle between auxiliary winding current I_a (or I_s) and main winding current I_m is 90°, so auxiliary current I_a must lead the applied voltage by

$$(90° - 40.3645°) \text{ or } 49.6355°$$

If X_C is the capacitive reactance of the capacitor connected in series with the auxiliary winding, the impedance of the auxiliary winding will be given as

$$Z_a = 17 + j6 - jX_C = [17 + j(6 - X_C)]\Omega$$

For auxiliary winding

$$\tan\phi_a = \frac{6 - X_C}{17}$$

or, $$17\tan\phi_a = 6 - X_C$$

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or, $$X_C = 6 - 17\tan\phi_a = 6 - 17\tan(49.6355°)$$

$$X_C = 6 - (-17 \times 1.176) = 6 - (-20.000) = 26\Omega$$

∴ Capacitance of capacitor

$$C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi \times 50 \times 26} = 122.4889\,\mu\text{F}.$$

13. a) Explain how the equivalent circuit parameters of a single phase induction motor can be determined experimentally. State the assumptions you have made. **[WBUT 2014, 2018]**

b) A 230 V, 4 Pole, 50 Hz, single phase induction motor has the following constants and losses:

$$r_1 = 2.3\Omega \;\; r_2 = 4.2\Omega \;\; X_m = 74\Omega \;\; X_1 = 3.2\Omega \;\; X_2 = 3.2\Omega$$

Core loss = 92 watts.

Friction and windage loss = 30 watts

If this motor is running with a slip 0.05 at rated voltage and frequency, then compute the (i) Stator current, (ii) pf, (iii) power output, (iv) torque and (v) efficiency with its auxiliary winding open. **[WBUT 2014]**

Answer:

a) In order to determine various constants, the most common tests performed on single-phase induction motors are:

i) Measurement of stator winding resistance: The resistance of each stator winding is measured separately; in case of capacitor start motor, the condenser is omitted.

ii) No load test and blocked rotor test: No load test is performed at rated voltage, exciting the main winding only and input current, voltage and power, as well as speed, are measured.

Blocked rotor test is carried out with main winding and starting winding separately and input voltage, amperes and watts are measured in each case. The test is sometimes performed at reduced voltage (about 40% of rated voltage) to avoid excessive short circuit current and heating.

Blocked-rotor test

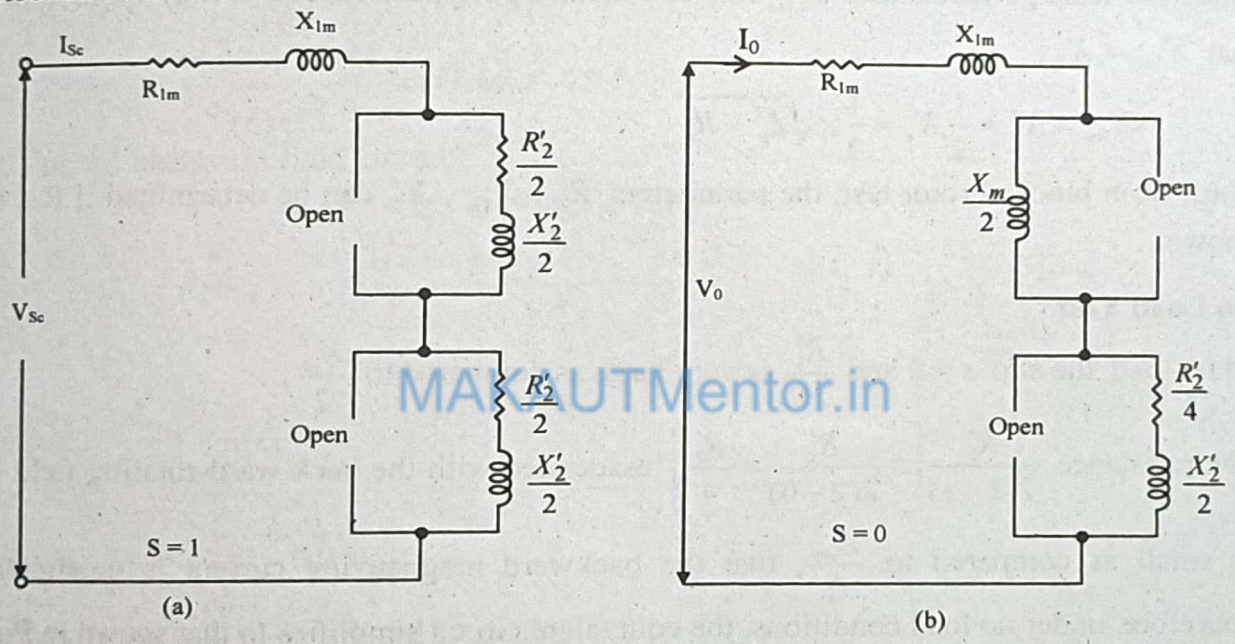

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Fig: 1. Simplified equivalent circuit of a single-phase induction motor
(a) locked rotor, (b) at no load

In the blocked rotor test, a low voltage is applied to the stator so that rated current flows in the main winding. The voltage (V_{sc}), Current (I_{sc}) and Power (P_{sc}) are measured under this condition. With the rotor blocked, S = 1 the impedance $\frac{X_m}{2}$ in the equivalent circuit is so large compared with $\left(\frac{R_2'}{2} + j\frac{X_2'}{2}\right)$ that it may be neglected form the equivalent circuit. Therefore the equivalent circuit at S = 1 reduces to that shown in Fig. 1.(a).

The equivalent impedance referred to stator is given by $Z_e = \frac{V_{sc}}{I_{sc}}$ ....(1)

From Fig. 1.(a) above, the equivalent series resistance R_e of the motor is:

$$R_e = R_{1m} + \frac{R_2'}{2} + \frac{R_2'}{2} = R_{1m} + R_2' = \frac{P_{sc}}{I_{sc}^2} \quad \text{.... (2)}$$

Since the resistance of the main stator winding R_{1m} is already measured, the effective rotor resistance at the line frequency is given by: -

$$R_2' = R_e - R_{1m} = \frac{P_{sc}}{I_{sc}^2} - R_{1m} \quad \text{.... (3)}$$

From Fig. 1(a), the equivalent reactance X_e is given by:

$$X_e = X_{1m} + \frac{X_2'}{2} + \frac{X_2'}{2} = X_{1m} + X_2' \quad \text{.... (4)}$$

Since the leakage reactances X_{1m} and X_2' cannot be separated out, it may be assumed that $X_{1m} = X_2'$.

$$\therefore \quad X_{1m} = X_2' = \frac{1}{2}X_e = \frac{1}{2} \times \sqrt{Z_e^2 - R_e^2} \quad \text{.... (5)}$$

Thus, from blocked rotor test, the parameters R_2', X_{1m}, X_2' can be determined if R_{1m} is known.

No Load Test

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At no load, the slip $s \approx 0$ and $\frac{R_2'}{2S}$ is very large as compared to $\frac{X_m}{2}$.

The resistance $\frac{R_2'}{2(2-s)}\left[\cong \frac{R_2'}{2(2-0)} = \frac{R_2'}{4}\right]$ associated with the back ward-rotating field is so small as compared to $\frac{X_m}{2}$, that the backward magnetizing current is negligible. Therefore, under no load conditions, the equivalent circuit simplifies to that shown in Fig. 1.(b). From Fig. 1.(b), the equivalent reactance at no load is given by:

$$X_0 = X_{1m} + \frac{X_m}{2} + \frac{X_2'}{2} \quad \text{.... (6)}$$

Since X_{1m} and X_2' are already known from the blocked rotor test, the magnetizing reactance X_m can be calculated from Eqn. (6).

If V_o, I_o and P_o denote the voltage, current and power respectively in the no load test, then the no load power factor is

$$\cos\phi_0 = \frac{P_o}{V_o I_o} \quad \text{.... (7)}$$

The no load equivalent impedance is:

$$Z_0 = \frac{V_0}{I_0} \quad \text{.... (8)}$$

The no load equivalent reactance is:

$$X_O = Z_O \sin\phi_O = Z_O\sqrt{1-\cos^2\phi_O} \qquad \text{.... (9)}$$

b) For the forward field circuit:

$$Z_f = R_f + jX_f = \frac{\left(R_2 + j\frac{X_2}{2}\right)\left(j\frac{X_m}{2}\right)}{\frac{R_2}{2s} + j\frac{X_2}{2} + j\frac{X_m}{2}}$$

$$= \frac{\left(\frac{4.2}{2\times 0.05} + j\frac{3.2}{2}\right)\left(j\frac{74}{2}\right)}{\frac{4.2}{2\times 0.05} + j\frac{3.2}{2} + j\frac{74}{2}} = \frac{(42+j1.6)(j37)}{42+j1.6+j37}$$

$$= \frac{-59.2+j1554}{42+j38.6} = (17.67+j20.76)\Omega$$

$\therefore$ For the backward field circuit:

$$Z_b = R_b + jX_b = \frac{\left(\frac{R_2}{2(2-s)} + j\frac{X_2}{2}\right)\left(j\frac{X_m}{2}\right)}{\frac{R_2}{2(2-s)} + j\frac{X_2}{2} + j\frac{X_m}{2}}$$

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$$= \frac{\left(\frac{4.2}{2(2-0.05)} + j\frac{3.2}{2}\right)\left(j\frac{74}{2}\right)}{\frac{4.2}{2(2-0.05)} + j\frac{3.2}{2} + j\frac{74}{2}} = \frac{(1.1+j1.6)(j37)}{(1.1+j1.6+j37)}$$

$$= \frac{-59.2+j40.7}{1.1+j38.6} = (1+j1.56)\Omega$$

$\therefore \quad Z_1 = R_1 + jX_1 = (2.3+j3.2)\Omega$

$\therefore$ The total series impedance

$$Z_e = Z_1 + Z_f + Z_b$$

$$= 2.3 + j3.2 + 17.67 + j20.76 + 1 + j1.56 = 20.97 + j25.52$$

(i) Stator current $(I_s) = \frac{V_s}{Z_e} = \frac{230}{20.97+j25.52} = (4.42 - j5.38)$ Amps.

$= 6.96\angle -0.88°$ Amps.

(ii) Power factor $= \cos(-0.88°) = 0.99$ lagging

(iii) Developed power $(P_d) = I_s^2(R_f - R_b)(1-s)$

$$= (6.96)^2(17.67-1)(1-0.05) = 767.14 \text{ W}$$

$\therefore$ Output power $= \left[767.14 - (92+30)\right] = 645.14$ W

$\therefore$ Input power $= VI_s \cos\phi = 230 \times 6.96 \times 0.999 = 1600$ W

(iv) $T_f = I_s^2 \left(\frac{r_2}{s}\right)$ synchronous watt

$= 6.96^2 \left(\frac{4.2}{0.05}\right) = 6.96^2 \times 84 = 4069.0944$ synchronous watt

$T_b = I_s^2 \left(\frac{r_2}{2-s}\right)$ synchronous watt

$= 6.96^2 \left(\frac{4.2}{2-0.05}\right) = 6.96^2 \times 2.1538 = 104.335$ synchronous watt

$T = T_f - T_b = 4069.0944 - 104.335 = 3964.7594$ synchronous watt

(v) Efficiency $= \frac{\text{Output}}{\text{Input}} = \frac{645.14}{1600} = 0.4032$ or 40.32%

14. a) Show, with the help of phasor diagram, that compensating winding in a large ac commutator motor is a must, for achieving higher power factor, improved commutation and better speed – torque characteristic. **[WBUT 2014]**

Answer:

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The commutator helps in both cases single phase and d.c. motors to exert a continuous torque. The frequency of alternation of flux and armature current is same in case of d.c. operation and thus the torque exerted by any particular armature conductor when under a given pole is always in the same direction. When this same conductor moves to a position under a pole of opposite polarity, the current in it is reversed due to the action of commutator and brushes and hence the torque remains in the same direction as before. The commutation is thus, as much necessary for single phase a.c. series motor as is for a d.c. motor.

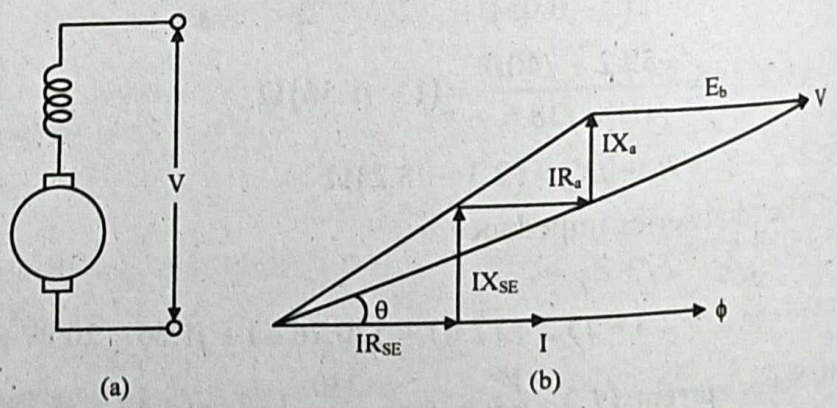

Fig: 1(a) A.C. Series motor (b) Phasor diagram

However, the pulsating flux causes heavy core losses in the field and yoke. Heavy sparking at the brushes would take place since the induced voltages and currents in the armature would be short-circuited at the time of commutation. The overall performance of the motor is thus poor.

In case of d.c. motors, the applied voltage V has to balance against the armature resistance drop and the back e.m.f. i.e., $V = E_b + I_a R_a$, whereas in case of a.c. motor, the

applied voltage is to be balanced against, besides the resistance drop in armature and field, there will be reactance drop due to both in addition to rotational e.m.f. The phasor diagram for an a.c. series motor is shown in Fig. 1.

Assuming no core loss, the flux is in phase with the current and the back e.m.f. in case of a.c. series motor is less than the back e.m.f. in case of d.c. series motor. Since field flux remains constant for the same current I, reduction in back e.m.f. in the case of a.c. series motor results in lower speed than that of d.c. series motor. In other words the output of a.c. series motor is less than that of d.c. series motor. The speed-torque characteristics of a.c. and d.c. series motors are shown in Fig. 2.

From the above analysis it is clear that in order to improve the performance of a.c. series motor, the e.m.f. must be made as far as possible equal to the back e.m.f. of d.c. series motors. This means that the value of armature and field reactances must be made very small. The field reactance can be reduced by using less number of turns on the field. This, of course, in turn reduces field flux. In order to develop same torque, the armature conductors should be increased in the same ratio. The net result of this exercise is that the field flux is reduced but the armature reaction (which introduces fictitious armature reactance) is increased. In order to decrease the effect of armature reaction a compensating winding, either in series with the armature or short circuited on itself.

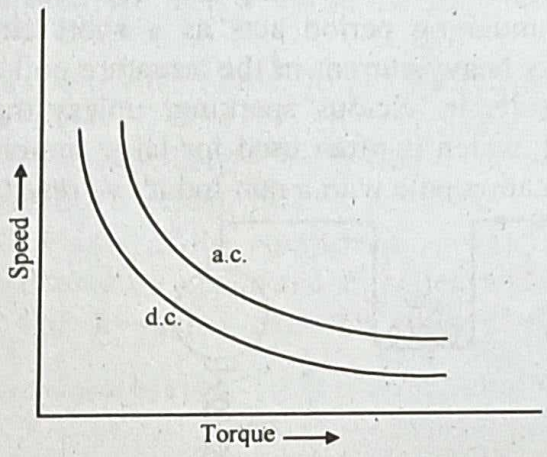

Fig: 2 Speed-torque characteristics of A.C. and D.C. series motors

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Since the compensating winding nullifies the effect of armature reaction the p.f. of the motor is, thereby improved. The p.f. of the motor at low speeds is poor as the rotational back e.m.f. at low speeds is low and hence the supply voltage has to be balanced against small rotational back e.m.f. and the impedance drops which, therefore, will be relatively large and hence the p.f. is poor. These motors are normally high-speed motors, for the same reason of better p.f.

Keeping in view the above factors, which contribute to better performance of a.c. series motors, these motors for traction purposes have a large number of poles, small air gaps, low flux per pole and moderate flux densities in the magnetic circuits. Compensating windings are provided to neutralize armature reaction and commutating poles are required for the better performance in terms of higher efficiency and a greater output from a given size of armature core.

b) Why commutation of an ac series motor is more complicated than a dc motor? Briefly described any one method of improvement of commutation in ac series motor. [WBUT 2014]

Answer:
Generally all d.c. series motors are 'provided' with commutating poles for improving commutation (as in d.c. motors). But commutating poles alone will not produce satisfactory commutation, unless something is done to neutralize the huge voltage induced in the short circuited armature coil by transformer action (this voltage is not there in d.c. series motor). It should be noted that in an a.c. series motor, the flux produced by the field winding is alternating and it induces voltage (by transformer action) in the short circuited armature coil during its commutating period. The field winding, associated with the armature coil undergoing commutation, acts as primary and the armature coil during its commutating period acts as a short circuited secondary. This transformer action produces heavy current in the armature coil as it passes through its commutating period and results in vicious sparking, unless the transformer voltage is neutralized. One method, which is often used for large motors, consists of shunting the winding of each commutating pole with a non-inductive resistance, as shown in Fig. 1(a).

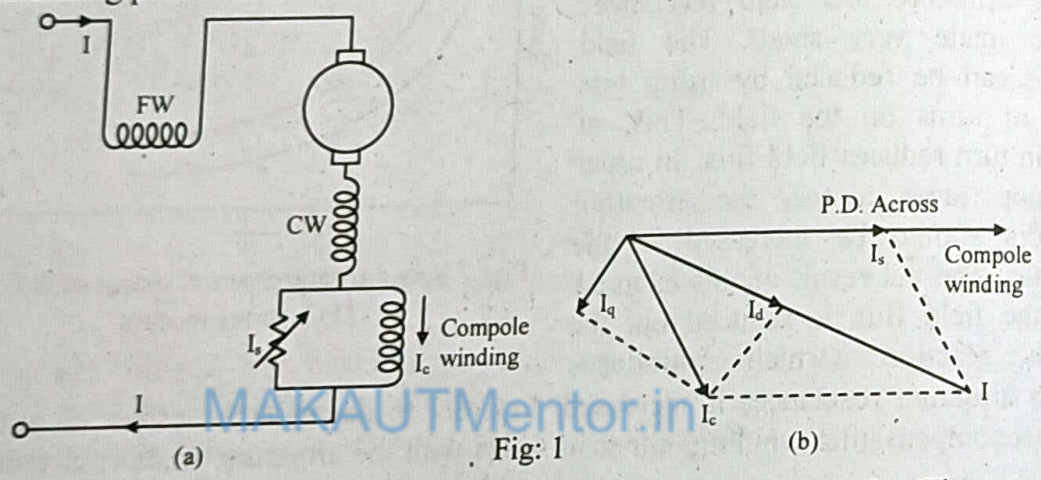

Fig: 1

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Fig. 1(b) shows the vector diagram of a shunted commutator pole. The current I_c through the commutating pole (which lags the total motor current) can be resolved into two rectangular components I_d and I_q produces a flux which is in phase with total motor current I whereas flux produced by I_q lags I by 90°. By proper adjustment of shunt resistance (and hence I_s), the speed voltage generated in a short circuited coil by the cutting of the 90° lagging component of the commutating pole flux may be made to neutralize the voltage induced by transformer action.

15. a) Explain with reasons why compensating winding is provided in a universal motor for AC operation.
b) What are the modifications that should be done in a dc series motor so that it will run satisfactorily with ac supply?
c) What may happen if one of the 3 – lines of a 3 – phase cage rotor induction motor suddenly gets disconnected? Justify your answer. **[WBUT 2015]**

Answer:
a) The compensating winding is provided in a Universal Motor to reduce the reactance voltage present in the armature when motors run on A.C. supply. This reactance voltage

is caused by the alternating flux by transformer action because the flux produced by the field winding is alternating.

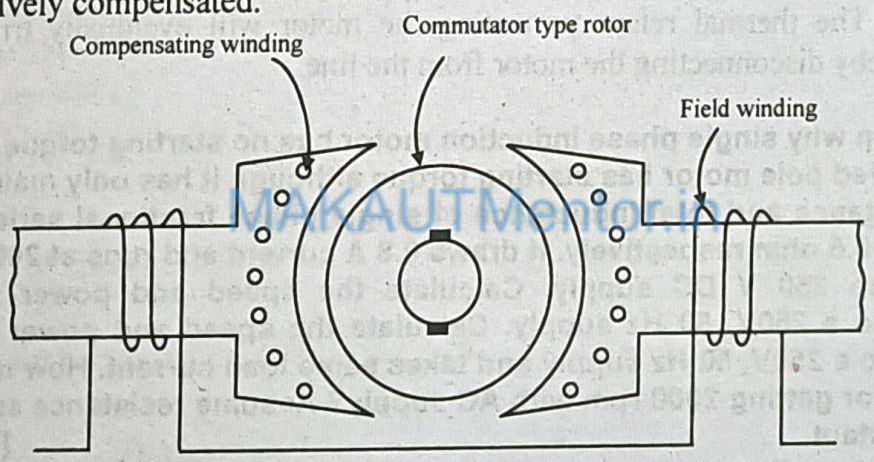
b) To overcome the above drawbacks the following modifications may be made in the d.c. series motor so that it can operate satisfactorily on alternating current: -

a) The field core is constructed of a material having low hysteresis loss and it is laminated to reduce eddy current loss.

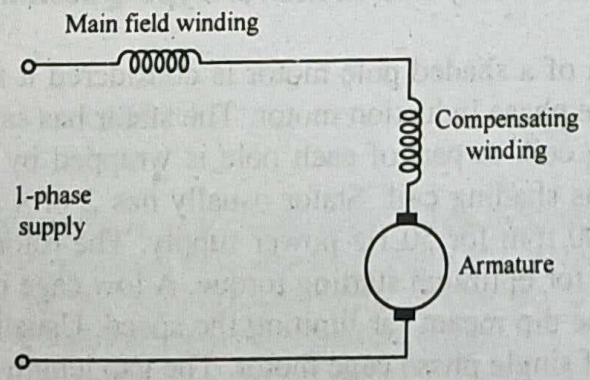
b) The field winding is provided with small number of turns. The field pole areas is increased so that the flux density is reduced. This reduces the iron loss and the reactive voltage drop.

c) The number of armature conductors is increased in order to get the required torque with the low flux.

d) In order to reduce the effect of armature reaction, thereby improving commutation and reducing armature reactance a compensating winding which is put in the stator slot is used and shown in Fig. (a) below. The axis of the compensating winding is 90° electrical with the main field axis and may be connected in series with both the armature and field as shown in Fig. (b). In such a case the motor is said to be conductively compensated.



a) Series motor with conductively compensated winding



b) Conductively compensated series motor

The compensating winding may be short circuited on itself in which case the motor is said to be inductively compensated as shown in Fig. (c)

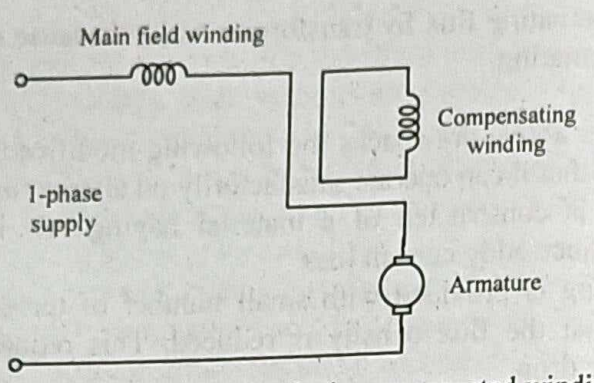


Fig: c) Series motor with inductively compensated winding

e) Inter poles are provided to eliminate the armature resistance leads, which occupy valuable space and lower the rating of the motor by their heating.

c) Single Phase Induction Motors

If one line of a 3-phase induction motor is accidentally opened or if a fuse blows while the motor is running, the machine will continue to run as a single-phase motor. The current drawn from the remaining two lines will almost double and the motor will begin to overheat. The thermal relays protecting the motor will eventually trip the circuit breaker, thereby disconnecting the motor from the line.

16. a) Explain why single phase induction motor has no starting torque.
b) Why shaded pole motor has starting torque although it has only main winding?
c) The resistance and total inductance of single phase fractional series motor are 30 ohm and 0.5 ohm respectively. It draws 0.8 A current and runs at 2000 rpm when connected to 250 V DC supply. Calculate the speed and power factor when connected to a 250V, 50 Hz supply. Calculate the speed and power factor when connected to a 250V, 50 Hz supply and takes same load current. How much voltage is required for getting 2000 rpm with AC supply? Assume resistance and reactance remain constant. **[WBUT 2016]**

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Answer:

a) ***Refer to Question No. 1 of Short Answer Type Questions.***

b) If the construction of a shaded pole motor is considered it may be seen that this is a split phase type single phase induction motor. The stator has salient poles, each provided with its own exciting coil. A part of each pole is wrapped by a copper strap forming a closed loop, known as shading coil. Stator usually has 2 or 4 poles giving synchronous speed of 3000 or 1500 rpm for 50 Hz power supply. The rotor is a simple squirrel cage type with a 60° skew for optimum starting torque. A low cage resistance imparts both the starting torque and the dip meant for limiting the speed. Usually the resistance is greater than any other type of single phase cage motor. The gap length is of the order of 0.25–0.5 mm too short air gap may result in starting torque variation due to rotor slotting.

When the exciting winding is connected to the single phase supply source an alternating current flows through it and sinusoidally varying flux is set up in the core. This change of flux induces short circuit currents in the shading coil in such a direction as to oppose the

core flux, the flux in the shaded part of the pole that lags behind the flux in the main part of the pole. At the same time, the main flux and the shaded pole flux are obviously displaced in space, although by less than 90°. Since two field have both space and time displacement, the conditions for setting up a rotating field are present, no matter how imperfectly starting torque is this developed in the squirrel cage rotor although it has only main winding.

c) ***Refer to Question No. 8.c) of Long Answer Type Questions.***

17. A 6-pole, 50Hz, single phase induction motor, when running at normal speed, has forward field and backward field resistances of 60Ω and 1.4Ω respectively. The stator current at a full-load slip of 5% is 3A. Determine the full-load torque in Nm. Assume rotational losses to be 4% of internal power developed. [WBUT 2018]

Answer:

A 6-pole, 50Hz, 1ϕ I.M.

Forward field resistance $= 60\Omega$

Backward field resistance $= 1.4\Omega$

Stator current at full load $= 3$ A

Full load slip $= 5\%$

Rotational losses $= 4\%$

$$N_s = \frac{120f}{p} = \frac{120 \times 50}{6} = 600$$

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Air gap power for forward field, $P_{gf} = \frac{1}{2} I_m^2 Rf = \frac{1}{2} \times (3)^2 \times 60 = \frac{1}{2} \times 9 \times 60 = 270$ W

Air gap power for backward field, $P_{gb} = \frac{1}{2} I_m{}^2 Rb = \frac{1}{2} \times (3)^2 \times 1.4 = 6.3$ W

$$\text{Torque} = \frac{1}{W_s}(P_{gf} - P_{gb})$$

$$W_s = \frac{2\pi Ns}{60} = 62.83$$

$$T = \frac{1}{62.83}(270 - 6.3) = 4.197 \text{ N-m}$$

18. A 50 Hz, four pole split-phase induction motor has auxiliary resistance of 5Ω and reactance of 20Ω, both in main and winding. Find the value of resistance and capacitance to be added to the auxiliary winding circuit so that the two winding carry same current and the currents are 90° to each other. [WBUT 2018]

Answer:

50Hz, 4-pole split phase Introduction Motor

$R_A = 5\Omega$

$X_A = 20\Omega$, $X_M = 20\Omega$

Let, the required value of additional resistance R

And additional capacitive reactance is X_c

Thus, total resistance of auxiliary winding becomes

$$R'_A = (5+R)\Omega$$

And effective reactance of the auxiliary winding becomes

$$X'_A = (X_C - 20)\Omega$$

When the currents in the main and auxiliary winding are at exactly 90° and the value of auxiliary winding capacitive reactance is given by:

$$X_C = X_A + \frac{R'_A \times R_m}{X_m} = 20 + \frac{(5+R)\times 5}{20} = \frac{425+5R}{20}\Omega \quad \text{.... (1)}$$

Impedance of the main winding:

$$Z_m = \sqrt{R_m^2 + X_m^2} = \sqrt{5^2 + 20^2} = \sqrt{425}\,\Omega$$

Impedance of auxiliary winding, when both extra resistance and capacitance added:

$$Z'_a = \sqrt{(R'_A)^2 + (X'_A)^2} = \sqrt{(5+R)^2 + (X_C - 20)^2}\ \Omega$$

For magnitude of the currents in the two windings to be equal, their impedances must be equal i.e. $Z_m = Z'_a$

$$\sqrt{425} = \sqrt{(5+R)^2 + (X_C - 20)^2}$$

$$(5+R)^2 + (X_C - 20)^2 = 425 \quad \text{.... (2)}$$

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Putting Eqn. (1) in (2) we get:

$$(5+R)^2 + \left(\frac{425+5R}{20} - 20\right)^2 = 425$$

or, $$(5+R)^2 + \left(\frac{425+5R-400}{20}\right)^2 = 425$$

or, $$(5+R)^2 + \left(\frac{25+5R}{20}\right)^2 = 425$$

or, $$(5+R)^2 + \left(\frac{5+R}{4}\right)^2 = 425$$

or, $$(5+R)^2 + \frac{(5+R)^2}{16} = 425$$

or, $$17(5+R)^2 = 425\times 16$$

or, $$(5+R) = 20$$

or, $$R = 15\Omega$$

This is the required value of resistance.

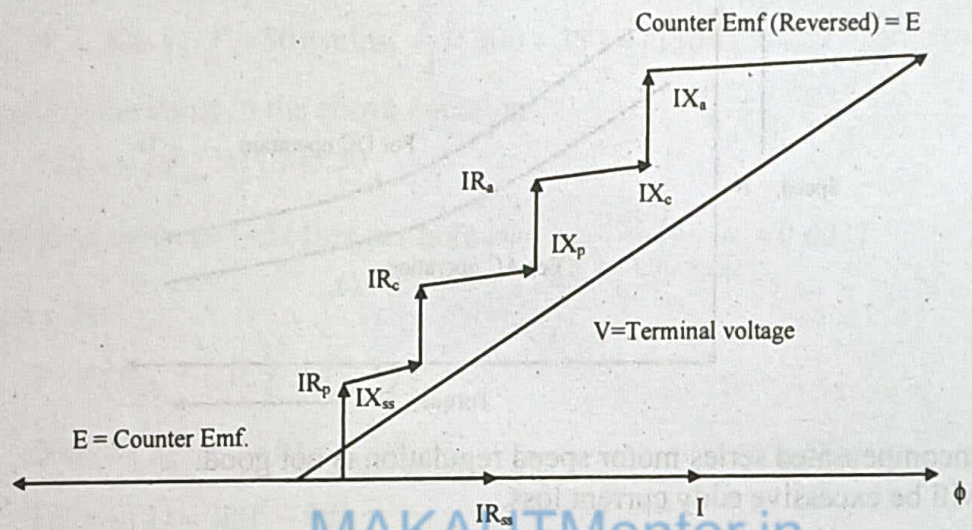
Putting this value of $R = 15\Omega$ in Eqn. (1) we get,

$$X_C = \frac{425 + 5 \times 15}{20} = 25\Omega$$

Value of capacitor, $C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi \times 50 \times 25} = 127\ \mu F$

19. a) Show with the help of phasor diagrams that a compensated series motor possesses better speed torque characteristics, better power factor and improved commutation as compared to an uncompensated series motor. [WBUT 2018]

Answer:



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For a compensated series motor let us write various notations for the above phasor diagram-

R_s – represent the resistance of the series field.

R_p – represent the resistance of the series field.

R_c – represent the resistance of the compensating winding.

R_a – represent the series of the armature circuit.

X_s – represent the reactance of the series field.

X_p – represent the reactance of the interpole circuit.

X_c – represent the reactance of the compensating winding.

X_a – represent the reactance of the armature circuit.

ϕ to represent the flux produced by the current I.

On taking the current I on the reference axis we have terminal voltage equals to summation of all the voltage drops and the counter emf. We have summation of the voltage drops equal.

$$I \times \left[\left(R_s + R_p + R_c + R_a \right) + j\left(X_s + X_p + X_c + X_a \right) \right]$$

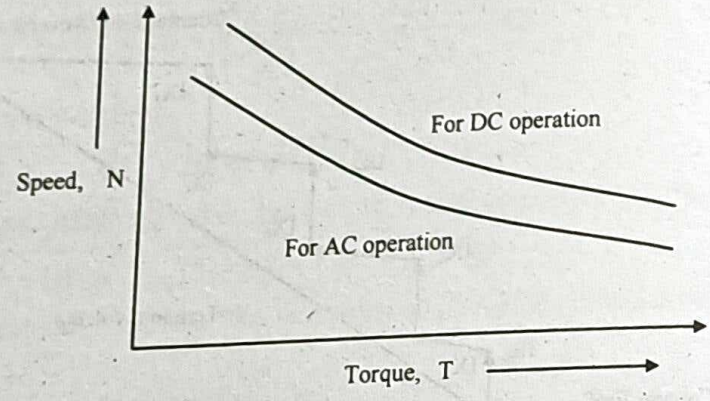
The main advantage is that we can easily obtain the phase angle for counter emf E.

Power factor characteristics: We can derive the expression for power factor with the help of phasor diagram –

$$\phi = \frac{\text{Summation of reactance drop}}{\text{terminal voltage}}$$

$$\sin\phi = I \times \frac{Xs + Xp + Xc + Xa}{V} = I\frac{X}{V}$$

Speed torque characteristics: The relation between the torque and speed can be derived with the help of torque current and speed current characteristics.



In case of uncompensated series motor speed regulation is not good. And there will be excessive eddy current loss.

b) A 2-pole, 50 Hz, 300 V, single phase series motor has 800 armature turns and 350 field turns. The total effective resistance is 6Ω and total leakage reactance is 14Ω. For a power input of 350 watts the motor draws 2A and the speed is 3600 rpm.

i) Compute the peak value of field flux per pole.

ii) If the motor is conductively compensated and draws the same amount of current, find the p.f. and speed. The motor has full compensation and the leakage impedance of compensating winding is 1+j2Ω. **[WBUT 2018]**

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Answer:

i) The flux per pole being alternating in A.C. series motor and brushes are in the neutral plane, then rms value of rotational Emf is given as

$$E_r = \frac{\phi_{max}}{\sqrt{2}} \cdot \frac{ZN}{60} \times \frac{P}{A} \text{ Volts} \quad \text{.... (1)}$$

Substituting $\frac{PN}{60} = 2f_r \quad \left(\therefore f_r = \frac{PN}{120}\right)$ in equation

(a) We get

$$E_r = \sqrt{2}\phi_{max}\frac{Z}{A}f_r$$

The frequency of rotational emf E_r is the same as the frequency of ϕ.

The cross flux ϕ' in the neutral on brush axis products alternating emf due to transformation and the frequency of transformer emf E_t is the same as that of cross-flux ϕ' and the equation and the equation stands as under:

$$E_t = \sqrt{2}\pi f \phi'_{max} \times \frac{2}{\pi} \times \frac{Z}{2A} = \sqrt{2}\phi'_{max} \frac{Z}{A} f \text{ Volts}$$

where $\frac{Z}{2A}$ is the number of turns per parallel path.

Now according problem

$$E_t = 300 \text{ V},\ f = 50 \text{ cycles},\ \frac{2}{A} = 800 + 350 = 1150$$

Now putting the value in the above equation

$$300 = \sqrt{2}\phi'_{max} \times 1150 \times 50$$

ϕ_{max} the peak value of field flux per pole is $= \frac{300}{\sqrt{2} \times 1150 \times 50} = 0.0037$

(b) First Case:

$$V^2 = \left(E_{ac_1} + I_a R_a\right)^2 + \left(I_a X_a\right)^2$$

$$\Rightarrow \quad 300^2 = \left(E_{ac_1} + 2 \times 6\right)^2 + \left(2 \times 14\right)^2$$

$$\Rightarrow \quad \left(E_{ac_1} + 12\right) = 300^2 - 28^2$$

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$$\Rightarrow \quad \left(E_{ac_1} + 12\right)^2 = 328.272$$

$$\Rightarrow \quad E_{ac_1} + 12 = 298.61$$

$$\Rightarrow \quad E_{ac_1} = 286.69$$

ii) When the motor is conductively compensated

$$V^2 = \left(E_{ac_2} + I_a R_a\right)^2 + \left(I_a X_a\right)^2$$

$$\Rightarrow \quad 300^2 = \left(E_{ac_2} + 2 \times 7\right)^2 + \left(2 \times 16\right)^2$$

$$\Rightarrow \quad \left(E_{ac_2} + 14\right)^2 = 300^2 - 32^2$$

$$\Rightarrow \quad E_{ac_2} + 14 = 298.288$$

$$E_{ac_2} = 298.288 - 14 \qquad [I_a = 2\text{A}]$$

$$= 284.288$$

Again, $Z_c = 1 + j2\Omega$

$$Z_{effc} = 6 + j14$$

$$\therefore \quad \cos\phi = \frac{E_{ac_2} + I_a R_a}{V} = \frac{284.288 + 7}{300} = \frac{291.288}{300} = 0.97096 \text{ lag}$$

To determine speed:

$$\frac{E_{ac_1}}{E_{ac_2}} = \frac{N_1}{N_2}$$

$$\Rightarrow \quad \frac{286.69}{284.288} = \frac{3600}{N_2}$$

$$\Rightarrow \quad N_2 = \frac{3600 \times 284.288}{286.69} = 3569.83 \text{ RPM}$$

20. a) A 250 W, 110 V, 60 Hz, 6-pole, split-phase induction motor has the following impedances:

$$R1 = 1.52\Omega,\ R2 = 3.13\Omega,\ X1 = 2.100\Omega,\ X2 = 1.56\Omega,\ XM = 58.2\Omega$$

The core losses of this motor are 35W and the friction, windage and stray losses are 16W. The motor is operating at the rated voltage and frequency with its starting winding open and the motor's slip is 5 percent. Find the following quantities in the motor at these conditions:

i) Speed in revolutions per minute
ii) Stator current in amperes
iii) Stator power factor
iv) Input power
v) Air-gap power
vi) Output power
vii) Efficiency **[WBUT 2019]**

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Answer:

Forward impedances and reverse impedance is 5%

$$Z_f = R_f + jX_f$$

$$= \left(\frac{1}{2} jX_m\right) \Big\| \left(\frac{R_2}{2s} + j\frac{X_2}{2}\right) = \frac{\left(\frac{1}{2} jX_m\right) \times \left(\frac{R_2}{2s} + j\frac{X_2}{2}\right)}{\frac{R_2}{2s} + j\frac{X_2}{2} + \frac{1}{2} jX_m}$$

$$= \frac{\left(\frac{1}{2} j58.2\right) \times \left(\frac{3.13}{2 \times 0.05} + j\frac{2.1}{2}\right)}{\frac{3.13}{2 \times 0.05} + j\frac{1.56}{2} + \frac{1}{2} j53.2} = \frac{(j29.1) \times (31.3 + j1.05)}{31.3 + j0.78 + j29.1}$$

$$= \frac{j(910.83) - 30.55}{31.3 + j29.88} = \frac{911.34\angle -1.92^\circ}{43.27\angle 43.67^\circ} = 21.06\angle -45.59^\circ = 14.73 - j15.04$$

Similarly, $Z_b = R_b + jX_b = \left(\frac{1}{2}jX_m\right) \Big\| \left(\frac{R_2}{2(2-s)} + j\frac{X_2}{2}\right) = \dfrac{\left(\frac{1}{2}jX_m\right)\times\left(\frac{R_2}{2(2-s)} + j\frac{X_2}{2}\right)}{\frac{R_2}{2(2-s)} + j\frac{X_2}{2} + \frac{1}{2}jX_m}$

$$= \frac{\left(\frac{1}{2}j58.2\right)\times\left(\frac{3.13}{2\times(2-0.05)} + j\frac{1.56}{2}\right)}{\frac{3.13}{2\times(2-0.05)} + j\frac{1.56}{2} + \frac{1}{2}j53.2} = \frac{(j29.1)\times(0.80+j0.78)}{0.80+j0.78+j29.1}$$

$$= \frac{j23.28-22.698}{0.80+j29.88} = \frac{32.50\angle 134.26}{29.89\angle 88.46} = 1.087\angle 45.8° = 0.757 + j0.779$$

Stator impedance, $Z_1 = R_1 + jX_1 = 1.52 + j2.1\Omega$

i) Speed in revolutions per minute $= \frac{120f}{P} = \frac{120\times 50}{6} = 1000$ rpm

ii) Stator current

$$I_1 = \frac{110\angle 0°}{1.52+j2.1+14.73-j15.04+0.757+j0.77} = \frac{110\angle 0°}{17.007-j12.16}$$

$$= \frac{110\angle 0°}{20.90\angle -35.56°} = 5.26\angle 35.56° \text{ A}$$

iii) Stator power factor $= \cos(35.56°) = 0.81$ leading

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iv) Input power $= VI\cos\theta = 110\times 5.26\times\cos(0.81) = 578.5$ W

v) Airgap power, $P_g = I_1^2\left[R_f - R_b\right] = (5.26)^2[14.73-0.75] = 27.66\times 13.98 = 386.68$ W

vi) Output power $= P_m - P_c - (P_{fw} + P_{stray}) = [(1-0.05)386.68] - 35 - 16$

$$= (367.34 - 51) = 316.34$$

vii) Efficiency $= \eta = \frac{\text{Output}}{\text{Input}} = \frac{316.34}{578.5}\times 100 = 54.68\%$

b) Write down the working principle of Hysteresis motor. **[WBUT 2019]**

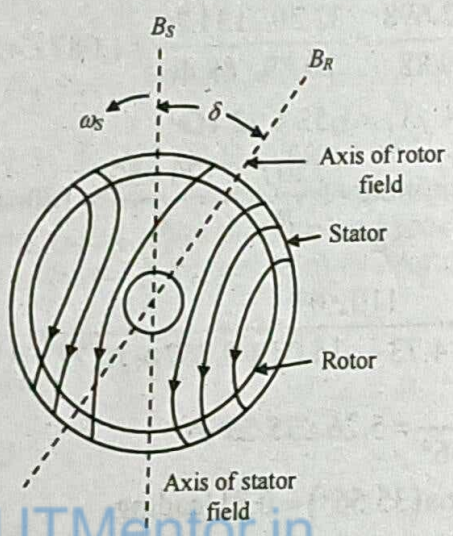
Answer:

Hysteresis motor is like a single phase induction motor and running behavior is same as a synchronous motor. Step by step its behavior can be realized in the working principle that is given below.

At the Starting Condition

- When stator is energized with single phase AC supply, rotating magnetic field is produced in stator.
- To maintain the rotating magnetic field the main and auxiliary windings must be supplied continuously at start as well as in running conditions.

- At the starting, by induction phenomenon, secondary voltage is induced in the rotor by stator rotating magnetic field. Hence eddy current is generated to flow in the rotor and it develops rotor.
- Thus eddy current torque is developed along with the hysteresis torque in the rotor. Hysteresis torque in the rotor develops as the rotor magnetic material is with high hysteresis loss property and high retentively.
- The rotor goes under the slip frequency before going to the steady state running condition.
- So it can be said that when the rotor starts to rotate with the help of these eddy current torque due to induction phenomenon, it behalves like a single phase induction motor.



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When supply is given applied to the stator, a rotating magnetic field is produced. This magnetic field magnetises the rotor ring and induces pole within it. Due to the hysteresis loss in the rotor, the induced rotor flux lags behind the rotating stator flux. The angle δ between the stator magnetic field B_S and the rotor magnetic field B_R is responsible for the production of the torque. The angle δ depends on the shape of the hysteresis loop and not on the frequency.

Thus, the value of Coercive force and residual flux density of the magnetic material should be large. The ideal material would have a rectangular hysteresis loop as shown by loop 1 in the hysteresis loop figure. The stator magnetic field produces Eddy currents in the rotor. As a result, they produce their own magnetic field.

c) Compare the single phase induction motor with a polyphone induction motor having the same size and speed. **[WBUT 2019]**

Answer:

The Single Phase induction motor uses single phase supply, for its operation and 3 Phase induction motor uses three phase supply.

- The Starting Torque of Single Phase induction motor is low, whereas the starting torque of Three Phase Induction motor is high.

- Single Phase motors are easy to repair and maintain, but the maintenance of three phase motors difficult.
- Single Phase motors are simple in construction, reliable and economical as compared to three phase induction motors.
- The efficiency of single phase motor is low, whereas the efficiency of three phase induction motors is high.
- The power factor of Single Phase Induction motor is low as compared to that of three-phase induction motor.
- Single Phase motors are mostly used in domestic appliances such as mixer grinder, fans, compressors, etc. Three phase induction motors are mostly

21. Write short notes on the following

a) Repulsion type motor **[WBUT 2010, 2016]**

b) A universal motor **[WBUT 2011]**

c) Cross-field Theory **[WBUT 2017]**

Answer:

a) In a repulsion motor the stator carries a single phase exciting winding, similar to the main winding of a single phase induction motor and the rotor carries an ordinary distributed d.c. type winding, connected to the commutator at one end as shown in Fig. 1.

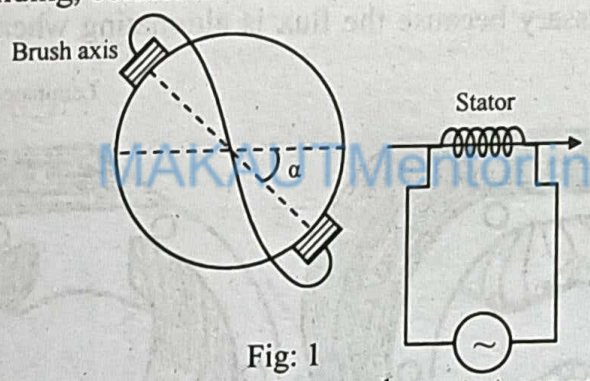

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Fig: 1

The brushes are short circuited on themselves and are not connected electrically to the supply circuit. In this case, the armature receives power from the stator by transformer action. The rotor mmf set up by the rotor currents is along the brush axis. In this motor, the brush axis is neither along $\alpha = 90°$ nor along $\alpha = 0°$ but occupies some intermediate position and the armature current is very high when the brush axis is aligned in the direction of stator field axis. The repulsion between like poles or, results in the clockwise direction of rotation. It is obvious that the direction of rotation can be reversed merely by shifting the brush axis to the other side of the field winding axis.

The following important points to be remembered:

1. The electromagnetic torque ∝ (Stator "d" axis mmf) × rotor q-axis mmf.
2. The exciting flux ϕ_f induces a transformer e.m.f. E_{tsf} in the d-axis stator winding itself, just like emf induced in the primary winding of a transformer and E_{tsf} lags ϕ_f by 90°. The applied voltage V_t has to be equal to $\left(-E_{ts} - E_{tsf}\right)$ plus the stator leakage

impedance drops. The angle between V_t and I_s is the stator p.f. angle. The power developed in the rotor $= E_{far} I_a \cos\left(E_{far}, I_a\right)$.

3. The speed control is obtained by varying the angle α.
4. To obtain superior commutation motor should be operated near synchronous speed.
5. It is used for loads requiring high starting torque such as hoists, lifts etc.

b) It is a type of motor, which may be operated either on direct - current or single-phase a.c. supply at approximately the same speed and output.
In fact it is series wound motor and has high starting toque and a variable speed characteristic. Since these motors run at dangerously high speed on no load, they are usually built-into the device they drive.

Construction

From constructional point of view, universal motors are manufactured in two types viz i) concentrated pole, non compensated type (low H.P. rating) and ii) Distributed field compensated type (high H.P. rating).
The non-compensated motor has two salient poles and is just like a 2 pole d.c. series motor except that whole of its magnetic path is laminated as shown in Fig.(1) below. The laminated stator is necessary because the flux is alternating when the motor is operated from a.c. supply.

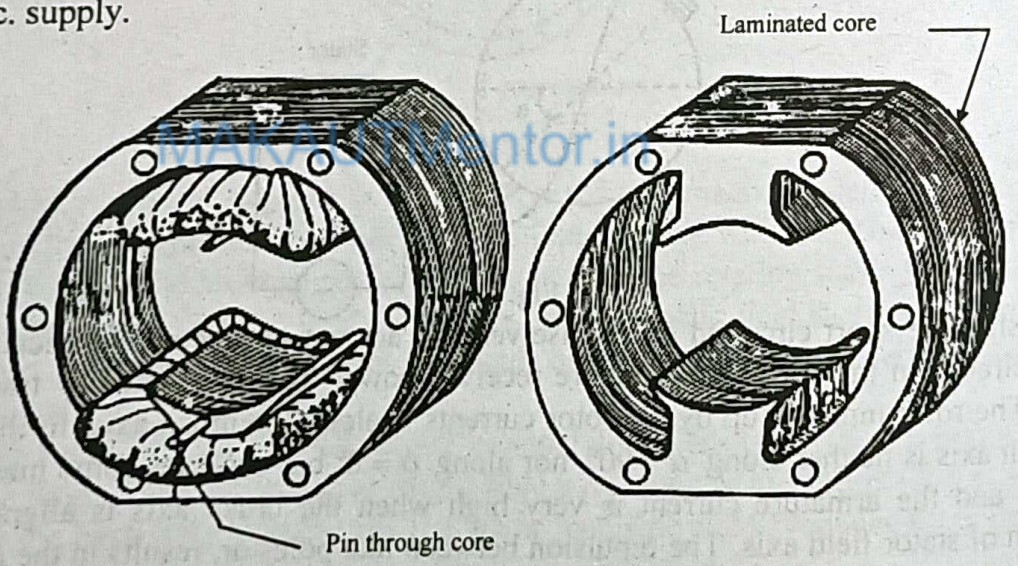

Fig: 1. Field core of a two pole universal motor

The armature is of wound type and is similar to that of a small d.c. motor. It consists essentially of laminated core having either straight or skewed slots and a commutater to which the leads of the armature winding are connected. In a 2 pole non-compensated motor, the voltage induced by transformer action in a coil during its commutation period is not sufficient to cause any serious commutation problem. High resistance brushes are used further to aid commutation.
So far the distributed field compensated type of motor is concerned it may be mentioned that it's stator core is similar to that of a split phase motor and a wound armature similar

to that of a small d.c. Motor. The compensating winding is used to reduce the reactance voltage present in the armature when motor runs on a.c. supply. This voltage is caused by the alternating flux by transformer action.

Operation:

The operation of the motor is based on the same principle as that of the d.c. motor i.e. the force between the main pole flux and the current carrying armature conductors. This is true regardless of whether current is alternating or direct. The production of unidirectional torque when the motor runs on a.c. supply; can be understood from Fig. (2) as shown below.

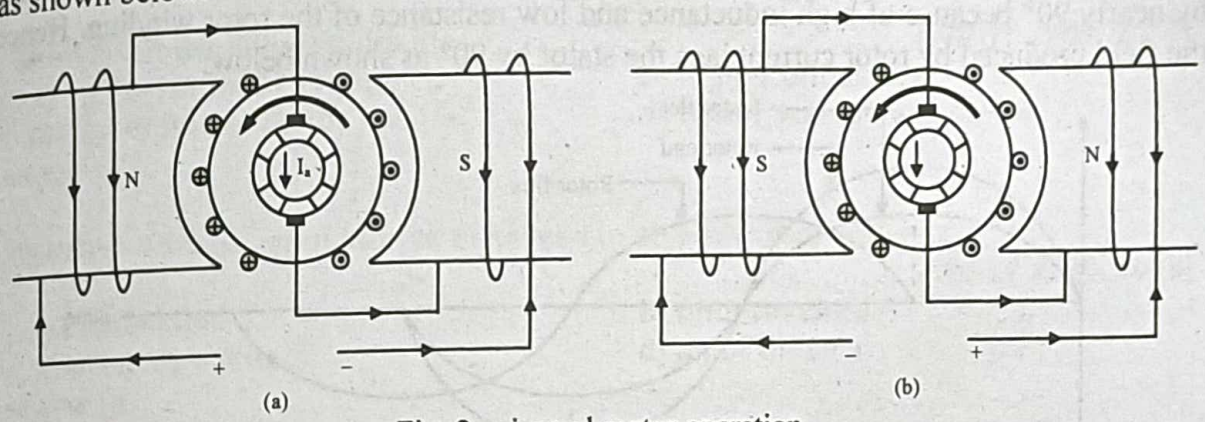

Fig: 2 universal motor operation

Speed-load Characteristics

Speed-torque characteristic of a universal motor both for d.c. and a.c. supply is shown in Fig. (3) below:

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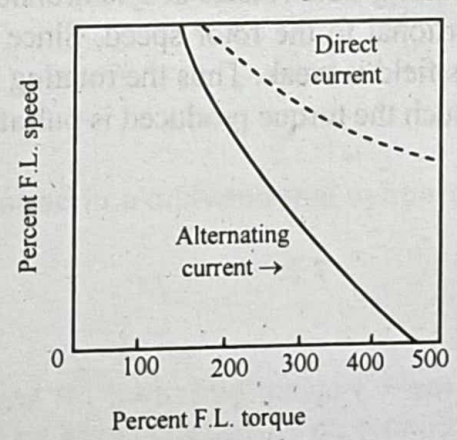


Fig: 3 Typical torque characteristics of a universal motor

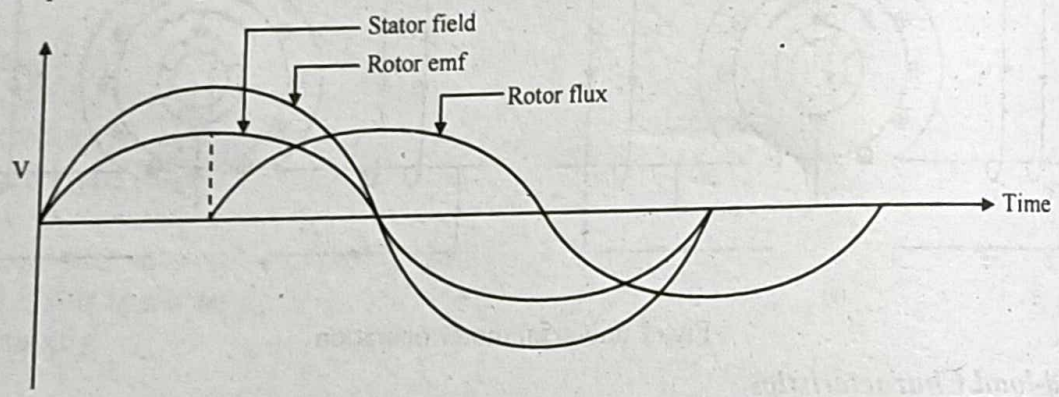
It may be seen from Fig. (3) that speed of a universal motor varies just like that of a d.c. motor i.e. low at full load and high on no load. On no load, the speed is limited by its own friction and windage losses.

c) Cross-field Theory:

Cross-field theory gives a conception of the reaction which actually takes place in the single phase induction motor.

When the stator winding of a single phase induction motor is connected to supply during starting, the stator current produces a magnetic field which is alternating. During one half cycle of stator current the stator pole is of one direction and is of opposite direction during the next half cycle of stator current. Thus the stator mmf is not rotating one but only pulsating. The rotor acts as a short circuited secondary in which induced currents flows establishing poles on the rotor surface, which are always in direct line with the stator poles resulting creation of no torque. Hence the motor will not start. However, if the rotor is rotated by some external force, the rotor conductor cuts the stator field and hence an emf called **speed emf** is induced in the rotor.

During the first half cycle, the rotor emf is reversed; the rotor current lags the rotor emf by nearly 90° because of high inductance and low resistance of the rotor winding. Hence the field produced by rotor current lags the stator by 90° as shown below:



The rotor field is called **cross-field**. Since there exists a phase difference of 90° between stator and rotor field, the resulting field rotates at synchronous speed. The strength of the cross-field is directly proportional to the rotor speed. Since rotor speed is less than the synchronous speed, the cross field is weak. Thus the rotating field strength is not constant but it is varying one and as such the torque produced is pulsating one.

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SYNCHRONOUS MACHINES

Multiple Choice Type Questions

1. In a synchronous generator operating at zero power factor lagging, the effect of armature reaction is [WBUT 2007, 2008, 2013, 2014, 2018]
   a) Magnetizing
   b) Demagnetizing
   c) Cross-magnetizing
   d) Both magnetizing and cross-magnetizing

Answer: (b)

2. Short pitch winding results in [WBUT 2008, 2018]
   a) higher terminal voltage
   b) higher efficiency
   c) higher power factor
   d) better voltage waveform

Answer: (d)

3. Negative voltage regulation is observed in an alternator which is [WBUT 2008, 2018]
   a) overexcited
   b) underexcited
   c) normally excited
   d) all of these

Answer: (b)

4. In a salient pole synchronous machine, where $X_d = d$ - axis synchronous reactance, $X_q =$ quadrature axis synchronous reactance. [WBUT 2011, 2012, 2015, 2018]

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   a) $X_q = X_d$
   b) $X_q > X_d$
   c) $X_q < X_d$
   d) $X_q = 0$.

Answer: (c)

5. Number of slip-rings required in a conventional synchronous machine is [WBUT 2011]
   a) 0
   b) 1
   c) 2
   d) 3

Answer: (c)

6. It is desirable to eliminate 5th harmonic voltage from the phase voltage of an alternator. The coils should be short pitched by an electrical angle of [WBUT 2011]
   a) 30°
   b) 36°
   c) 18°
   d) none of these

Answer: (b)

7. If the prime mover of the alternator supplying load to an infinite bus is suddenly shut down, then it will [WBUT 2011]
   a) stop
   b) continue to run as an alternator
   c) continue to run as a synchronous motor in the reverse direction
   d) continue to run as a synchronous motor in the same direction

Answer: (d)

8. A 400V-60 Hz synchronous machine has 6 poles. The synchronous speed in rpm is [WBUT 2012]
a) 1200 b) 3000 c) 1000 d) 1500
Answer: (a)

9. Armature reaction AT of a synchronous generator at rated voltage zero power lagging is [WBUT 2012]
a) magnetizing b) demagnetizing
c) cross magnetizing d) both magnetizing and cross magnetizing
Answer: (b)

10. Cylindrical rotor synchronous machines are mainly used in [WBUT 2012, 2015]
a) hydel power plants b) steam power plants
c) in both hydel and steam power plants d) none of these
Answer: (b)

11. A salient pole synchronous machine has maximum power output when the power angle δ is [WBUT 2012]
a) 90° b) 45° c) less than 90° d) more than 90°
Answer: (a)

12. A fractional-pitch winding is mainly used to reduce [WBUT 2013]
a) amount of copper in the winding b) size of the machine
c) harmonics in the generated emf d) cost of the machine
Answer: (a, c)

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13. The synchronous-impedance method of finding the voltage regulation by a cylindrical rotor alternator is generally considered as [WBUT 2013, 2015]
a) a pessimistic method because saturation is not considered
b) an optimistic method because saturation is not considered
c) a fairly accurate method even if power factor is not taken into account while determining synchronous impedance
d) a fairly accurate method even if power factor is taken into account while determining synchronous impedance.
Answer: (a)

14. A salient pole synchronous machine has maximum power output when power angle δ is [WBUT 2013, 2015]
a) 90° b) either 90° or more c) less than 90° d) more than 90°
Answer: (a)

15. Zero power factor characteristic for Potier diagram can be obtained by loading the alternator using [WBUT 2014]
a) lamp load b) synchronous motor
c) water load d) dc motor
Answer: (a)

16. The maximum possible speeds in rpm at which an alternator can be driven to generate voltages at 60Hz and 50Hz are respectively [WBUT 2014, 2018]
a) 2000, 2400 b) 3000, 3600 c) 2400, 2000 d) 3600, 3000
Answer: (d)

17. The power factor of an alternator under short circuit conditions is almost near [WBUT 2014]
a) zero leading b) zero lagging c) unity
d) zero leading or zero lagging depending upon the type of alternator
Answer: (a)

18. Potier reactance of an alternator is almost the same as [WBUT 2014]
a) field winding resistance
b) total armature reactance
c) leakage reactance of field winding
d) armature leakage reactance
Answer: (d)

19. A three phase synchronous generator is operating at constant load while the excitation is adjusted to give unity pf current. If the excitation is now increased, the pf will [WBUT 2014]
a) become leading b) become lagging
c) remain at unity d) become zero
Answer: (b)

20. If the power factor of an alternator is zero lagging the armature reaction is [WBUT 2015]
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a) demagnetizing b) magnetizing
c) cross magnetizing d) both demagnetizing
Answer: (a)

21. Armature reaction mmf for a synchronous machine cross magnetizes the field mmf in [WBUT 2016]
a) ZPF lagging b) ZPF leading c) UPF d) 0
Answer: (c)

22. In case of synchronous generator electromagnetic torque and prime mover torque are in [WBUT 2016]
a) same direction b) reverse direction
c) not produced d) none of these
Answer: (b)

23. The expression for power (with reference to Power Angle characteristics) for a cylindrical pole rotor synchronous machine is given by [WBUT 2016]
a) $\frac{E_f V_t}{X_s}\sin\delta$ b) $\frac{E_f V_t}{X_s}\cos\delta$ c) $\frac{E_f V_t X_s}{\cos\delta}$ d) $\frac{E_f V_t X_s}{\sin\delta}$
Answer: (a)

24. The speed of an alternator is [WBUT 2016]
a) always same as synchronous speed
b) less than synchronous speed
c) above synchronous speed
d) none of these

Answer: (a)

25. Damper winding is used [WBUT 2016]
a) for starting a synchronous generator
b) for starting a synchronous motor
c) not at all
d) in DC machine.

Answer: (a)

26. Distribution winding [WBUT 2016]
a) gives reduction of harmonics
b) gives mechanical strength
c) gives increased harmonics
d) both (a) and (b)

Answer: (d)

27. In an alternator, voltage drops occurs in [WBUT 2017]
a) armature resistance only
b) armature resistance and leakage reactance
c) armature resistance, leakage reactance and armature reaction
d) armature resistance, leakage reactance, armature reaction and earth connections

Answer: (c)

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28. For an alternator when the power factor of the load is unity [WBUT 2017]
a) the armature flux will have square waveform
b) the armature flux will be demagnetising
c) the armature flux will be cross-magnetising
d) the armature flux will reduce to zero

Answer: (c)

29. An alternator is supplying 10A to an inductive load at 220V, while running at 1000rpm. Now if the speed of the alternator is reduced to 750 rpm but the field current remains unchanged, the load current will become [WBUT 2017]
a) 18A
b) 13.3A
c) 10A
d) 7.5A

Answer: (c)

30. An alternator is rated for 75kW at 0.8 power factor. It means that [WBUT 2017]
a) alternator has 4 poles
b) alternator can supply 75kW at 0.8 power factor
c) alternator can supply power only to loads having power factor 0.8 only
d) the peak efficiency of alternator occurs only at 75kW load having 0.8 lagging power factor

Answer: (b)

31. Two alternators are running in parallel. The excitation of one of the alternator is increased. The result will be [WBUT 2017]
   a) machine with excess excitation will burn
   b) both machines will start vibrating
   c) power output will decrease
   d) wattless component will change

Answer: (d)

32. The back emf in the stator of a synchronous motor depends on [WBUT 2017]
   a) speed of rotor
   b) rotor excitation
   c) number of poles
   d) flux density

Answer: (b)

33. At lagging loads, armature reaction of an alternator is [WBUT 2019]
   a) magnetizing
   b) demagnetizing
   c) cross-magnetizing
   d) non-effective

Answer: (b)

34. Synchronous machine operates at which power factor? [WBUT 2019]
   a) Lagging b) Leading c) Unity d) All of these

Answer: (b)

35. Which one of the following methods would give a higher than the actual value of regulation of alternator? [WBUT 2019]
   a) zpf method b) mmf method c) emf method d) ASA method

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Answer: (c)

36. A 3-phase double layer stator winding has a coil span of 150 deg. Its coil span factor will be [WBUT 2019]
   a) 0.96 b) 1.0 c) 0.966 d) 0.98

Answer: (c)

37. Slip test performed of alternator to determine [WBUT 2019]
   a) Slip
   b) X_d and X_q
   c) positive and negative sequence reactance
   d) sub-transient reactance

Answer: (b)

Short Answer Type Questions

1. In a salient pole synchronous machine, the value of x_d is greater than that of x_q. [WBUT 2006, 2008, 2017]

Answer:

In a salient pole synchronous machine, at one instant when the peak of armature m.m.f wave is in line with the field pole or direct axis, the reluctance offered by the small air gap is minimum as shown in the Fig. (1). At this instant the impressed terminal voltage per phase divided by the corresponding armature current per phase, gives d-axis synchronous reactance x_d.

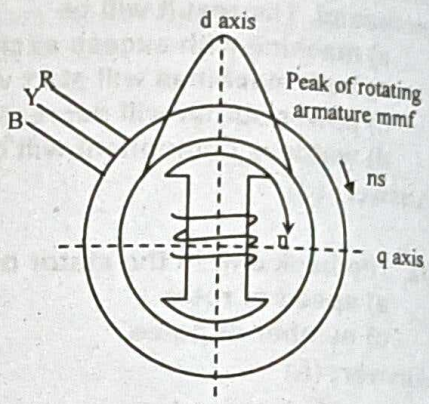

Fig: 1

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

After one-quarter of slip cycle, the peak of armature m.m.f wave acts on the interpolar or q-axis of the magnetic circuit. In this position the reluctance offered by long air gap is maximum as shown in Fig. (2). At this instant the ratio of armature terminal voltage per phase to corresponding armature current per phase gives q-axis synchronous reactance x_q.

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

Hence x_d is greater than that of x_q

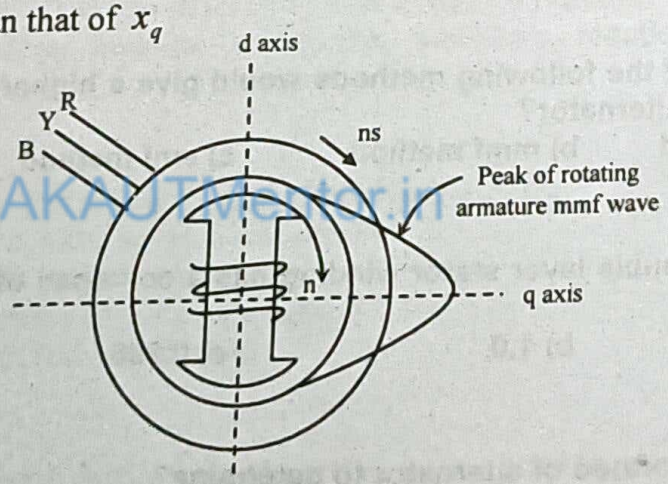

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Fig: 2

2. Explain why cylindrical rotor alternators have small diameter and large core length while salient pole alternators have large diameter and small core length?

[WBUT 2007, 2013, 2015, 2017]

Answer:

The cylindrical rotor alternators have small diameter and large core lengths because this type of rotor is used for alternators, which are coupled to steam turbines, which run at very high speeds. To reduce the peripheral speed of the alternator the diameter of the rotor is reduced and axial length is increased. Since these rotors have large lengths of core forced ventilation is necessary for proper cooling.

Forced air-cooling is used up to about 50 MVA sizes and for bigger sizes hydrogen cooling is invariably employed because the conductivity of hydrogen is about 7 times that of air.

Salient pole alternators have large diameter and small core length because this type of rotor is used for alternators, which are coupled to hydraulic turbines, which run at low speeds divided, by the type of turbine and water head, having large number of poles. This diameter thus becomes very large to accommodate large number of poles. With diameter as large as 15m with several hundred tones of load, it is just not possible to transport the machine as a single unit and in fact it is transported to the site in sections.

3. What is a damper winding? Why is damper winding used in salient pole synchronous machine? [WBUT 2007, 2010, 2017]

Answer:

1st Part:

In a synchronous machine damper windings are used to damp out or control the oscillations. Damper windings consist of low resistance copper, brass or aluminium bars, embedded in slots in the pole faces of salient pole machines. The projecting ends of the bars are connected to short-circuiting rings on both sides, as is done with squirrel cage winding in induction motors.

Two types of Damper windings are:

i) Incomplete, non-connected or open type

ii) Complete or connected type

2nd Part:

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Salient pole type synchronous machine are used for low and medium speeds and their construction cannot be made strong enough to withstand the mechanical stresses encountered at high speeds. In this type of rotor, projecting poles made of thick steel laminations are ratted together to the rotor by dovetail joints. The pole faces are usually, provided with slots for damper winding which are placed inside the holes present in the rotor face, which are short circuited, EMF is induced in the bars whenever there is oscillation, which will circulate current in the bars thereby producing torque that opposes the oscillation. That is why damper winding is used in salient pole synchronous machine.

4. What is distribution factor? What are the advantages of distributing a winding in slots? [WBUT 2008, 2017]

Answer:

1st Part:

The ratio of the vector sum of the emfs induced in all the coils distributed in a number of slots under one pole to the arithmetic sum of the emfs induced (or to be resultant of the emfs induced in all the coils concentrated in one slot under one pole) is known as distribution factor K_d

$$\text{or, } K_d = \frac{\text{emf induced in a distributed winding}}{\text{emf induced of the winding would have been concentrated}} = \frac{\text{Vector sum}}{\text{Arithmetic sum}}$$

The distribution factor is less than unity.

2nd Part:

Advantages of distributing a winding in slots are:

i) Mechanical strength of the coils is increased.
ii) Improved waveform of the induced emf.
iii) Less copper loss.
iv) Less winding space resulting in a shorter unit.
v) Distinct reduction in machine harmonics.
vi) Reduction of tooth ripples.

5. Explain what causes hunting in a synchronous machine. Explain the methods adopted to minimize hunting. **[WBUT 2008, 2009]**

OR,

What is hunting in an alternator? Discuss the measures to be taken to minimize such hunting. **[WBUT 2012, 2015]**

OR,

What is hunting in an alternator? Explain how hunting can be minimized? **[WBUT 2017]**

Answer:

The phenomenon of oscillation of the rotor of a synchronous machine about its final equilibrium position is called hunting. The main causes of hunting are

1. Sudden changes of load.
2. Fault occurring in the system, which the generator supplies.
3. Sudden changes in the field current.
4. Cyclic variations of the load torque.

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Due to hunting there may be (i) loss of synchronism (ii) undesirable lamp flickering for variation of supply voltage (iii) possibility of resonance (iv) development of mechanical stress in the rotor shaft (v) increase of machine losses and rise of temperature of the machine. Some of the methods that are adopted for reduction of hunting are:

a) Use of flywheels: The prime-mover is provided with a large and heavy flywheel. This increases the inertia of the prime-mover and hence in maintaining the rotor-speed.
b) Damper winding: Damper winding is nothing but copper bars placed inside the holes present in the rotor face, which are short-circuited. EMF is induced in the bar whenever there is oscillation, which will circuit current in the bars there by producing torque that opposes the oscillation.
c) By designing synchronous machines with suitable synchronizing power co-efficients.

6. Explain the use of damper winding. **[WBUT 2010, 2017]**

Answer:

The damper winding is useful in preventing the hunting (momentary speed fluctuations) in generators and is needed in synchronous motors to provide the starting torque. Turbo-generators do not usually these damper windings (except in special cases to assist in synchronizing) because the solid field poles themselves act as efficient dampers.

7. Describe the Slip test to determine the *d*-axis synchronous reactance (X_d) and *q*-axis synchronous reactance (X_q) of a salient pole synchronous machine.

[WBUT 2010, 2014, 2018]

Answer:

Determination of X_d and X_q

The direct and quadrature-axis synchronous reactance of a salient pole synchronous machine can be determined by slip test. In this test, a small voltage at rated frequency and not more than about 25% of the rated value is applied to the 3-phase stator winding. The field winding is un-excited and left open circuited as shown in the connection diagram given below:

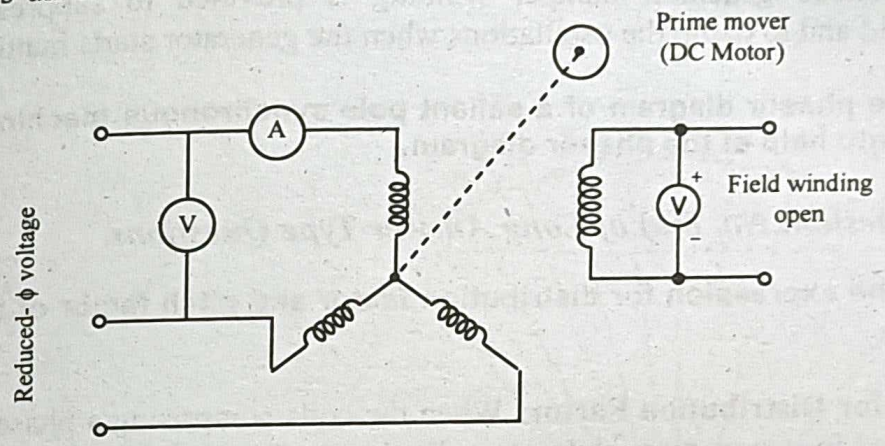

Fig: 1 Slip test connection diagram to determine X_d and X_q

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The ratio $\left(\frac{X_d}{X_q}\right)$ is found out from the slip test. The direct axis synchronous reactance X_d is determined from open and short circuit test as in the case of cylindrical rotor machine. X_q can therefore be calculated from the ratio $\left(\frac{X_d}{X_q}\right)$ through slip test and knowing the value of X_d from O.C. & S.C. tests.

8. With appropriate circuit and connection diagrams, explain the "2 bright and 1 dark" lamp method of synchronizing a 3-phase alternator to the grid or to another existing alternator. Is a '1 bright and 2 dark' lamp method possible? Justify your answer in brief.

[WBUT 2011]

Answer:

1st Part: ***Refer to Question No. 3(b) of Long Answer Type Questions.***

2nd Part: If one bright lamp and 2 dark lamps are used, it will be difficult to ascertain whether the incoming machine is fast or slow because light waves will not travel in counter clockwise direction creating problems of sequence of brightness of the lamp. Further, when paralleling switches closed changes in light will not be very slow and at instant three phases may become dark. As such the method is not justifiable.

9. What is a damper winding and in which machine is it found? Where is it placed within the machine? Briefly explain its working. [WBUT 2011]

Answer:

In salient pole type rotor of synchronous generator, projecting poles made of thick steel laminations are ratted together to the rotor by dovetail joints. The pole faces are usually, provided with slots for **"damper winding"** to avoid hunting (oscillations). The damper windings are nothing but copper bars placed inside the holes present in the rotor face, which are short-circuited. EMF is induced in the bars whenever there is oscillation, which will circulate current in the bars thereby producing torque that opposes the oscillation In a synchronous generator damper winding is provided to suppress the negative sequence field and to damp the oscillations when the generator starts hunting.

10. Draw the phasor diagram of a salient pole synchronous machine and find out the power with help of the phasor diagram. [WBUT 2012]

Answer:

Refer to Question No. 8(a) of Long Answer Type Questions.

11. Derive the expression for distribution factor and pitch factor of a synchronous machine. [WBUT 2012]

Answer:

Expression for Distribution Factor: When the coils comprising a phase of the winding are distributed in two or more slots per pole, the e.m.fs. in the adjacent coils will be out of phase with respect to one another and their resultant will be less than their algebraic sum. The ratio of the vector sum of the e.m.fs induced in all the coils distributed in a number of slots under one pole to the arithmetic sum of the e.m.fs induced (or to be resultant of the e.m.fs induced in all the coils concentrated in one slot under one pole) is known as distribution factor k_d

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

The distribution factor is always less than unity.

Let $n =$ number of slots / pole

$q =$ number of slots/pole/phase

$E_S =$ induced e.m.f. in each coil side

$\beta =$ angular displacement between the slots

$$= \frac{180°}{n}$$

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

E.M.F., induced in each coil side,

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

$$\text{Arithmetic} = q \times 2 \times 0A \sin\frac{\beta}{2}$$

The resultant e.m.f. induced in one polar group of one phase would be the vector sum as represented by the Vector AF as shown in Fig (1).

$\therefore$ The resultant e.m.f., $E_r = AF = 2 \times OA\sin\frac{AOF}{2} = 2 \times OA\sin\left(\frac{q\beta}{2}\right)$

Distribution factor,

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

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

Hence $K_d = \dfrac{\sin\left(\frac{q\beta}{2}\right)}{q\sin\frac{\beta}{2}}$

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

Value of the distribution factor for nth harmonic is: - $K_d = \dfrac{\sin\left(\frac{qn\beta}{2}\right)}{q\sin\left(\frac{n\beta}{2}\right)}$

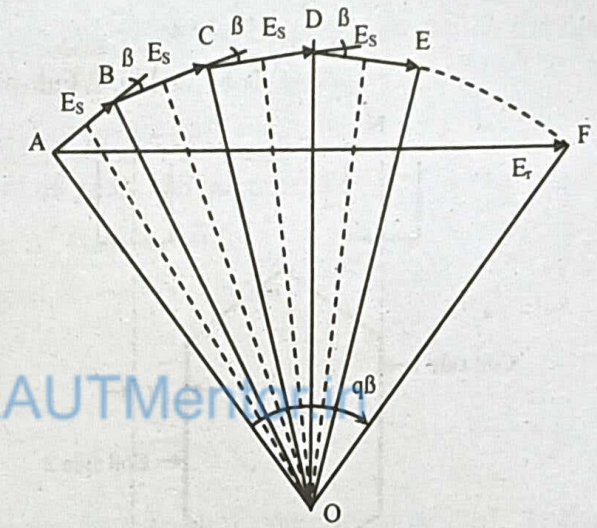
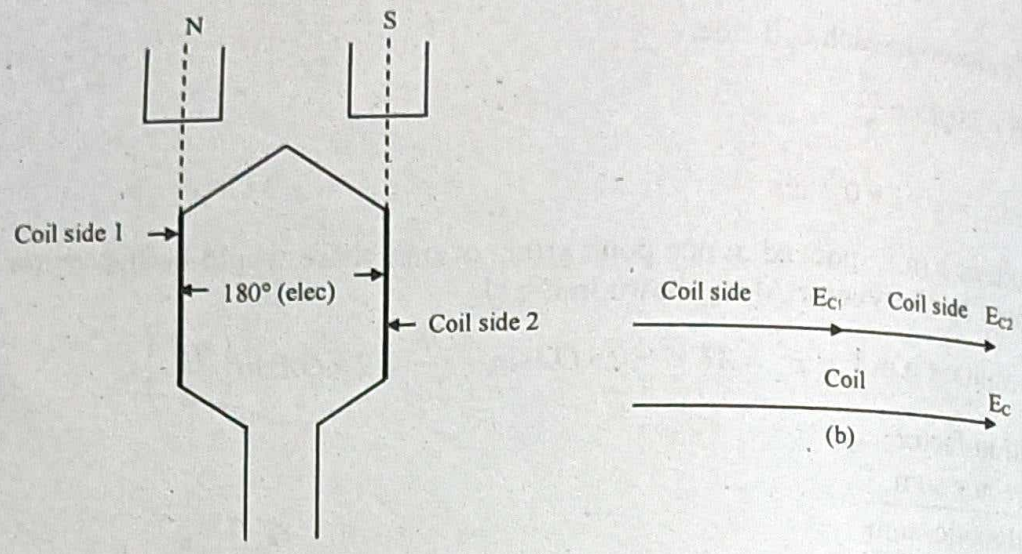


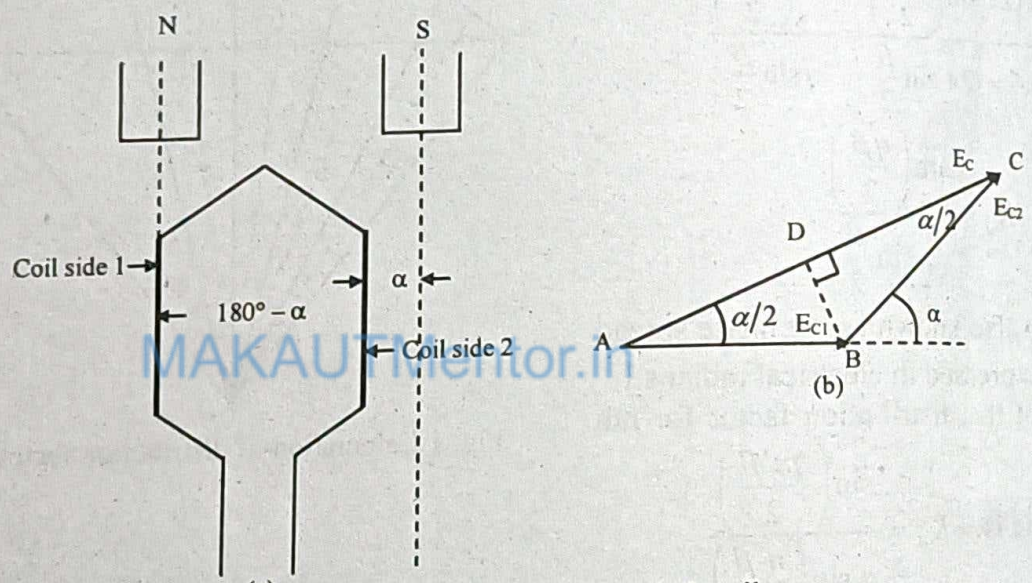
Fig: 1 Calculation of distribution factor

Expression for Pitch factor: The distance between the two sides of a coil is called the coil span or coil pitch. The angular distance between the central line of one pole to the central line of the next pole is called pole pitch. A pole pitch is always 180 electrical degrees regardless of the number of poles on the machine. A coil having a span equal to 180° electrical is called a full-pitch coil as shown in Fig. 2(a).



(a)

Fig: 2 Full-pitch coil



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(a)

Fig: 3 Short-pitch coil

A coil having a span less than 180° electrical is called a short-pitch coil, or fractional-pitch coil. It is also called a chorded coil. A stator winding using fractional-pitch coils is called a chorded winding. If the span of the coils is reduced by an angle α-electrical degrees, the coils span will be $(180° - \alpha)$ electrical degrees as shown in Fig. 3.(a).

In case of a full-pitch coil, the two coil sides span a distance exactly equal to the pole pitch of 180 electrical degrees. As a result, the voltage generated in a full-pitch coil is such that the coil-side voltages are in phase as shown in Fig. 2(b). Let E_{C_1} and E_{C_2} be the voltages generated in the coil sides and E_C the resultant coil voltage. Then

$$E_C = E_{C_1} + E_{C_2}$$

$$|E_{C_1}| = |E_{C_2}| = E_1 \ (say)$$

Since E_{C_1} and E_{C_2} are in phase, the resultant coil voltage E_C is equal to their arithmetic sum.

$$\therefore \quad E_C = E_{C_1} + E_{C_2} = 2E_1$$

If the coil span of a single coil is less than the pole pitch of 180° (elec.), the voltages generated in each coil side are not in phase. The resultant coil voltage E_C is equal to the phasor sum of E_{C_1} and E_{C_2}.

If the coil span is reduced by an angle α electrical degrees, the coil span is $(180° - \alpha)$ electrical degrees. The voltages generated E_{C_1} and E_{C_2} in the two coil sides will be out of phase with respect to each other by an angle α electrical degrees as shown in Fig. 3(b). The phasor sum of E_{C_1} and E_{C_2} is E_C (= AC).

The coil span factor or pitch factor or chording factor is the factor by which the emf per coil is reduced, because of the pitch being less and can be denoted by k_C.

$$k_C \overset{\Delta}{=} \frac{\text{actual voltage generated in the coil}}{\text{voltage generated in the coil of span 180° electrical}}$$

$$= \frac{\text{Phasor sum of the voltags of two coil sides}}{\text{arithmetic sum of the voltages of two coil sides}}$$

$$= \frac{AC}{2AB} = \frac{2AD}{2AB} = \cos\frac{\alpha}{2}$$

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$$\therefore \quad k_C = \cos\frac{\alpha}{2} \qquad \text{.... (1)}$$

The pitch factor given by Eqn. (1) is for the fundamental component of emf. If the flux density distribution contains space harmonics, the pitch factor for the nth harmonic is given by: -

$$k_{Cn} = \cos\frac{n\alpha}{2} \qquad \text{.... (2)}$$

The nth harmonic emf is reduced to zero if the angle α is such that

$$\cos\frac{n\alpha}{2} = 0 \text{ or } \frac{n\alpha}{2} = 90°$$

This enables the windings to be designed such that specified harmonics will not be generated e.g. if $\alpha = 60°$, there can be no third harmonic generation. Thus fractional pitch windings result in a voltage waveform which resembles a sinusoidal to a better degree than would a full pitch winding. It may be noted that if the value of α is not given in question, $k_C = 1$ is to be assumed. For a short pitch coil, $k_C < 1$.

Advantages of short pitching or chording

(1) Shortens the ends of the winding and therefore there is a saving in the conductor material.

(2) Reduces effects of distorting harmonics, and thus the waveform of the generated voltage is improved and making it approach a sine wave.

12. Briefly describe the 'one dark and two bright method' of alternator synchronization. Name one substitute of this method. [WBUT 2013]

Answer:

It is supposed that alternator I is already connected to the bus-bars and alternator 2 is to be synchronized. Set up circuit as shown in Fig. 1. It should be remembered that two lamps L_2 and L_3 are cross-connected with the bus-bars. Keeping the switch S open, observe the brightness of the lamps. Perfect synchronizing occurs when lamp L_1 is dark; while L_2 and L_3 are equally bright. Now bring the prime mover of alternator 2 to the rated speed (and hence, frequency $f = NP/120$) and then vary the field excitation, till the generated emf equals to that of bus-bars. When the speed and emf have been adjusted, the synchronizing switch S of the incoming alternator 2 is closed, when lamp L_1 is dark; while lamps L_2 and L_3 are equally bright.

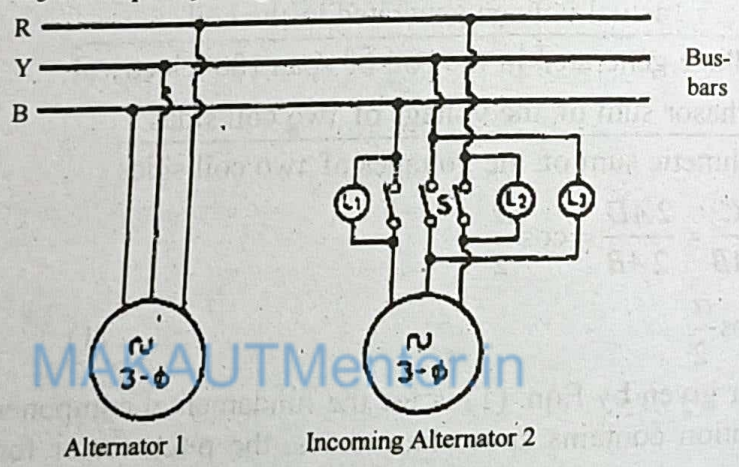

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Fig: 1 Lamp method of synchronizing alternator

If the frequency of the incoming alternator is: (a) higher, then lamps will become dark in the sequence L_1, L_2, L_3, (b) lower, than lamps will become dark in sequence L_1, L_3, L_2. In both cases, the frequency of incoming alternator will have to be adjusted so that the lamp L_1 become dark and lamps L_2 and L_3 become equally bright.

One substitute of the above method is Synchronization by using synchroscope.

13. What types of alternators are used in Thermal power stations and Hydel power stations? Draw the general phasor diagram of a cylindrical rotor alternator showing various mmf, emf, flux, currents, voltage, voltage drops etc. developed in the machine. [WBUT 2014]

Answer:

1st Part:

Thermal power stations → Cylindrical type alternator

Hydel power stations → Salient type alternator

2nd Part:

a) Lagging Power factor $\cos\phi$

In the Fig. (1), the terminal voltage V is taken as reference phasor along 0A such that OA = V. The direction of the armature current I_a lags V by an angle ϕ along OB, where OB = I_a. Phasor AC represents armature resistance drop I_aR_a. CD represents synchronous reactance $I_a X_S$. The total voltage drop in the synchronous impedance is the phasor sum $I_a R_a$ and I_aX_S. It is represented by AD. The phasor OD represents E_a.

The magnitude of E_a can be found from the right angled triangle OGD.

$$\therefore \quad OD^2 = OG^2 + GD^2 = (OF + FG)^2 + (GC + CD)^2$$

$$E_a^2 = (V\cos\phi + I_aR_a)^2 + (V\sin\phi + I_aX_S)^2$$

$$E_a = \sqrt{(V\cos\phi + I_aR_a)^2 + (V\sin\phi + I_aX_S)^2} \quad \text{.... (1)}$$

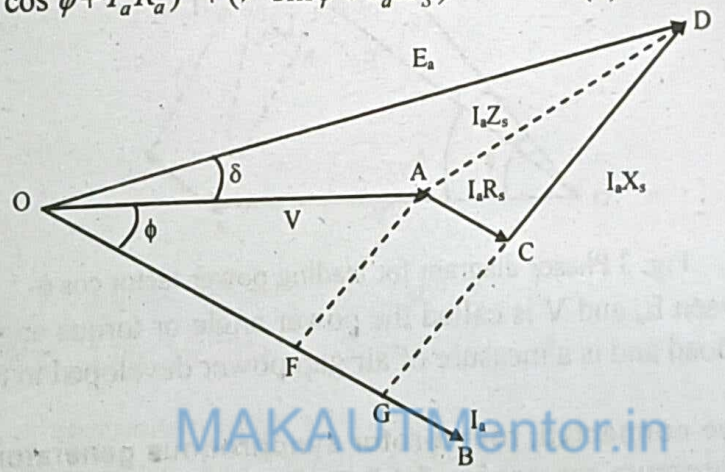

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Fig: 1 Phaser diagram for lagging p.f wsϕ

b) Unity Power factor

From right angled triangle OCD of Fig. (2):

$$(OD)^2 = (OC)^2 + (CD)^2 = (OA+AC)^2 + (CD)^2$$

$$E_a^2 = (V + I_aR_a)^2 + (I_aX_S)^2$$

$$E_a = \sqrt{((V + I_aR_a)^2 + (I_aX_S)^2} \quad \text{.... (2)}$$

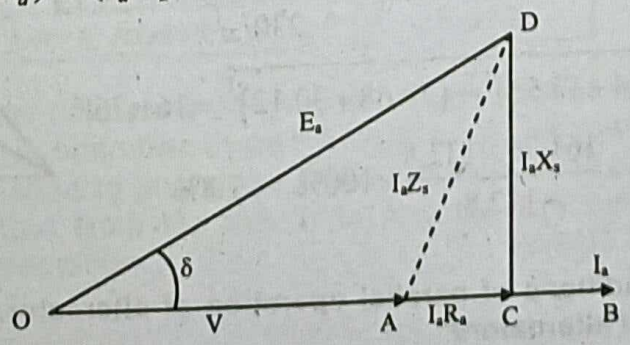

Fig: 2 Phasor diagram for unity power factor

c) Leading Power factor

From the right angled triangle OGO of the Figure below -

$$OD^2 = OG^2 + GD^2 = (OF+FG)^2 + (GC-CD)^2$$

$$E_a^2 = (V\cos\phi + I_aR_a)^2 + (V\sin\phi - I_aX_S)^2$$

$$E_a = \sqrt{(V\cos\phi + I_aR_a)^2 + (V\sin\phi - I_aX_S)^2} \quad \ldots (3)$$

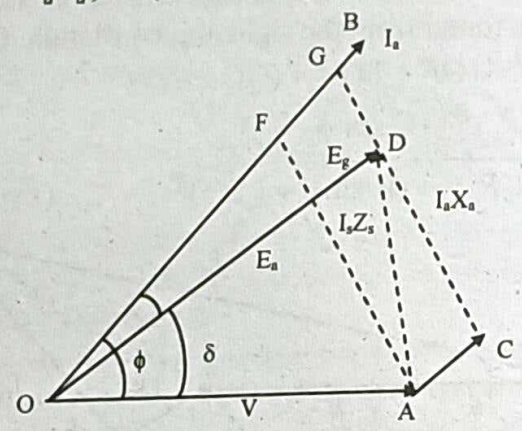

Fig: 3 Phasor diagram for leading power factor cos ϕ

The angle δ between E_a and V is called the power angle or torque angle of the machine, which varies with load and is a measure of air gap power developed in the machine.

14. A 3-phase, wye-connected, round-rotor synchronous generator rated at 10 kVA, 230V has a synchronous reactance of 1.2 Ω per phase and an armature resistance of 0.5 Ω per phase. Calculate the per cent voltage regulation at full-load with 0.8 lagging power factor. [WBUT 2016]

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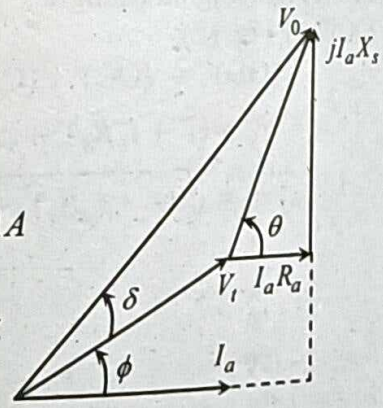
Answer:

The phasor diagram is shown in figure from which



$$V_0 = \sqrt{(V_t\cos\phi + I_aR_a)^2 + (V_t\sin\phi + I_aX_s)^2}$$

Substituting $V_t = \dfrac{230}{\sqrt{3}} = 132.8V \qquad I_a = \dfrac{(10\times10^3)/3}{230/\sqrt{3}} = 25.1A$

We get $V_0 = \sqrt{(106.24+12.55)^2 + (79.68+30.12)^2} = 161.76V$

Then $\dfrac{V_0 - V_t}{V_t}\times100\% = \dfrac{161.76-132.8}{132.8}\times100\% = 21.8\%$

15. Explain the conditions of parallel operation of alternator. What is the need of parallel operation of alternator? [WBUT 2019]

Answer:

1st Part: ***Refer to Question No. 9(b) of Long Answer Type Questions.***

2nd Part:

The need of parallel operation of alternator:

i) It helps in dealing with bigger load demands.

ii) Presence of many generators in the system increases the reliability of the system. The failure of one generator will not cause total black out.

iii) With more than one generator in the system, it becomes easy to remove the faulty generator from the system for the purpose of maintenance.

iv) With many generators operating in parallel, depending on the load condition, it is possible to run only a fraction of them, so that it is operated at near to full load, thus increasing the efficiency of the system.

16. Calculate the distribution factor of fundamental and third harmonics of 3-phase alternator for a stator having 54 slots, 6 poles. [WBUT 2019]

Answer:

$$n = 54/6 = 9$$

$$\beta = 180°/9 = 20°$$

$$m = \frac{54}{6 \times 3} = 3$$

$$k_d = \frac{\sin m3\beta/2}{m\sin 3\beta/2} = \frac{\sin(3\times 3)20°/2}{3\sin(3\times 20°)/2} = \frac{\sin 180°/2}{3\sin 60°/2} = \frac{1}{1.5} = 0.66$$

17. Explain hunting phenomenon of an alternator. [WBUT 2019]

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Answer: ***Refer to Question No. 5 (1st part) of Short Answer Type Questions.***

18. Why the S.C. characteristics of alternator is straight line? [WBUT 2019]

Answer:

The short circuit characteristic of an alternator is a curve plotted between short circuit current and field current while the alternator being driven at the rated speed. The curve usually a straight line passing through the origin because the net excitation is so small that there is no saturation in the magnetic circuit.

Long Answer Type Questions

1. A 20 MVA, 3-phase star connected alternator, with an impedance of 5 ohms and a resistance of 0.5 ohm, is operating in parallel with constant voltage 11kV busbar. If its field current is adjusted to give an excitation voltage of 12 KV, then calculate (i) Maximum power output from the alternator and (ii) Armature current and pf under maximum power condition. [WBUT 2007, 2014, 2016]

Answer:

(i) Alternator terminal voltage per phase, $V_t = \frac{11,000}{\sqrt{3}} = 6350\text{ V}$

Alternator excitation voltage per phase $E_f = \frac{12,000}{\sqrt{3}} = 6930\text{ V}$

The equation for maximum power output from the alternator can be written as:-

$$P_{op(max)} = \frac{E_f V_t}{Z_s} - \frac{V_t}{Z_s^2} R_a = \frac{(6930)(6350)}{5} - \frac{(6350)^2}{(5)^2} \times \frac{1}{2}$$

$$= \frac{6350}{5}[6930 - 6350]$$

$$= 8 \text{ MW per phase} = 24 \text{ MW for 3-phases}$$

(ii) $\cos\theta_z = \frac{r_a}{Z_s} = \frac{0.5}{5} = 0.1$

Again, $I_a Z_s = \sqrt{E_{f2} + V_t^2 - 2E_t V_t \cos\theta_z}$

$$= \sqrt{(6930)^2 + (6350)^2 - 2(6930)(6350)(0.10)} = 8920$$

$\therefore \quad I_a = \frac{8920}{5} = 1784\text{ A.}$

The power-factor under maximum power condition is expressed as:

$$\cos\theta = \frac{E_f Z_s - V_1 r_a}{I_a Z_s^2} = \frac{6930 \times 5 - 6350 \times \frac{1}{2}}{1784(5)^2} = 0.706 \text{ leading.}$$

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2. Explain two reaction field theory for a salient pole synchronous machine. Using this theory, draw the phasor diagram for lagging current for (i) salient pole generator, (ii) salient pole motor. **[WBUT 2008, 2015]**

Answer:

Two reaction theory proposes to resolve the given armature mmfs into two mutually perpendicular components, one located along the axis of the rotor salient pole, called direct-axis (or d-axis) component and the other located perpendicular to the axis of rotor salient pole which is known as the quadrature axis (or q axis) component.

The d-axis component of the armature mmf F_a is denoted by F_d which is either magnetizing or demagnetizing and q axis component F_q which results in a cross-magnetizing effect.

If ψ is the angle between the armature current I_a and the excitation voltage E_f and F_a is the amplitude of the armature mmf then

$$F_d = F_a \sin\psi \quad ; \quad F_q = F_a \cos\psi$$

If ϕ_d is the direct axis flux and ϕ_q is the quadrature axis flux, then assuming reluctance of direct axis flux path, it may be written as:

$$\phi_d = \frac{F_d}{R_d} \text{ and } \phi_q = \frac{F_q}{R_q}$$

It may be noted that:

i) As $R_d < R_q$, the direct axis component of mmf F_d produces more flux than the Quadrature axis component of mmf F_q.

ii) The direct and quadrature axis stator fluxes produce voltages in the stator winding by armature reaction.

The complete phasor diagram of a salient-pole synchronous generator based on two axis theory is shown in Fig. (1).

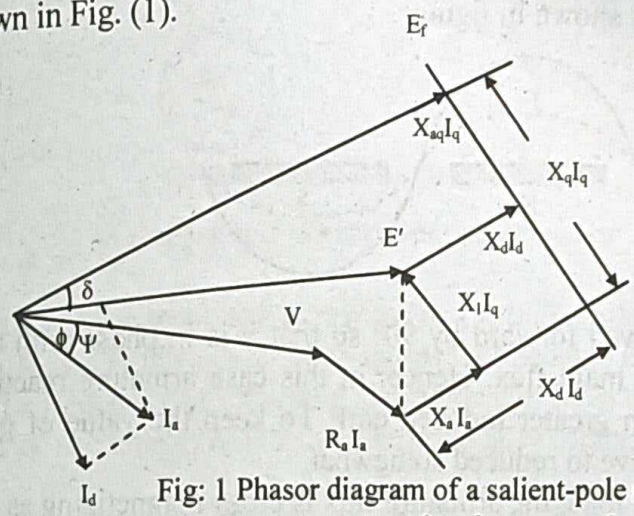

Fig: 1 Phasor diagram of a salient-pole synchronous generator at lagging power factor

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The simplified phasor diagram is shown in Fig. 2.

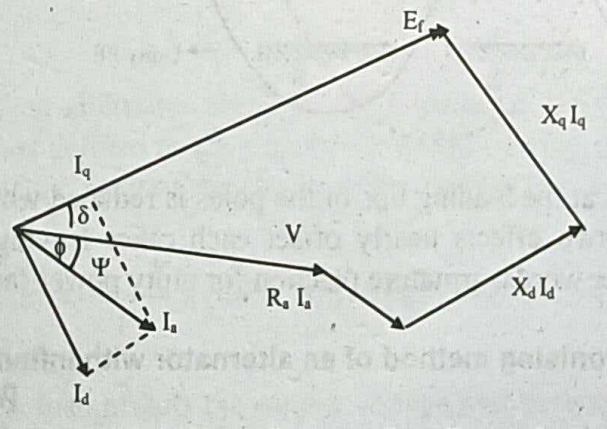


Fig: 2 Simplified phasor diagram of a salient pole synchronous generator at lagging power factor

In the phasor diagram of Fig. 2 the angle $\Psi = \phi + \delta$, is not known for given values of V, I_a and ϕ. The components I_d and I_q of the armature current are usually not given. These component current depend upon δ, the torque angle and from the phasor diagram, $|E_f| = V\cos\delta + R_a I_q + X_d I_d$ since $\psi = \delta + \phi$ and $\delta = \psi - \phi$. ϕ is negative for leading power factor since ϕ is taken positive for lagging p.f.

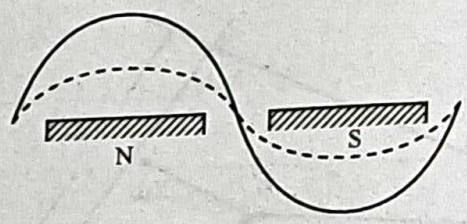
3. a) Describe the armature reaction of an alternator for zero *p.f.* lagging, zero *p.f.* leading and unity *p.f.* load. **[WBUT 2009, 2012]**

Answer:

The armature reaction of an alternator is the magneto motive force produced by the armature currents in the armature conductors.

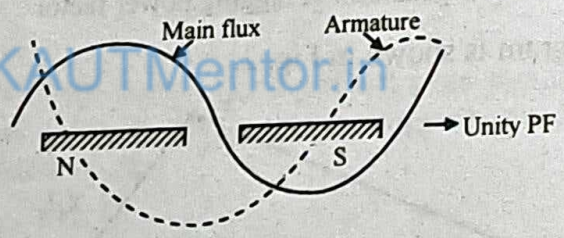
In case of p.f. lagging, a mmf is set up by the current in the armature conductors which opposes the mmf of the main field and causes a decrease in the main flux. This is inturn, results in decrease in the induced voltage. The lower the value of lagging p.f., the greater will be the armature mmf which will oppose and weaker the field.

In case of zero p.f. leading as shown in figure:



Armature flux wave has moved forward by 90° so that it is in phase with the main flux wave. This results in added main flux. Hence, in this case armature reaction is wholly magnetising which results in greater induced emf. To keep the value of generated emf same, field excitation will have to reduced somewhat.

In case of unity power factor load, the armature flux is cross-magnetizing as shown.



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The result is that the flux at the leading tips of the poles is reduced while it is increased at the trailing tips. These two effects nearly offset each other leaving the average field strength constant. In other words, armature reaction for unity power factor is distortional.

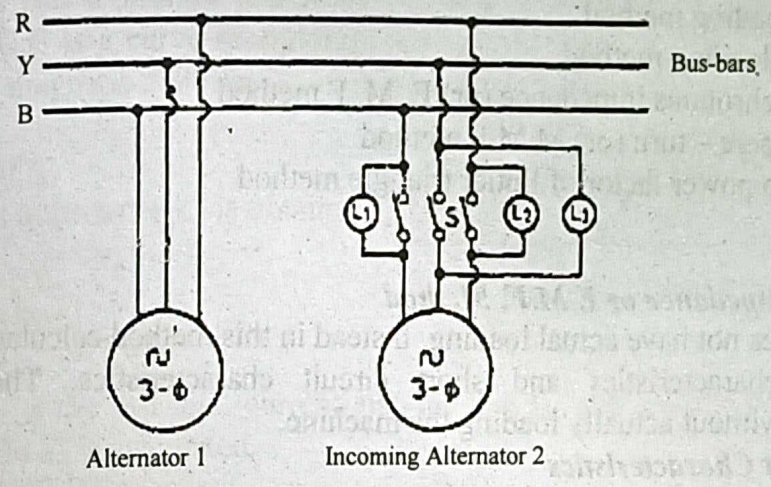
b) Describe any synchronising method of an alternator with infinite bus. **[WBUT 2009, 2017]**

Answer:

Lamp method of synchronizing:

It is supposed that alternator 1 is already connected to the bus-bars and alternator 2 is to be synchronized. Set up circuit as shown in the figure below. It should be remembered that two lamps L_2 and L_3 are cross-connected with the bus-bars. Keeping the switch S open, observe the brightness of the lamps. Perfect synchronizing occurs when lamp L_1 is dark; while L_2 and L_3 are equally bright. Now bring the prime mover of alternator 2 to the rated speed (and frequency $f = NP/120$) and then vary the field excitation, till the generated emf equals to that of bus-bars. When the speed and emf have been adjusted, the

synchronizing switch S of the incoming alternator 2 is closed, when lamp L_1 is dark; while lamps L_2 and L_3 are equally bright.



Lamp method of synchronizing alternator

Note:
If the frequency of the incoming alternator is: (a) higher, then lamps will become dark in the sequence L_1, L_2, L_3, (b) lower, than lamps will become dark in sequence L_1, L_3, L_2. In both cases, the frequency of incoming alternator will have to be adjusted so that the lamp L_1 become dark and lamps L_2 and L_3 become equally bright.

4. What do you mean by regulation of an alternator? Describe the Synchronous Impedance method of determination regulation of an alternator at UPF load. Why is it called a pessimistic method? [WBUT 2010, 2017]

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Answer:

1st Part:

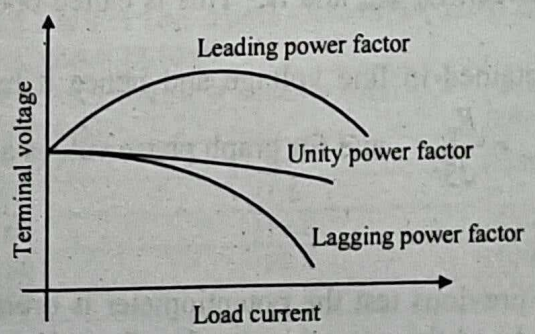
Whenever load of an alternator changes, the magnitude of the output voltage changes. Voltage regulation is defined as the percentage change in the output voltage.

It is also defined as the ratio of the rise in voltage when full load is removed to the rated terminal voltage.

$$\%\text{regulation} = \frac{E_0 - V}{V} \times 100\% \quad \text{where } E_0 \text{ is the no load emf}$$

V is the terminal voltage.

Power factor of the load affects the output voltage and the variation of the load voltage with respect to load current is shown below.



Determination of voltage regulation

There are many methods of finding voltage regulation. They are:

1. Direct loading method
2. Indirect loading method
   (a) Synchronous impedance (or) E. M. F method
   (b) Ampere – turn (or) M.M.F method
   (c) Zero power factor of Potier triangle method

2nd Part:

Synchronous Impedance or E.M.F. Method

This method does not have actual loading. Instead in this method calculation is done from open circuit characteristics and short circuit characteristics. The regulation is predetermined without actually loading the machine.

1. Open Circuit Characteristics

In the Fig. (1) TPST switch is kept opened and the motor is made to run at the rated speed by closing DPST and varying rheostat R_1.

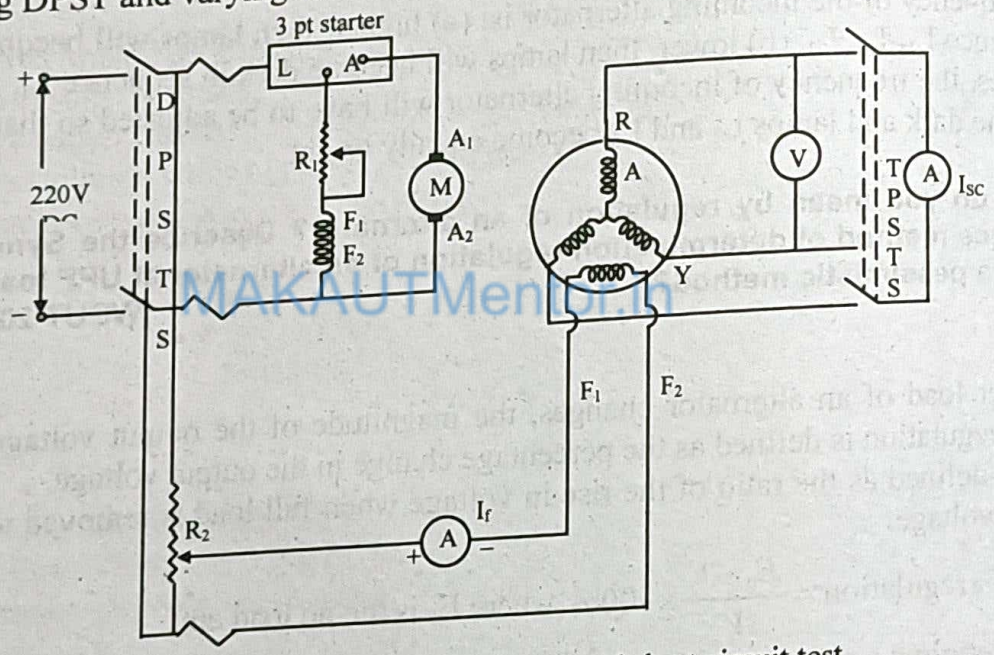


Fig: 1 Circuit for open circuit test and short circuit test

Now the potentiometer R_2 is varied and for various values of I_F, E_0 is noted and tabulated. A graph is plotted between $E_{0\ phase}$ and I_F. This is called open circuit characteristic (i.e.) O.C.C.

It is noted that E_0 obtained in line voltage and hence it has to be converted to phase voltage (i.e.) $E_{0\,phase} = \frac{E_0}{\sqrt{3}}$ and for graph phase values are considered.

2. Short Circuit Test

After completing the previous test the potentiometer is brought to original position. The TPST switch is closed and the potentiometer is adjusted to obtain the full load armature

current (I_{SC}). The corresponding I_F is noted. A graph is plotted between I_F and I_{SC}. This is called as Short circuit Characteristic (S.C.C.). This is just a straight line from origin, while O.C.C is a curve resembling B – H curve of a magnetic material.

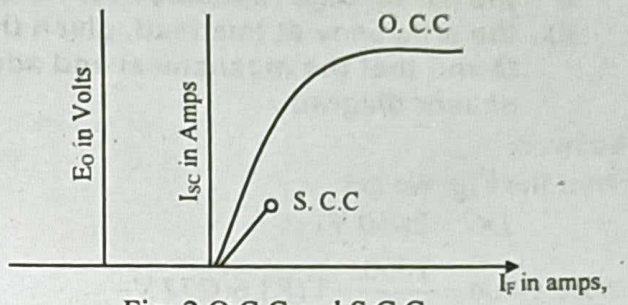


Fig: 2 O.C.C and S.C.C

3. *Calculation of X_s*

The synchronous impedance Z_S is obtained as follows:

$$Z_S = \frac{(E_0)_{phase}}{I_{SC}}\Bigg|_{\text{for same } I_f}$$

For example: I_{SC} is the full load current and for that I_{SC} the corresponding E_0 is taken from the graph and Z_s is calculated.

but $Z_s = \sqrt{R_a^2 + X_S^2}$

$$X_S = \sqrt{Z_S^2 - R_a^2}$$

where R_a is the armature resistance of the alternator found using a multimeter.

Voltage regulation

$$\% \text{ Regulation} = \frac{E_{0\,\text{Phase}} - V_{L\,\text{Phase}}}{V_{L\,\text{Phase}}} \times 100$$

where $E_{0\,\text{Phase}} = \sqrt{(V_{\text{Phase}}\cos\phi + I_a R_a)^2 + (V_{\text{Phase}}\sin\phi \pm I_a X_s)^2}$

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where V_{Phase} is the rated phase voltage

I_a the current considered.

$\cos\phi$ – Power factor of load.

+ sign for lagging pf and negative for leading pf.

3rd Part:

This method is called pessimistic method, since Z_s calculation is not accurate and so % Regulation calculated is always above the actual value.

The regulation can be predetermined for any load current I_a and power factor.

5. a) A 1.0 MVA, 11 kV, 3-phase, *Y*-connected alternator has an effective resistance of 2Ω per phase. The characteristics on open-circuit and with full load current at zero power factor and core losses (on open current at zero power factor and core losses (on open circuit) are given below:

Field current (A)	*Open ckt. Voltage, V (line value)*	*Core loss, kW*	*Saturation curve, zero p.f., V*
40	—	—	0
50	7000	7.5	—
110	12500	16.6	8500
140	13750	22.4	10500
180	15000	33.5	12400

Deduce by the zero power-factor method **[WBUT 2011]**

i) the percentage regulation for full load at a p.f. of 0.8 lag and

ii) the efficiency at this load, given that the field circuit has a resistance of 0.5 Ω and that the mechanical and additional losses add up to 10 kW. Draw the phasor diagram.

Answer:

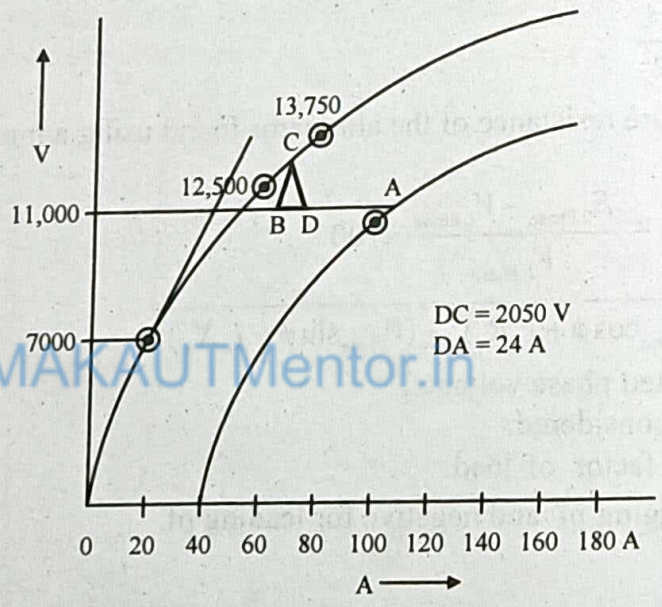
From the Fig. we get

$$DC = 2050 \text{ V}$$

$$\text{Phase value} = \frac{2050}{\sqrt{3}} = 1183.60277 \text{ V}$$

$$DA = 24 \text{ A}$$

$$\text{Full load current} = \frac{1000}{11 \times \sqrt{3}} = 52.4879 \text{ A}$$



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With I as reference

$$V = \frac{11,000}{\sqrt{3}}(0.8 + j0.6) = 5080.831 + j3810.623$$

$$RI = 2 \times 52.4879 = 104.9758 \simeq 105 \text{ V}$$

Reactance drop $= 1183.602$ V [from Fig.]

The phase value

$$= 5080.831 + j3810.623 + 105 + j1183.602 = 56185.831 + j4994.602$$

$$= \sqrt{5185.831^2 + j4994.602^2} \tan^{-1} \frac{4994.602}{5185.831} = 7199.923\angle 44°$$

Line value $= 7199.923\sqrt{3} \simeq 12500$ V

This requires an excitation pf 110A (from o.c.c.)

$$DA = 24 \text{ A}$$

The excitation required on load is $= 110\angle 44° + j24 = 129\angle 53°$

This will give 13800 V (from o.c.c.)

$$\text{The regulation} = \frac{13,800 - 11,000}{11,000} \times 100 = 25.5\%$$

Core loss at 129 A = 20 kW (approximate)

$$\text{Field loss} = 0.5 \times 129^2 \times 10^{-3} = 8.3 \text{ kW}$$

$$\text{Stator } I^2R \text{ loss} = 3 \times 2 \times 52.5^2 \times 10^{-3} = 16.5 \text{ kW}$$

$$\text{Other losses} = 10 \text{ kW}$$

$$\text{Total} = 8.3 + 16.5 + 10 + 20 = 54.8 \text{ kW}$$

$$\text{Output} = 1000 \times 0.8 = 840 \text{ kW}$$

$$\text{Input} = 854.8 \text{ kW}$$

$$\eta = \frac{800}{854.8} \times 100 = 93.59\%$$

b) Define regulation of an alternator. Name the different methods of determination of regulation of an alternator. Which of these methods is known 'optimistic' and why? Briefly describe the method only. [WBUT 2011]

Answer:

1st Part:

Whenever load of an alternator changes, the magnitude of the output voltage changes. Voltage regulation is defined as the percentage change in the output voltage.

It is also defined as the ratio of the rise in voltage when full load is removed to the rated terminal voltage.

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$$\%\text{regulation} = \frac{E_0 - V}{V} \times 100\%$$

where E_0 is the no load emf

V is the terminal voltage.

2nd Part:

There are many methods of finding voltage regulation. They are:

1. Direct loading method
2. Indirect loading method
   (a) Synchronous impedance (or) E. M. F method
   (b) Ampere – turn (or) M.M.F method
   (c) Zero power factor of Potier triangle method

3rd Part:

AT method is known as 'optimistic method.

AT method is called optimistic method because the value of voltage regulation obtained in this method is less than the actual value, therefore, the method is called optimistic method.

4th Part:

MMF method/Ampere turn method

In this method, the armature leakage reactance drop is taken as additional armature reaction drop. This method also uses the open circuit and short circuit characteristic. This field current or field AT required to produce full load voltage is assumed to be consisting of 2 parts:

1. First part is the field current (I_{f_1}) or field AT required to produce the full load voltage under no load condition. This is obtained from open circuit characteristics.
2. Second part is the field current (I_{f_2}) or field AT which balances the armature reaction effect (demagnetizing effect) which is the field current required under short circuit condition to produce the full load current. Under short-circuited condition, the reactance is very small (because of low voltage), since armature resistance is also very small, the impedance drop can be neglected.

If I_{f_1} and I_{f_2} are represented by the vectors, then the net field current required to produce full load voltage, when the alternator is supplying full load current at zero p.f. lagging as shown in which the two currents aid each other. This is because, at zero p.f. lagging the armature reaction is totally demagnetizing.

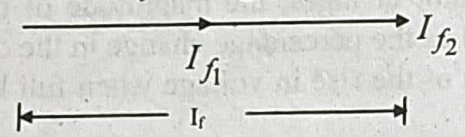

Fig: 1 Zero p.f. lagging

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When the alternator is supplying full load current at zero p.f. leading, the two currents oppose each other, because under this condition, the armature reaction is wholly magnetizing.

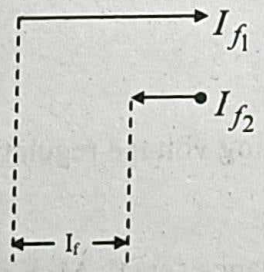

Fig: 2 Zero p.f. leading

When the alternator supplies full load current at unity pf, then the armature reaction is cross magnetizing, therefore the two currents are assumed to be perpendicular to each other. The net field current I_f is vector sum of I_{f_1} and I_{f_2}.

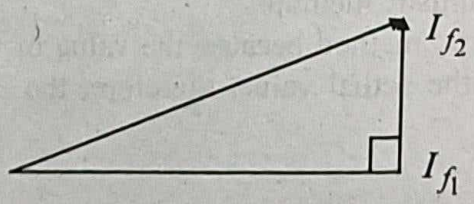

Fig: 3 unity P.f

In case when the alternator supplying full load current at lagging power factor $\cos\phi$, the total field current is shown in Fig. 4 and 5. The field current I_{f_2} is drawn at (90 +ϕ) from tip of I_{f_1}. When pf is leading, the net field current is shown here the I_{f_2} is drawn at an angle of (90 - ϕ) from tip of I_{f_1}.

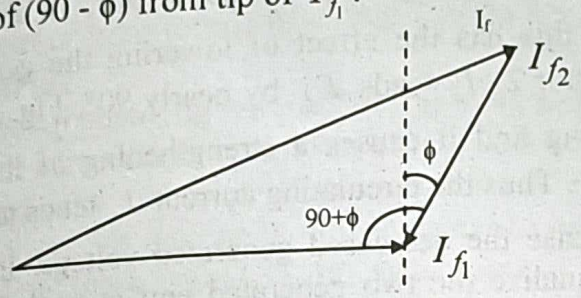

Fig: 4 Lagging p.f.

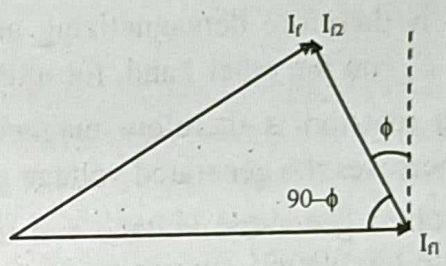

Fig: 5 Leading p.f.

Procedure to obtain the voltage regulation by mmf method

1. Open circuit characteristics (O.C.C) is drawn.
2. Short circuit characteristics (S.C.C) is drawn.
3. Field current I_{f_1} required to produce the full load voltage (V) or more exactly ($V_{Lph} + I_aR_a \cos\phi$) is found from O.C.C.
4. Field current I_{f_2} required to produce the full load current is found from S.C.C.
5. I_{f2} is drawn at (90 ± ϕ) at the tip of I_{f_1} + for lagging, (–) for leading.
6. The net field current I_f is found by adding I_{f_1} and I_{f_2} vectorially.
7. The open circuit voltage (E_0) corresponding to I_f is found from O.C.C.
8. The % regulation is % regulation $= \dfrac{E_{0ph} - V_{Lph}}{V_{Lph}} \times 100\%$

This method gives the regulation, which is less compared to that obtained in Emf method. Hence this method is called optimistic method.

6. Describe the effect of change of excitation and mechanical input of an alternator. [WBUT 2012, 2015]

Answer:

The effect of change of excitation of an alternator can be described as under: –

1. For parallel running alternators, it will be seen that a change in excitation effects only the operating power factor of the alternator and has almost no effect on the active power sharing of the alternators. In fact a change in excitation changes the armature current and therefore the armature copper loss. This change in armature ohmic loss will alter active power output by a very small amount only.
2. Under no load operation, here again, their excitation emf say E_{f_1} and E_{f_2} are equal so that there is no current in their local path. Now if excitation of alternator 1 is increased,

magnitude of E_{f_1} becomes more than the magnitude of E_{f_2} and consequently, a resultant voltage $\overline{E}_c = \overline{E}_{f_1} - \overline{E}_{f_2}$ appears in the local circuit as shown in Fig. 1.(a). Since synchronous impedances in the local circuit are mainly reactive local circulating current I_c lags E_c by nearly 90°. For alternator 1, I_c lags E_{f_2} by about 90°, its armature reaction is therefore demagnetizing and this has the effect of lowering the generated voltage E_{f_1} on the other hand, for alternator 2, I_c leads E_{f_2} by nearly 90°, Fig. 1(a) its armature reaction is therefore magnetizing and it causes a strengthening of its field, which increases the generated voltage E_{f_2}. Thus the circulating current I_c tends to lower the increased generated voltage and to raise the decreased generated voltage. In other words the circulating current tends to equalize the two generated emf at no load. The power angle δ, however, remains zero.

With an increase in excitation of alternator 1, the terminal voltage changes to a new value as follows.

From Fig. 1(a), $\overline{V}_t = \overline{E}_{f_1} - \overline{I}_c\overline{Z}_{\theta_1}$ ~and $V_t = \overline{E}_{f_2} + \overline{I}_c\overline{Z}_{\theta_2}$

For $Z_{\theta_1} = Z_{\theta_2}$

$$V_t = \frac{\overline{E}_{f_1} + \overline{E}_{f_2}}{2} \quad \text{.... (1)}$$

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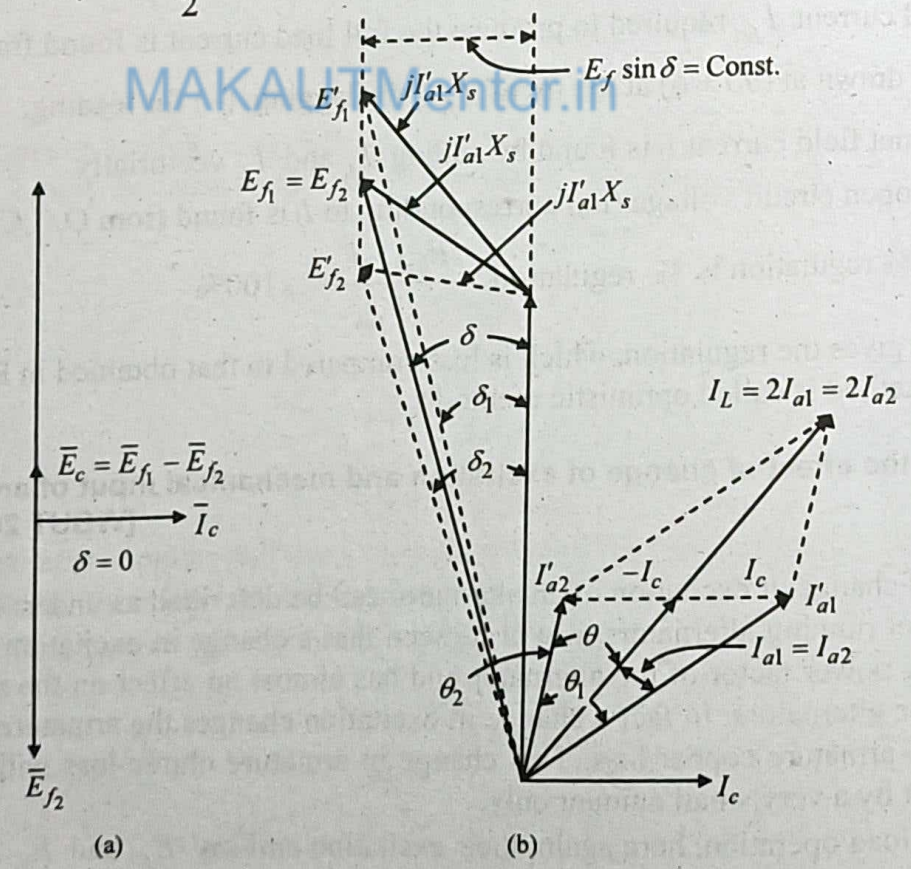

Fig: 1 Effect of changing the field excitation of two parallel-connected alternators, (a) No load operation and (b) On-load operation

3. Under on load operation, their operating power factor is $\cos\theta$, terminal voltage is V_t and the phasor diagrams of Fig 1(b) illustrates this.
An increase in the excitation of alternator say I, increases its excitation voltage E_{f_1} to a new value E'_{f_1} and this has the effect raising the terminal voltage V_t as given by equation (1). However their terminal voltage can be kept constant by decreasing the excitation of alternator (2).
The effect of changing the mechanical input in a cylindrical rotor alternators operating in parallel is considered for simplicity both under no load and under loaded conditions.
Under no load condition if the mechanical input vis-à-vis the driving torque of the alternator say I is increased, the increment in torque tends to accelerate the rotor and as a result of it, there would be no synchronizing power tending to speed up the slower machine. It indicates that the reactance is useful for auto synchronizing action but is bad for voltage regulation.
When working under loaded conditions assuming to be such that each alternator is sharing load equally the effect of increasing mechanical input of an alternator is to make it to take an increased share of load. The other alternator operating in parallel with it is relieved of its load by a corresponding amount.

7. a) How will you synchronize two alternators to work in parallel in the laboratory with the help of three lamps? Draw a neat circuit diagram and describe the procedure.
b) What is voltage regulation? Explain the zero power factor lagging method for calculating the voltage regulation of an alternator.
c) Why E.M.F method is called Pessimistic Method and M.M.F method is called Optimistic Method for calculating the voltage regulation of an alternator?
[WBUT 2012]

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Answer:
a) ***Refer to Question No. 3(b) of Long Answer Type Questions.***

b) Voltage Regulation:
Refer to Question No. 4 of Long answer Type Questions.

Zero Power Factor Method / Potier Method
This method gives more accurate results because it is based on the separation of armature leakage reactance drop and the armature reaction effects. It makes use of the first two methods to some extent. The experimental data required is i) no-load curve and ii) full load zero power factor curve (not the short circuit characteristics).
The reduction in voltage due to armature reaction is found from (ii) and voltage drop due to armature leakage reactance (also called potier reactance) is found from both. Combining these two E_0 can be calculated.

Assumptions to be made

In the potier method, the following assumptions are made:

1. The armature resistance R_a is neglected.
2. The O.C.C. taken on no load accurately represents the relation between mmf and voltage on load.
3. The leakage reactance voltage I_aX_{aL} is independent of excitation.
4. The armature reaction mmf is constant.

Construction of Potier Triangle

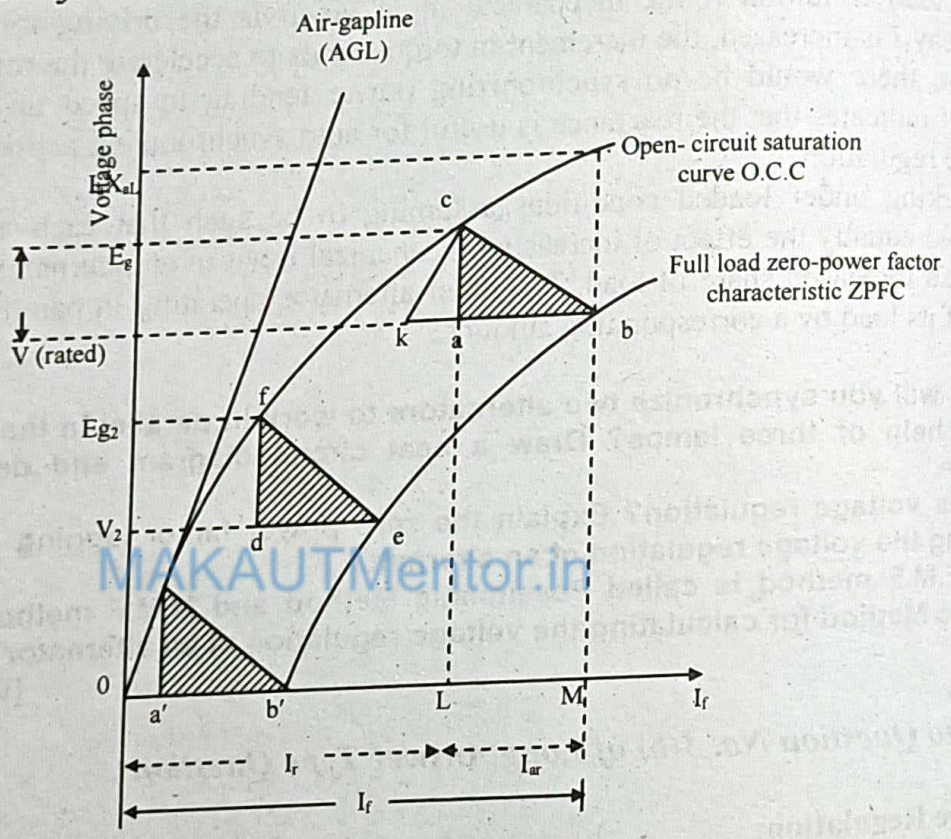

Fig: 1 potier triangle

Fig. (1) represents the potier triangle. Here the ZPFC (Zero power factor characteristic) is used in conjunction with the O.C.C. to find the armature reaction mmf and the approximate leakage reactance voltage of the machine for which the construction method may be followed as under:

1) a point 'b' on ZPFC is taken preferably well upon the knee of the curve.
2) bk is drawn in such a manner that it is equal to b' 0 (b' is the point for zero voltage, full load current) i.e. $0b'$ is the short circuit excitation which is represented here by F_{SC}.
3) Through k, k c is drawn parallel to $0c'$ to meet O.C.C. in c.
4) Perpendicular ca is dropped on to bk.

5) Then, to scale, ca is the leakage reactance drop I_aX_{aL} and ab is the armature reaction mmf F_{aR} or field current I_{faR} equivalent to armature reaction mmf at rated current.

The effect of field leakage flux in combination with the armature leakage flux gives rise to an equivalent leakage reactance X_{pr}, known as the Potier reactance, which is greater than the armature leakage reactance.

Also, Potier reactance

$$X_p = \frac{\text{Voltage drop per phase}(ac)}{(ZPF \text{ rated armature current per phase } I_a)}$$

In case of cylindrical rotor machine, X_p is approximately equal to leakage reactance X_{aL} and for salient pole machine, X_p may be as large as 3 time X_{aL}.

Procedural steps for calculating Voltage Regulation

The phasor diagram for lagging p.f. is shown in Fig. (2) below:

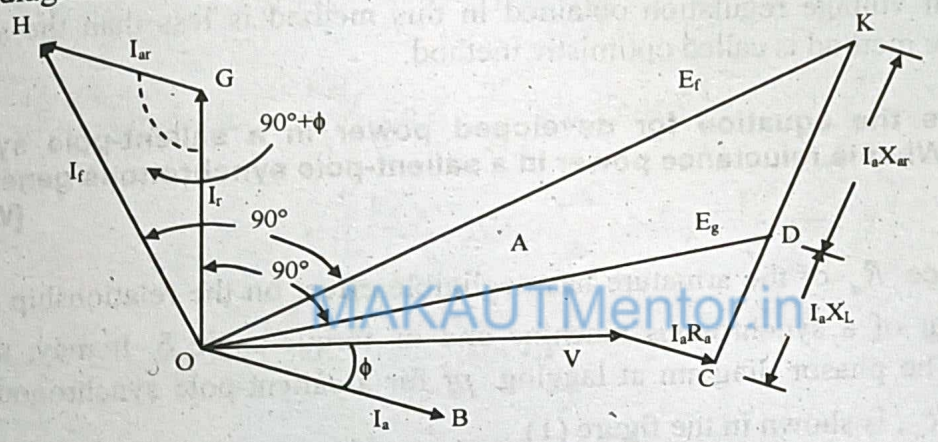

Fig: 2

In the phasor diagram:

OA = V = terminal phase voltage at full load and is taken as reference phasor and drawn horizontally.

OB = I_a = full load current lagging V by an angle ϕ , cos ϕ is the power factor of the load.

AC = Voltage drop I_aR_a in the armature resistance (if R_a is given). It is drawn Parallel to I_a(OB).

CD = I_aX_{aL} = Leakage reactance voltage drop which is perpendicular to AC.

OD is joined, and it represents the generated emf Eg.

Field excitation current I_r corresponding to this generated emf Eg is found out from O.C.C. OG is drawn and it is equal to I_r, perpendicular to OD.

GH is drawn parallel to load current OB (= I_a) to represent excitation (field current) equivalent to full load armature current I_{ar} and then OH will give total field current I_f .

Now if the load is thrown off, the terminal voltage will be equal to generate emf corresponding to field excitation OH.

E_f (= OK) corresponding to field excitation OH from O.C.C. is determined and the phasor OK will lag phasor OH by 90°. DK represents the voltage drop due to armature reaction.

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This will enable to obtain voltage regulation from the relation:

$$\text{Percentage voltage regulation} = \frac{E_f - V}{V} \times 100\%$$

c) The methods for finding out the voltage regulation of an alternator are i) Synchronous impedance (or emf) method ii) Ampere-turn (or mmf) method and iii) Potier (or Zero power factor) method.

Out of these methods, synchronous impedance or emf method gives pessimistic value. This is due to the fact that in synchronous impedance method of determination of voltage regulation synchronous reactance is assumed to be constant will actually it varies with the saturation (at low saturation its value is higher because the effect of armature reaction is larger than that at high saturation). Now under short circuit conditions, saturation is very low and, therefore, the value of synchronous impedance measured is higher than that in actual operating conditions and the regulation determined is higher than actual one. The value of voltage regulation obtained in this method is less than the actual value, therefore, the method is called optimistic method.

8. a) Derive the equation for developed power in a salient-pole synchronous generator. What is reluctance power in a salient-pole synchronous generator? **[WBUT 2012]**

Answer:

The resistance R_a of the armature has negligible effect on the relationship between the power output of a synchronous machine and its torque-angle δ. It may, therefore, be neglected. The phasor diagram at lagging *pf* for a salient-pole synchronous generator, neglecting R_a, is shown in the figure (1).

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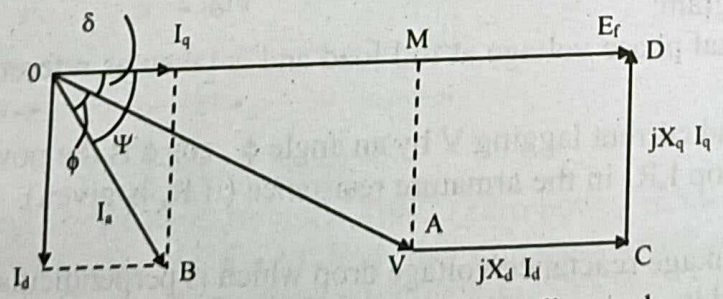

Fig: 1 Phasor diagram at lagging pf of a salient-pole generator, neglecting R_a

From the phasor diagram of the figure (1).

The complex power output per phase

$$S_{1\phi} = V\, I_a \qquad \text{.... (1)}$$

Taking E_f as the reference phasor.

$$\therefore \quad V = V\angle -\delta = V\cos\delta - jV\sin\delta$$

$$I_a = I_q - jI_d$$

$$I_a^* = I_q + jI_d$$

$$\therefore \quad S_{1\phi} = VI_a^* = (V\cos\delta - jV\sin\delta)(I_q + jI_d) \qquad \text{.... (2)}$$

From the phasor diagram of figure (1)

$$X_q I_q = CD = AM = V\sin\delta$$

$$\therefore \quad I_q = \frac{V\sin\delta}{X_q} \qquad \text{.... (3)}$$

$$X_d I_d = AC = MD = OD - OM = E_f - V\cos\delta$$

$$\therefore \quad I_d = \frac{E_f - V\cos\delta}{X_d} \qquad \text{.... (4)}$$

Substituting the values of I_q and I_d in Eqn. (2) we get

$$S_{1\phi} = (V\cos\delta - jV\sin\delta)\left(\frac{V\sin\delta}{X_q} + j\frac{E_f - V\cos\delta}{X_d}\right)$$

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

$$+ j\left(\frac{VE_f}{X_d}\cos\delta - \frac{V^2}{X_d}\cos^2\delta - \frac{V^2}{X_q}\sin^2\delta\right)$$

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

$$+ j\left[\frac{VE_f}{X_d}\cos\delta - \frac{V^2}{2X_d}(1+\cos 2\delta) - \frac{V^2}{2X_q}(1-\cos 2\delta)\right]$$

$$= \left[\frac{VE_f}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta\right] + j\left[\frac{VE_f}{X_d}\cos\delta - \frac{V^2}{2X_dX_q}\left(X_d + X_q\right) - \left(X_d - X_q\right)\cos 2\delta\right]$$

Also, $S_{1\phi} = P_{1\phi} + jQ_{1\phi}$ .... (5)

Therefore the real power per phase in watts is

$$P_{1\phi} = \frac{VE_f}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta \qquad \text{.... (6)}$$

Total real power in watts

$$P_{3\phi} = 3P_{1\phi} = \frac{3VE_f}{X_d}\sin\delta + \frac{3V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta \qquad \text{.... (7)}$$

The reactive power per phase in vars is

$$Q_{1\phi} = \frac{V E_f}{X_d}\cos\delta - \frac{V^2}{2X_d X_q}\left[(X_d + X_q) - (X_d - X_q)\cos 2\delta\right]$$

Total reactive power in vars

$$Q_{3\phi} = 3Q_{1\phi} = \frac{3VE_f}{X_d}\cos\delta - \frac{3V^2}{2X_d X_q}\left[(X_d + X_q) - (X_d - X_q)\cos 2\delta\right] \quad \text{.... (8)}$$

The first term of Eqn. (7) is the same as that obtained for the cylindrical-rotor machine. The second term of Eqn. (7) depends on the saliency defined by the quantity $\left[\frac{1}{X_q} - \frac{1}{X_d}\right]$. The saliency disappears when $X_d = X_q$ (that is, for a cylindrical rotor). Also, this term exists even when there is no field current ($E_f = 0$).

Eqns. (7) and (8) are applicable to both salient-pole synchronous generator and synchronous motor. The torque angle δ is positive for the generator and negative for the motor. P – Q versus δ curves for a salient-pole machine are shown in Fig. (2.)

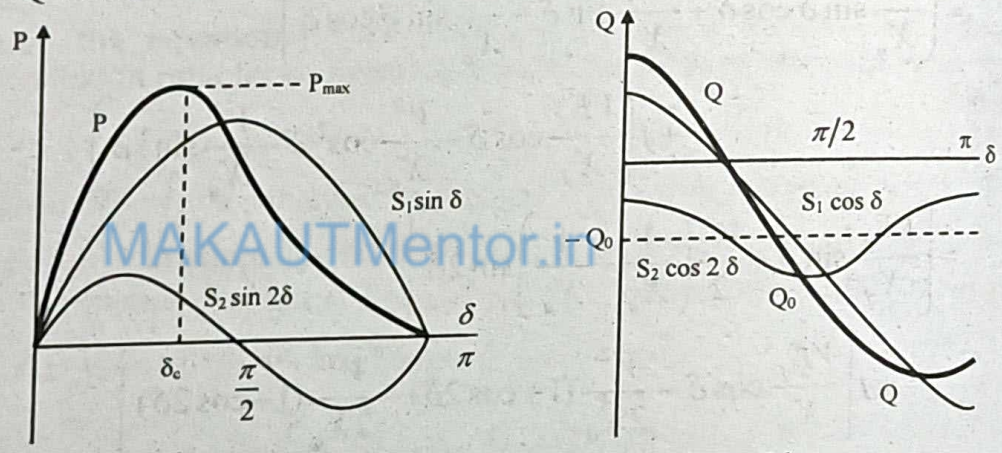

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Fig: 2 Q versus δ curves for a salient-pole machine

The electromagnetic torque or torque developed for a 3-phase synchronous machine is given by

$$\tau_{em} = \frac{3P_{1\phi}}{\omega_m} = \frac{3}{2\pi n_S}\left(\frac{VE_f}{X_d}\sin\delta + \frac{X_d - X_q}{2X_d X_q}\sin 2\delta\right) \quad \text{.... (9)}$$

It is to be noted that the resulting torque has two components. The first term represents the torque τ_{exe} due to field excitation. Thus,

$$\tau_{exe} = \frac{3V\ E_f}{2\pi n_S X_d}\sin\delta \quad \text{.... (10)}$$

The second term in Eqn. (9) is known as reluctance torque, τ_{rel}

$$\therefore \quad \tau_{rel} = \frac{3}{2\pi n_S}\left(\frac{X_d - X_q}{2X_d X_q}\right)\sin 2\delta \qquad \text{.... (11)}$$

b) A 9 KVA, 208 V, 1200 r.p.m., 3-phase, 60 Hz, star-connected generator has a field winding of 4.5Ω. The armature impedance is $(0.3+j5)\Omega$ per phase. When the generator operates at full load and 0.8 p.f. lagging, the field winding current is 5A. Its rotational loss is 500 W. Determine (i) voltage regulation, (ii) efficiency of alternator and (iii) torque applied by the prime mover. [WBUT 2012]

Answer:

Given data rating 9 kVA, 208 V; $R_a = 0.3\Omega$/phase

$X_s = X_a = 5\Omega$/phase. $\cos\phi = 0.8$ lagging

$\therefore$ Rated voltage (phase) $= \dfrac{208}{\sqrt{3}} = 120.089$ V.

$\therefore$ Full-load current, $I = \dfrac{9\times 1000}{\sqrt{3}\times 208} = 24.98 \simeq 25$ A.

$\therefore IR_a$ drop $= 25\times 0.3 = 7.5$ V

$\therefore IX_a$ drop $= 25\times 5 = 125$ V

$\phi = \cos^{-1}(0.8) = 36.87°$

$\therefore \quad \sin\phi = 0.6$

$\therefore$ At 0.8 p.f. lagging:

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

$$= \sqrt{(120\times 0.8 + 7.5)^2 + (120\times 0.6 + 125)^2}$$

$$= \sqrt{(96+7.5)^2 + (72+125)^2} = \sqrt{103.5^2 + 197^2} = 222.53 = 223\text{ V}$$

(i) $\therefore$ Voltage regulation $= \dfrac{223-120}{120} = 0.8583 = 86\%$

Again,

Its rotational loss $= 500$ W

Field winding resistance $= 4.5\Omega$

Field current $= 5$ A

$\therefore$ Field copper loss $= I_f^2 R_f = 25\times 4.5 = 112.5$ W

$\therefore$ Armature copper loss $= I_a^2 R_a = 625\times 0.3 = 187.5$ W

At full load 0.8 lagging power factor load output $= 9000\times 0.8 = 7200$ W

$\therefore$ Total losses $= 500 + 112.5 + 187.5 = 800$ W.

(ii) $\therefore$ Efficiency $(\eta) = \dfrac{7200}{7200+800} = 0.9 = 90\%$.

(iii) $N_s = 1200$ r.p.m., $f = 60$ Hz

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

$$\Rightarrow \quad P = \frac{120 \times 60}{1200} = 6$$

At no load $\delta = 0$ [δ = load angle]

Synchronizing power

$$P_{syn} = \frac{3V_p E_f}{X_s}\cos\delta \times \frac{\pi P}{360} = \frac{3\cdot(120.089)^2}{5} \times \frac{\pi \cdot 6}{360} = 452.8309 \text{ W}$$

Torque applied by the prime mover

$$T_{syn} = \frac{P_{syn}}{2\pi N_s} = \frac{P_{syn}}{2\pi \cdot \frac{1200}{60}} = \frac{452.8309}{2\pi \cdot \frac{1200}{60}} \text{ V}$$

$$= \frac{452.8309}{2\pi \times 2} = \frac{452.8309}{4\pi} = 36.0534 \text{ N-m.}$$

9. a) Explain two reaction theory for a salient pole synchronous machine. Using this theory, draw the phasor diagram for lagging current for a salient pole generator. [WBUT 2013]

OR,

Draw the phasor diagram of a sailent pole synchronous generator based on two reaction theory. [WBUT 2016]

b) Explain conditions for parallel operation of alternators. [WBUT 2013]

c) Describe Static or Brushless Method of excitation of an alternator. What is its advantage over dc exciters? [WBUT 2013]

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Answer:

a) Two-Reaction Theory

Two reaction theory proposes to resolve the given armature mmfs into two mutually perpendicular components, one located along the axis of the rotor salient pole, called direct-axis (or d-axis) component and the other located perpendicular to the axis of rotor salient pole which is known as the quadrature axis (or q axis) component.

The d-axis component of the armature mmf F_a is denoted by F_d which is either magnetizing or demagnetizing and q axis component F_q which results in a cross-magnetizing effect.

If ψ is the angle between the armature current I_a and the excitation voltage E_f and F_a is the amplitude of the armature mmf then

$$F_d = F_a \sin\psi$$

$$F_q = F_a \cos\psi$$

If ϕ_d is the direct axis flux and ϕ_q is the quadrature axis flux, then assuming reluctance of direct axis flux path, it may be written as:-

$$\phi_d = \frac{F_d}{R_d} \quad \text{and} \quad \phi_q = \frac{F_q}{R_q}$$

It may be noted that:

i) As $R_d < R_q$, the direct axis component of mmf F_d produces more flux than the Quadrature axis component of mmf F_q.

ii) The direct and quadrature axis stator fluxes produce voltages in the stator winding by armature reaction.

Salient – Pole Synchronous Machine – Two – Reaction Model

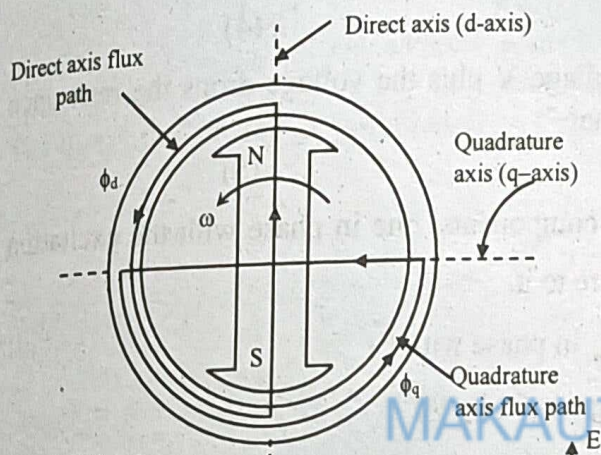

Fig: 1

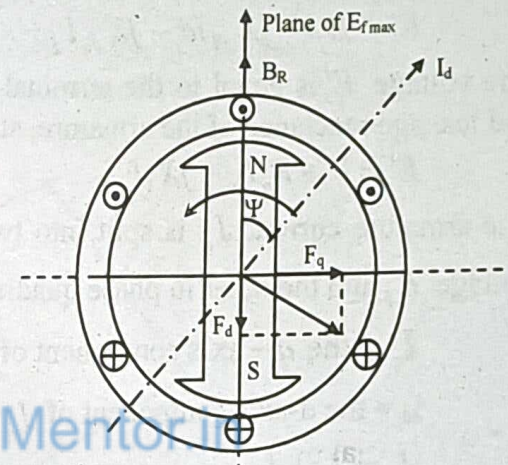

Fig: 2

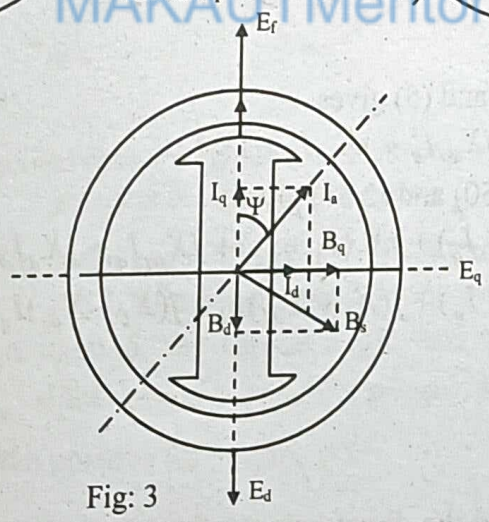

Fig: 3

In Fig. (1) as above a 2 pole salient pole rotor rotating in the anticlockwise direction with a 2 pole stator along with d-axis and q-axis are shown. In this figure, path denoted by ϕ_q has two large air gaps as shown and is the path of maximum reluctance.

The rotor flux B_R is shown vertically upwards in Fig.(2) above and it induces a voltage E_f in the stator. When a lagging p.f. load is connected to the synchronous generator, a stator current 'I_a' will flow which will lag the generated voltage E_f by an angle ψ as shown in Fig. (2) above.

As each armature reaction voltage is directly proportional to its stator current and lags the stator current by 90°, the armature reaction voltages for direct and d-quadrature axis if denoted by E_{ad} and E_{aq} can be expressed as: -

$$E_{ad} = -jX_{ad}I_d \quad \text{.... (1)}$$

$$E_{aq} = -jX_{aq}I_q \quad \text{.... (2)}$$

where X_{ad} and X_{aq} are the armature reaction reactance for direct and quadrature axis respectively and $X_{aq} < X_{ad}$ since the emf induced by a given mmf acting on the direct axis is smaller than for the quadrature axis due to its higher reluctance.

The total voltage induced in the stator is the sum of emf induced by the field excitation and these two emfs.

Thus, $$E' = E_f + E_{ad} + E_{aq} \quad \text{.... (3)}$$

$$E' = E_f - jX_{ad}Id - jX_{aq}I_q \quad \text{.... (4)}$$

The voltage E' is equal to the terminal voltage V plus the voltage drops the resistance and leakage reactance of the armature, so that

$$E' = V + R_aI_a + jX_1I_a \quad \text{.... (5)}$$

The armature current I_a is split into two components, one in phase with the excitation voltage E_f and the other in phase quadrature to it.

If I_q = the $q-$axis component of I_a in phase with E_f

I_d = the d-axis component of I_a lagging E_f by 90°

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$$\therefore \quad I_a = I_d + I_q \quad \text{.... (6)}$$

Combination of Eqns. (4) and (5) gives

$$E_f = V + R_aI_a + jX_{ad}I_d + jX_{aq}I_q + jX_lI_a \quad \text{.... (7)}$$

Combination of Eqns. (2.50) and (2.51) gives

$$E_f = V + R_a(I_d + I_q) + jX_1(I_d + I_q) + jX_{aq}I_q + jX_dI_d$$

$$= V + R_a(I_d + I_q) + j(X_1 + X_{ad})I_d + j(X_1 + X_{aq})I_q \quad \text{.... (8)}$$

Assuming $X_d \overset{\Delta}{=} X_1 + X_{ad}$ .... (9)

$$\boxed{X_q \overset{\Delta}{=} X_1 + X_{aq}} \quad \text{.... (10)}$$

The reactance X_d is called the direct-axis synchronous reactance and the reactance X_q is called the quadrature-axis synchronous reactance.

Combination of Eqns. (8) and (9) and (10) gives

$$E_f = V + R_aI_d + R_aI_q + jX_dI_d + jX_qI_q \quad \text{.... (11)}$$

$$E_f = V + R_aI_a + jX_dI_d + jX_qI_q \quad \text{.... (12)}$$

Eqn. (11) is the final form of the voltage equation for a salient-pole synchronous generator.

Phasor diagram

The complete phasor diagram of a salient-pole synchronous generator based on two axis theory is shown in Fig. (a).

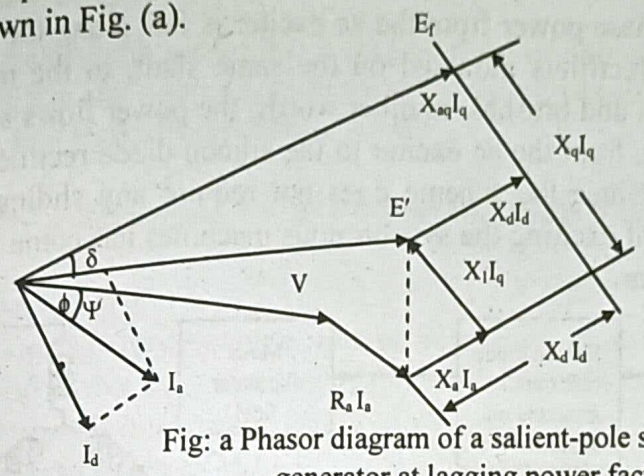

Fig: a Phasor diagram of a salient-pole synchronous generator at lagging power factor

The Simplified phasor diagram based on Eqn. (11) is shown in Fig b.

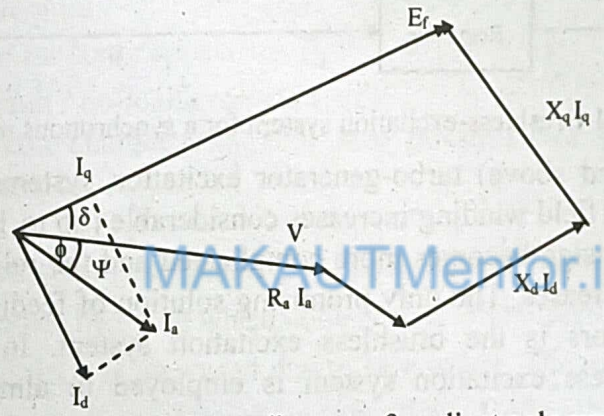

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Fig: b Simplified phasor diagram of a salient pole synchronous generator at lagging power factor

In the phasor diagram of Fig. b the angle $\Psi = \phi + \delta$, is not known for given values of V, I_a and ϕ. The components I_d and I_q of the armature current are usually not given. These component current depend upon δ, the torque angle and from the phasor diagram, $|E_f| = V\cos\delta + R_aI_q + X_dI_d$ since $\psi = \delta + \phi$ and $\delta = \psi - \phi$. ϕ is negative for leading power factor since ϕ is taken positive for logging p.f.

b) For proper synchronization vis-à-vis parallel operation of alternators, the following three conditions must be satisfied:

i) The terminal voltage (effective) of the incoming alternator must be same as bus-bar voltage.

ii) The speed of the incoming machine must be such that its frequency equals bus-bar frequency.

iii) The phase of the alternator voltage must be identical with the phase of the bus bar voltage.

c) The scheme of supplying dc power to the rotating field winding is illustrated in Fig. 1. The a.c. exciter driven by the main synchronous machine has stationary field and rotating 3-phase armature. The 3-phase power from the ac exciter is fed, along the main shaft, to the rotating silicon-diode rectifiers mounted on the same shaft, to the main alternator field, without any slip-rings and brushes. In other words, the power flows along the wires mounted on the main shaft, from the ac exciter to the silicon diode rectifiers and then to the main alternator field. Since the scheme does not require any sliding contacts and brushes, this arrangement of exciting the synchronous machines has come to be called as **brushless excitation system.**

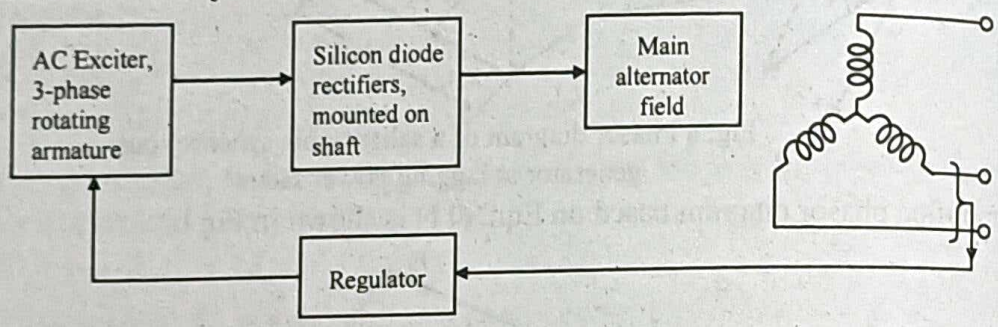

Fig: 1 Brushless-excitation system for a synchronous machine

For large (500 MW and above) turbo-generator excitation systems, the direct current required by the rotating field winding increases considerable (up to 10 kA or so). In such cases, the brush-gear design becomes more complicated and the reliability of the turbo-generator operation decreases. The only promising solution of feeding the field winding of large turbo-generators is the brushless excitation system. In view of its many advantages, the brushless excitation system is employed in almost all large turbo-generators also.

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10. a) Define regulation of a synchronous generator. Why is it important to know the value of regulation? Can regulation be negative? If yes, give example. **[WBUT 2013]**

Answer:

1st Part: ***Refer to Question No. 4 of Long Answer Type Questions.***

2nd Part:

The value of voltage regulation of an alternator is important because of the following reasons:

i) It indicates the range of field excitation required.

ii) It indicates the magnitude of torque angle.

iii) It indicates the performance of machine when operating in parallel with others.

3rd & 4th Part:

Yes, the voltage regulation can be negative.

From Definition we know that change in terminal voltage due to armature reaction depends upon the armature current as well as power factor of the load. For leading p.f.

the no load voltage is less than the full load voltage. Hence voltage regulation is negative in this case.

b) Describe briefly the principle of emf method of calculation of regulation. How is it experimentally determined in laboratory by conducting Open circuit and Short circuit tests and Unity power factor load? [WBUT 2013]

Answer:

1st Part: ***Refer to Question No. 4(2nd Part) of Long Answer Type Questions.***

2nd & 3rd Part:

As it is not feasible to determine voltage regulation of an alternator by direct loading indirect method (Laboratory method) is followed determine voltage regulation:

1. Synchronous impedance or E.M.F. method.
2. The Ampere-turn or M.M.F. method.
3. Zero power-factor or Potier method.

All these methods require:

(i) Armature for stator resistance R_a.

(ii) Open-circuit / no-load characteristic.

(iii) Short-circuit characteristic (but zero power factor lagging characteristic for Potier method).

(i) Value of R_a**:** Armature resistance R_a per phase can be measured directly by voltmeter and ammeter method or by using wheatstone bridge. The effective value of R_a, however, under working conditions is increased due to skin effect. The value of R_a so obtained in increased by sixty percent or so to allow this effect. Generally, a value 1.6 times D.C. value is taken.

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(ii) Open-circuit Characteristic: This type of characteristic (as in D.C. machines) is plotted by running the machine on no-load and noting the values of induced voltage and field excitation current.

(iii) Short-circuit Characteristic: Short-circuit characteristic is obtained by short-circuiting the armature (i.e., stator) windings through a low resistance ammeter. The excitation is so adjusted as to give 1.5 to 2 times the value of full-load current. The speed (not necessarily synchronous) is kept constant during the test.

Synchronous Impedance Method: This method involves the following steps:

(i) Plot the open-circuit characteristic (O.C.C.) from a given data as shown in Fig. (1).

(ii) Plot short-circuit characteristic (S.C.C.) from the data given by short-circuit test.

Both these curves are drawn on a common field current base.

Consider a field current I_f corresponding to this field current the O.C. voltage is E_1.

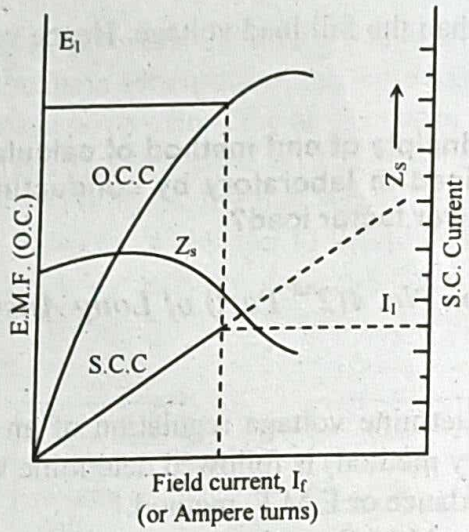

Fig: 1 O.C and S.C. test curves

When winding is short-circuited, the terminal voltage is zero. Hence, it may be assumed that the whole of this voltage E_1 is being used to circulate the armature short-circuit current I_1 against the synchronous impedance Z_s.

$$\therefore \quad E_1 = I_1 Z_s$$

$$\text{or,} \quad Z_s = \frac{E_1\,(\text{open-circuit})}{I_1\,(\text{short-circuit})}$$

(iii) Then synchronous reactance X_s are determined

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

(R_a can be found as discussed earlier)

(iv) After finding R_a and X_s vector diagrams for any load any power factor may be drawn. Three cases are considered in Fig. 2.

Unity power factor

$$OC^2 = (OA + AB)^2 + BC^2$$

$$E_0^2 = (V + IR_a)^2 + (IX_s)^2$$

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

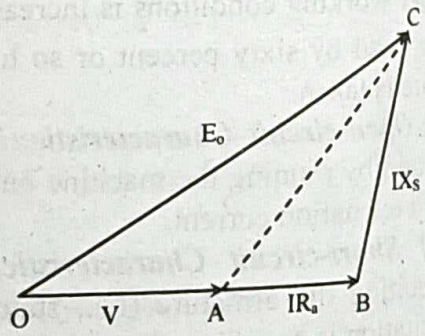

Fig: 2

11. a) Explain EMF method of calculation voltage regulation of synchronous generator and state why it leads to pessimistic value at lagging power factor load. [WBUT 2014, 2018]

Answer:

1st Part: ***Refer to Question No. 4(2nd Part) of Long Answer Type Questions.***

2nd Part:

In EMF method of calculation voltage regulation it is found that the percentage being obtained becomes higher than the actual value. This is called the pessimistic value of synchronous impedance.

b) The effective resistance of a 3 phase, star connected, 50 Hz, 2200 V, synchronous generator is 0.5 ohms per phase. On short circuit, a field current of 40 A gives full load current of 200 A. An emf (Line to line) of 1100 V is produced on open circuit with the same excitation. Determine synchronous impedance. Hence compute power angle and regulation at full load and 0.8-pf lagging.

[WBUT 2014, 2018]

Answer:

The OCC and SCC characteristics of the synchronous generator are given in Fig. 1.

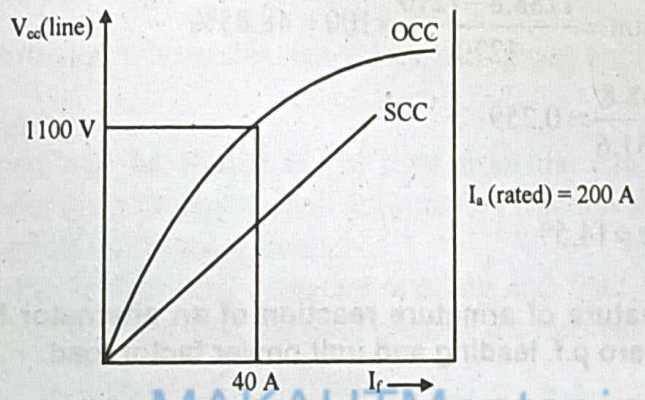

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Fig: 1 OCC and SCC characteristics

Synchronous impedance

$$Z_s = \frac{\text{open circuit voltage for } I_f \text{ of } 40A}{\text{short circuit current for the same } I_f \text{ of } 40A}$$

Thus $X_s \approx Z_s = \dfrac{1100}{\sqrt{3} \times 200} = 3.18\Omega$

Percentage voltage regulation is defined as $\dfrac{E_f - V_{t(\text{rated})}}{V_{t(\text{rated})}} \times 100\%$

The phasor diagram is given in Fig. 2.

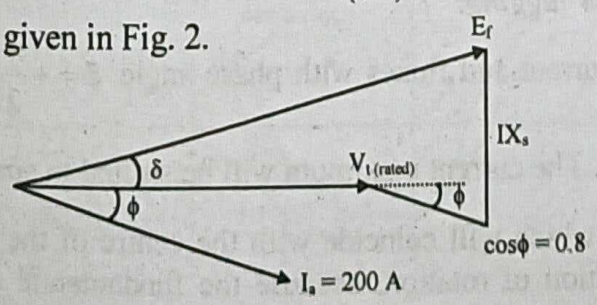

Fig: 2 Phasor diagram

Here $V_{t(\text{rated})} = \dfrac{2200}{\sqrt{3}}$

$$\cos\phi = 0.8$$

$$E_f^2 = (V_t + Ir_a\cos\phi + IX_s\cos\phi - Ir_a\sin\phi)^2$$

where V_t (terminal voltage) and E_f (field voltage) are per phase values

$$\Rightarrow E_f = \left[\left(\frac{2200}{\sqrt{3}} + 200\times0.5\times0.8 + 200\times3.18\times0.6\right)^2 + (200\times3.18\times0.8 - 200\times0.5\times0.6)^2\right]^{1/2}$$

$$E_f = \sqrt{1731.6^2 + 448.8^2} = 1788.8$$

$$\text{Percent regulation} = \frac{E_f - V_{t(\text{rated})}}{V_{t(\text{rated})}}\times100$$

$$\Rightarrow \quad \%\text{ regulation} = \frac{1788.8 - 1270}{1270}\times100 = 48.85\%$$

$$\tan\delta = \frac{448.8}{1731.6} = 0.259$$

$$\delta = 14.5°$$

Thus power angle $= 14.5°$

12. Discuss the nature of armature reaction of an alternator for zero p.f. lagging, zero p.f. leading zero p.f. leading and unit power factor load. **[WBUT 2015]**

Answer:

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In an alternator, for a given armature current, the direction and magnitude of the armature reaction cannot depend on the brush position, as in case of a d.c. machine but depends on the phase displacement of the stator current with respect to the e.m.f. induced in the stator winding by the field winding flux.

In case of alternator the phase displacement or phase angle ϕ between current I and e.m.f. E can be within the limits of

$$\frac{-\pi}{2} \le \phi \le \frac{+\pi}{2}$$

Now:

i) At zero power factor lagging:

The distribution of current and fluxes with phase angle $\phi = +\frac{\pi}{2}$ radians i.e., this is for purely inductive load. The current maximum will be shifted in space by an angle $\frac{\pi}{2}$ from the e.m.f. maximum which will coincide with the centre of the pole. This shift will be opposite to the direction of rotation, because the fundamental armature reaction wave rotates in step with the field poles, while when $\phi = +\frac{\pi}{2}$ current wave lags the e.m.f. wave

by an angle $\frac{\pi}{2}$. The field created by the armature reaction m.m.f. will be in opposition to the main field flux and will therefore, have wholly demagnetizing effect.

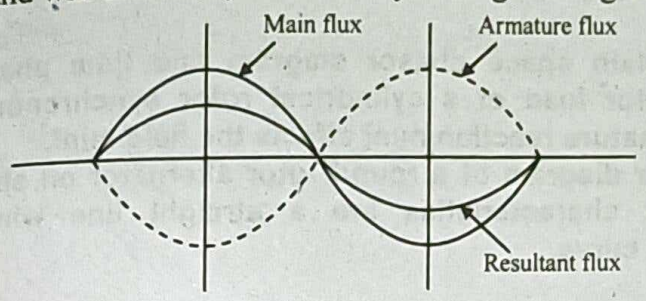

Fig: 1 Armature reaction at zero p.f. lagging

ii) At zero power factor leading:

In this case the distribution of currents and fluxes with phase angle $\phi = -\frac{\pi}{2}$ i.e., for a purely capacitive load.

The current maximum will be shifted to the right from the e.m.f. maximum, which remains as before under the pole centres, and the armature reaction will therefore have a a wholly magnetizing effect on the main field.

The phasor sum of the fundamental armature winding and field winding mmf. wave constitutes, in a synchronous machine, the mmf creating the resultant magnetic flux.

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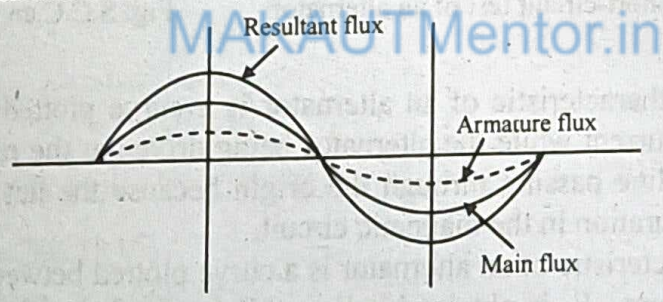

Fig: 2 Armature reaction at zero p.f. leading

iii) At unity power factor:

In this case armature reaction has got distortion effect.

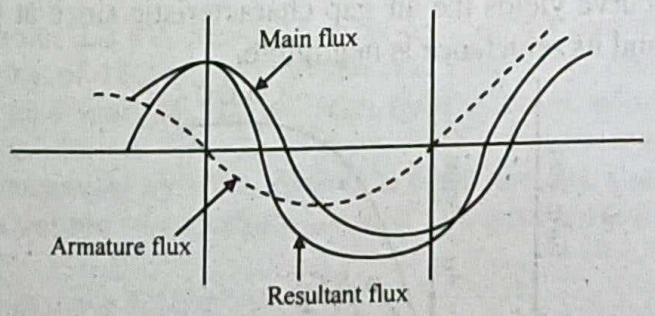

Fig: 3 Armature reaction at unity power factor

It can be seen from the phasor diagram that there exists a phase difference of 90° between the armature flux and the main flux. The waveforms for the two fluxes are also shown in

the Fig. 3. From the waveforms it can be seen that the two fluxes oppose each other on the left half of each pole while assist each other on the right half of each pole. Hence average flux in the air gap remains constant but its distribution gets distorted.

13. a) Clearly explain space phasor diagram and time phasor diagram under lagging power factor load of a cylindrical rotor synchronous generator. State clearly how the armature reaction mmf affects the field mmf.
b) Draw the phasor diagram of a round rotor alternator on short circuit. Discuss why short circuit characteristics are a straight line whereas open circuit characteristics is a curve. **[WBUT 2016]**

Answer:

a) 1st Part: ***Refer to Question No. 9(a) of Long Answer Type QUestions.***

2nd Part: ***Refer to Question No. 10 of Long Answer Type Questions.***

b) 1st Part:

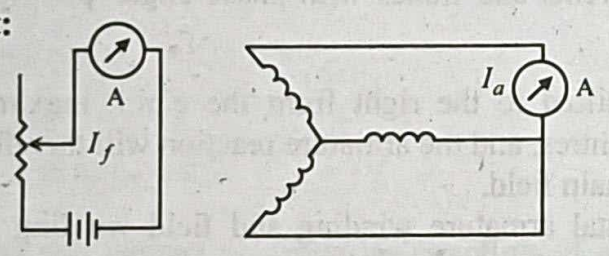

Fig: Short-circuit test of an alternator

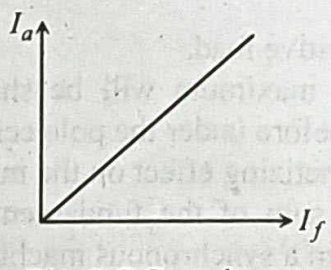

Fig: S.C.C an alternator

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2nd Part:

The short circuit characteristic of an alternator is a curve plotted between short circuit current and field current while the alternator being driven at the rated speed. The curve usually a straight line passing through the origin because the net excitation is so small that there is no saturation in the magnetic circuit.

Open circuit characteristic of an alternator is a curve plotted between open circuit voltage (E_0) and field current. E_0 is obtained is line voltage and hence it has to be converted to phase voltage i.e. $E_{0\,phase} = \frac{E_0}{\sqrt{3}}$ and for graph phase values are considered. The initial straight part of the curve yields the air gap characteristic since at that low excitation the iron is unsaturated and its reluctance is negligible.

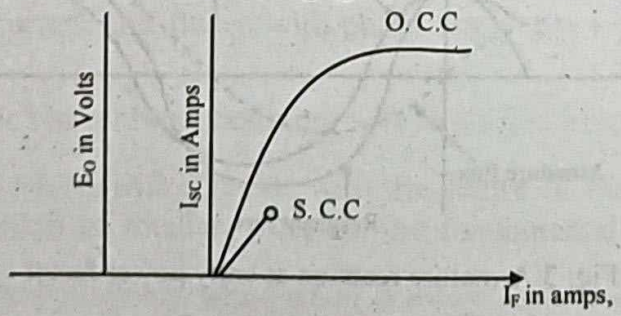


Fig: O.C.C and S.C.C

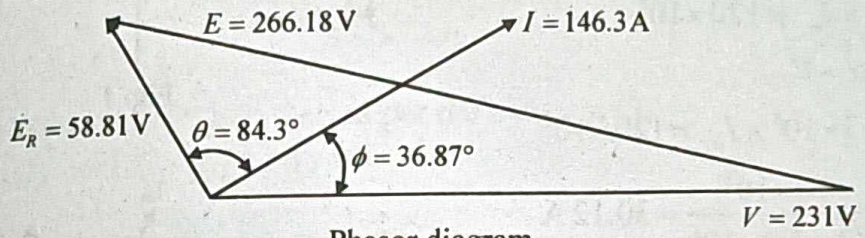
14. A 75kW, 400V, 3 phase star connected synchronous motor has a resistance and synchronous reactance per phase of 0.04Ω and 0.4Ω respectively. Compute for full load 0.8 pf lead the open circuit emf per phase and gross mechanical power developed. Assume an efficiency of 92.5%. [WBUT 2017]

Answer:

Motor input $\frac{\text{Motor output}}{\eta} = \frac{75}{92.5} = 81.081\text{kW or } 81{,}081\text{Watts.}$

Armature current, $I = \frac{\text{Motor input}}{\sqrt{3}V_L \cos\phi} = \frac{81081}{\sqrt{3}\times 400\times 0.8} = 146.3\text{ A}$

Supply voltage/phase $V = \frac{400}{\sqrt{3}} = 231\text{ V}$



Phasor diagram

Resultant voltage, $E_R = IZ_s = 146.3\sqrt{(0.04)^2 + 0.4^2} = 58.81\text{ V}$

Internal phase angle $\theta = \tan^{-1}\frac{X_s}{R_e} = \tan^{-1}\frac{0.4}{0.04} = 84.3°$

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From phasor diagram:

$$E = \sqrt{V^2 + E_R^2 - 2VE_R\cos(\theta+\phi)}$$
$$= \sqrt{(231)^2 + (58.81)^2 - 2\times 231\times 58.81\times\cos(84.3° + 36.87°)}$$
$$= \sqrt{70.855} = 266.18\text{ V}$$

So open circuit emf/phase, $E = 266.18\text{ V}$

Cross mechanical/power developed for all 3 phases

$$P_m = P_{IN} - 3I^2R_e = 81.081 - 3\times(146.3)^2\times 0.04 = 78{,}512\text{ Watts or } 78.512\text{ kW.}$$

15. a) A 3-phase, 6-pole, 2.3 kV, 200 kVA, star-connected synchronous motor has synchronous reactance of 12 ohm per phase and negligible resistance. The motor is initially operating at a load of 120 kV with field current adjusted such that the armature current is minimum. The field current is now increased such that the armature current is increased by 50%. With this field current, the load is reduced to 60 kW. Calculate new values of armature current and power factor. [WBUT 2018]

Answer:

Rating of synchronous motor = 2.3 kV, 200 kVA

Synchronous reactance, $X_1 = 12\Omega/\text{Ph}$

Initial load = 120 kW

i) If the armature current is adjusted to minimum then the power factor $\cos\phi_1 = 1$ and $\phi_1 = 0$. The vector diagram is

E_b = Emf per phase

V = Terminal voltage per phase

E_R = Resultant voltage which 90° phase with I_{a_1} since R_a is negligible.

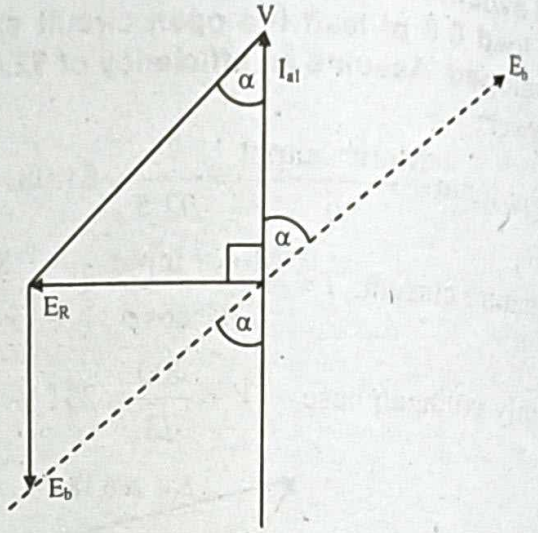

Fig: 1

Load $= 3 \times E_b \times I_{a_1} \times \cos$ of angle between E_b and I_{a_1}

$= 3 \times E_b \times I_{a_1} \times \cos 0 = 120$ kW

$\therefore \quad \sqrt{3} \times V \times I_{a_1} = 120 \times 10^3$

Since $\quad E_b \cos\alpha = V$

$\therefore \quad \sqrt{3} \times 2.3 \times 10^3 \times I_{a_1} = 120 \times 10^3$

$$\therefore \quad I_{a_1} = \frac{120 \times 10^3}{\sqrt{3} \times 2.3 \times 10^3} = 30.12 \text{ A}$$

ii) If the armature current is increased to 50% by increasing the field current then

$$I_{a_2} \cos\phi_2 = I_{a_1}$$

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Since I_{a_1} will be constant for all the field current. Only the reactive component will be changed. The diagram (2) is given below

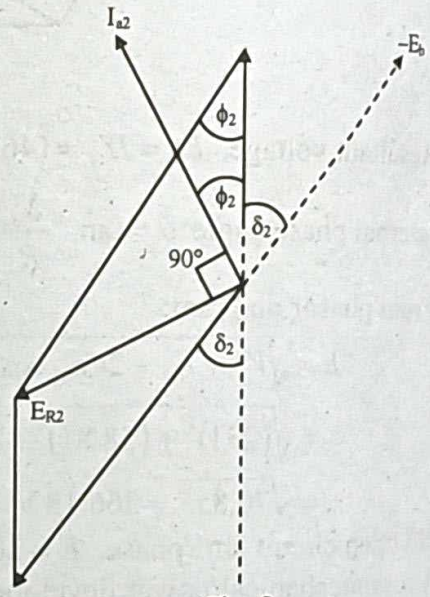

Fig: 2

E_{R_2} is 90° phase with I_{a_2} since R_a is negligible.

Also, $\quad I_{a_2} = 150\% I_{a_1} = 1.5 I_{a_1}$

$$\therefore \quad \frac{I_{a_1}}{I_{a_2}} = \cos\phi_2 = \frac{1}{1.5} = 0.67$$

$$\therefore \quad \phi_2 = \cos^{-1}(0.67) = 48.2°$$

From the diagram (2)

$$E_b = \sqrt{V^2 + E_{R_2}^2 - 2 \times V \times E_{R_2} \cos(90° + \phi_2)}$$

$$= \sqrt{V^2 + E_{R_2}^2 + 2 \times V \times E_{R_2} \sin\phi_2}$$

$$E_{R_2} = I_{a_2} Z_s = I_{a_2} X_s = 1.5 I_{a_1} \times X_s$$

Here, $\quad = 1.5 \times 30.12 \times 12$

$= 542.16 V$

$$E_b = \sqrt{\left(\frac{2.3\times10^3}{\sqrt{3}}\right)^2 + (542.16)^2 + 2\times\frac{2.3\times10^3}{\sqrt{3}}\times542.16\times\sin 48.2^\circ} = 1769.2\text{ V}$$

From the diagram (2)

$$\frac{E_b}{\sin(90^\circ+\phi_2)} = \frac{E_{R_2}}{\sin\delta_2}$$

$$E_{R_2} = I_{a_2}\times S_s = 12 I_{a_2}$$

$$\therefore \quad \sin\delta_2 = \frac{12 I_{a_2}\cos\phi_2}{E_b} = \frac{12 I_{a_1}}{E_b} \qquad [\text{Since } I_{a_2}\cos\phi_2 = I_{a_1}]$$

$$= \frac{12\times30.12}{1769.2}$$

$$\phi_2 = 11.79^\circ$$

If the load I is reduced to 60 kW then as per the diagram (3)

$$3\times E_b\times I_{a_3}\cos(\delta_3+\phi_3) = 60\times10^3$$

$$\therefore \quad I_{a_3}\cos(\delta_3+\phi_3) = \frac{60\times10^3}{3\times1769.2} = 11.31$$

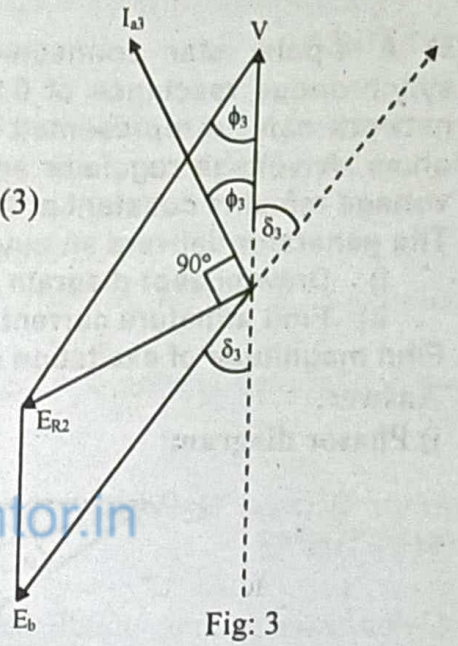

Fig: 3

But the field is constant so that E_b is from diagram (3)

$$\frac{E_b}{\sin(90^\circ+\phi_3)} = \frac{V}{\sin(180^\circ-(90+\phi_3+\delta_3))}$$

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$$\frac{E_b}{\cos\phi_3} = \frac{V}{\cos(\phi_3+\delta_3)}$$

$$\therefore \quad \cos\phi_3 = \frac{E_b}{V}\cos(\phi_3+\delta_3) = \frac{1769.2}{1327.9}\cos(\phi_3+\delta_3) = 1.33\cos(\phi_3+\delta_3)$$

Also from diagram (3)

$$\frac{E_b}{\sin(90+\phi_3)} = \frac{E_{R_3}}{\sin\delta_3}$$

$$\therefore \quad E_b = \frac{E_{R_3}}{\sin\delta_3}\cos\phi_3 = \frac{12\times I_{a_3}\times1.33\cos(\delta_3+\phi_3)}{\sin\delta_3}$$

From (1)

$$I_{a_3}\cos(\delta_3+\phi_3) = 11.31$$

$$\sin\delta_3 = \frac{12\times11.31\times1.33}{1769.21} = 0.102$$

$$\therefore \quad \delta_3 = 5.86^\circ$$

$$\cos\phi_3 = 1.33\cos(\phi_3+\delta_3) = 1.33[\cos\phi_3\cos\delta_3 - \sin\phi_3\sin\delta_3]$$

$$= 1.33[\cos\phi_3\cos5.86^\circ - \sin\phi_3\sin5.86^\circ]$$

$\therefore \quad \cos\phi_3 = 1.32\cos\phi_3 - 0.136\sin\phi_3$

$\therefore \quad \tan\phi_3 = \dfrac{0.32}{0.136} = 2.353$

$\therefore \quad \phi_3 = 67°$

$\therefore \quad \cos\phi_3 = 0.3911$

$\therefore \quad I_{a_3}\cos(\delta_3 + \phi_3) = 11.31$

$\therefore \quad I_{a_3} = \dfrac{11.31}{\cos(5.86° + 67°)} = 38.38\text{ A}$

b) A 4-pole, star connected, 50 Hz, 11 kV, 40 MVA turbo-generator, with synchronous reactance of 0.8 pu is connected to a power network. This power network can be represented by 11kV infinite but with a series reactance of j0.5 ohms. A voltage regulator adjusts the field current such that alternator terminal voltage remains constant at 11 kV.

The generator delivers an output of 40 MVA.

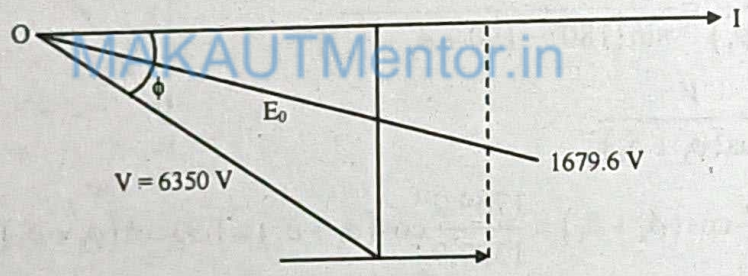
i) Draw phasor diagram under condition specified.

ii) Find armature current and alternator P.F.

Find magnitude of excitation emf. **[WBUT 2018]**

Answer:

i) Phasor diagram:



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ii) $Q = \sqrt{3}V_L I_a$

$$I_a = \frac{40\times10^6}{\sqrt{3}\times11\times10^3} = \frac{40\times10^3}{\sqrt{3}\times11} = 2.0995\times10^3\text{ A}$$

$$= \frac{E}{\sqrt{E^2+V^2}} = \frac{\frac{11000}{\sqrt{3}}}{\sqrt{\left(\frac{11000}{\sqrt{3}}\right)^2+\left(\frac{11000}{\sqrt{3}}\right)^2}} = \frac{\frac{11000}{\sqrt{3}}}{\sqrt{2}\cdot\frac{11000}{\sqrt{3}}} = \frac{1}{\sqrt{2}} = 0.703\text{ (lead)}$$

iii) $E = \sqrt{(V\cos\phi + IR_a)^2 + (V\sin\phi - IX_L)^2}$

$$= \sqrt{\left(\frac{11000}{\sqrt{3}} + 0\times0.707\right)^2 + \left(\frac{11000}{\sqrt{3}} - (2.0995\times0.8\times10^3)^2\times0.707\right)}$$

$$= \sqrt{(6350.85 \times 0.707)^2 + (6350 - 1679)^2 \times 0.707}$$
$$= \sqrt{(4490.05)^2 + (4490.5 - 1679.6)^2}$$
$$= \sqrt{20160549 + (2810.4)^2}$$
$$= \sqrt{20160549 + 7898348.6}$$
$$= \sqrt{28052897.2}$$

16. a) Why is armature winding of alternator kept stationary and field rotating? **[WBUT 2019]**

Answer:

When armature winding is stationary and field winding rotates we get more output as field winding is quite lighter than armature winding. The current is drawn directly from fixed terminals on the stator without the use of brush contacts.

- The insulation of stationary armature winding is easier.
- The number of sliding contacts (slip rings) is reduced. Moreover, the sliding contacts are used for low-voltage DC Source.
- Armature windings can be constructed more rigidly to prevent deformation due to any mechanical stress.

b) What happens, if the field excitation of alternator suddenly get opened during running condition of alternator? **[WBUT 2019]**

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Answer:

If the field excitation of alternator suddenly get opened during running condition of alternator then there will be change in the field magnetism created inside the alternator and the voltage generated in the stator winding is likely to be affected.

17. Explain how Potier triangle can be drawn with the help of OCC and any two points from zpfc. **[WBUT 2019]**

Answer:

Refer to Question No. 7(b) (2nd part) of Long Answer Type Questions.

18. The stator resistance of a 1-phase induction motor is 2.5 ohm and its leakage reactance is 2.0 ohm. On no-load, the motor takes 4A at 96V and at 0.25 lagging power factor. The no-load friction windage loss in negligible. Under the blocked rotor condition the input power is 130W at 6A and 42V. Obtain the equivalent circuit parameters. **[WBUT 2019]**

Answer:

Blocked rotor test:

$$R_{sc} = r_1 + \frac{r_2}{2} \times 2 = r_1 + r_2 = \frac{P_{sc}}{(I_{sc})^2} = \frac{130}{(6)^2} = 3.61\Omega$$

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} = \frac{42}{6} = 7\Omega$$

$$X_{sc} = x_1 + \frac{x_2}{2} \times 2 = x_1 + x_2$$

$$= \sqrt{Z_{sc}^2 - R_{sc}^2} = \sqrt{(7)^2 - (3.61)^2} = \sqrt{46 - 13.04} = 5.99\Omega$$

$$\therefore \quad r_2 = r_1 = \frac{3.61}{2} = 1.81\Omega$$

$$\therefore \quad x_2 = x_1 = \frac{5.99}{2} = 2.99\Omega$$

No load test:

$$Z_0 = \frac{V_0}{I_0} = \frac{96}{4} = 24\Omega$$

$$\cos\theta_0 = 0.25$$

$$\sin\theta_0 = 0.96$$

The no load equivalent reactance:

$$\therefore \quad X_0 = Z_0 \sin\theta_0 = 24 \times 0.96 = 23.04$$

Since, $X_0 = x_1 + \frac{x_m}{2} + \frac{x_2}{2}$

$$x_m = 2 \times \left(X_0 - x_1 - \frac{x_2}{2} \right) = 2\left(23.04 - 2.99 - \frac{2.99}{2}\right) = 37.12\Omega$$

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19. Write short notes on the following:

a) Condition for parallel operation of alternators **[WBUT 2008, 2017]**

b) Synchronizing Power **[WBUT 2013]**

c) Hunting **[WBUT 2014]**

Answer:

a) Condition for parallel operation of alternators:

The following three conditions must be satisfied for parallel operation of alternators:-

i) The terminal voltage (effective) of the incoming alternator must be same as bus-bar voltage.

ii) The speed of the incoming machine must be such that its frequency equals bus-bar frequency.

iii) The phase of the alternator voltage must be identical with the phase of the bus-bar voltage.

Advantages of synchronization of alternators

(i) Repair and maintenance of individual generating unit can be carried out keeping the "continuity of supply" by proper maintenance schedule of alternators one after the other. Supply cannot be restored during repair and maintenance, if only one large generator is installed.

(ii) For operating an alternator on maximum efficiency, it is always to be run near to full-load capacity, since it is uneconomical to operate it on low loads. However, if a number of small alternators are used in parallel, then desired number of alternator units can be added or put off, depending on the load requirements and consequently, the units can be operated near to their rating capacity.

(iii) To meet the increasing demand, additional units can be operated in parallel, thereby reducing the initial capital cost of purchasing larger units in anticipation of any future increasing demands.

(iv) There is physical as well as economic limit to build a single very large alternator of large rating to meet the demand of a power station, which may be as high as 1,200 MVA. Such demands are met only by synchronization of a number of alternators.

b) Synchronizing Power:

It is the inherent tendency of a synchronous generator or motor to remain synchronism when connected to in finite bus bars. However, if there is a transient disturbance during the operation of a synchronous generator, which is transferring steady power P_o at steady load angle δ_o, its rotor accelerates thereby increasing the load angle $d\delta$. The operating point of the machine shifts to a new constant power line and the load on the machine increases to $(P_o+\delta P)$. Similarly, if due to transient disturbance, the rotor of the machine retards, the load angle decreases thereby decreasing the load on the machine to $(P_o-\delta P)$. As in both the cases, the steady power input remains unchanged, the additional load / reduction in load, decreases/increases the speed of the rotor thereby bringing the machine in synchronism. This leads to conclude that the effectiveness of this correcting action depends on the change in power transfer for a given change in load angle.

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A measure of effectiveness is given by synchronizing power co-efficient and is denoted by P_{syn} and defined as the rate at which the synchronous power P varies with the load angle δ. It is also called stability factor

$$\therefore \quad P_{Syn} \stackrel{\Delta}{=} \frac{dP}{d\delta} \qquad \text{.... (1)}$$

Power output per phase of the cylindrical rotor generator

$$P = \frac{V}{Z_S}\left[E_f \cos(\theta_Z - \delta) - V\cos\theta_Z\right] \qquad \text{.... (2)}$$

$$P_{Syn} = \frac{dp}{d\delta} = \frac{VE_f}{Z_S}\sin\left(\theta_z - \delta\right) \qquad \text{.... (3)}$$

The synchronizing torque co-efficient

$$\tau_{Syn} \stackrel{\Delta}{=} \frac{d\tau}{d\delta} = \frac{1}{2\pi n_S}\cdot\frac{dp}{d\delta} \qquad \text{.... (4)}$$

$$\tau_{Syn} = \frac{VE_f}{2\pi n_S Z_S}\sin(\theta_Z - \delta) \qquad \text{.... (5)}$$

It is observed that in many synchronous machines $X_S >> R$ and as such for a cylindrical rotor machine, neglecting saturation and stator resistance, Eqns. (3) and (5) may be written as:

$$P_{Syn} = \frac{V\ E_f}{X_S}\cos\delta \qquad \text{.... (6)}$$

$$\tau_{Syn} = \frac{VE_f}{2\ pin_S X_S}\cos\ \delta \qquad \text{.... (7)}$$

For a salient pole machine:

$$P = \frac{VE_f}{X_S}\sin\delta + \frac{1}{2}V^2\left(\frac{1}{X_d} - \frac{1}{X_q}\right)\sin 2\delta$$

$$\therefore \qquad P_{Syn} = \frac{VE_f}{X_S}\cos\delta + V^2\left(\frac{1}{X_d} - \frac{1}{X_q}\right)\cos 2\delta$$

So far the units of synchronizing power co-efficient (P_{Syn}) are concerned it may be mentioned that if P = total number of pair of poles of the machine, then

$$\theta_{\text{electrical}} = p\,\theta_{\text{mechanical}} \text{ and}$$

Synchronizing power co-efficient per mechanical **radian** is given by:

$$P_{Syn} = p\frac{dp}{d\delta} \text{ Watts}$$

Synchronizing power co-efficient per mechanical **degree**

$$P_{Syn} = \frac{p\pi}{180}\frac{dp}{d\delta} \text{ watts.}$$

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c) Hunting: ***Refer to Question No. 5 of Short Answer Type Questions.***

3 PHASE SYNCHRONOUS MOTOR

Multiple Choice Type Questions

1. During hunting of synchronous motor [WBUT 2008, 2018]
   a) negative phase sequence currents are generated
   b) harmonies are developed in the armature circuit
   c) damper bar develops torque
   d) field excitation increases

Answer: (a)

2. When a 3-phase synchronous motor is running at synchronous speed, the damper winding produces [WBUT 2011, 2015]
   a) damping torque
   b) eddy current torque
   c) torque aiding the developed torque
   d) no torque

Answer: (d)

3. A synchronous motor is operating on no load at unity p.f. If the field current is increased, the p.f. will become [WBUT 2011, 2014]
   a) leading and current will decrease
   b) lagging and current will increase
   c) lagging and current will decrease
   d) leading and current will increase

Answer: (a)

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4. A synchronous motor is floating on infinite mains at no load. If its excitation is increased, it will draw [WBUT 2012]
   a) unity power factor current
   b) zero power factor lagging current
   c) zero power factor leading current
   d) no current

Answer: (c)

5. V-curve of a synchronous motor is the curve between [WBUT 2016]
   a) armature current vs field current
   b) power factor vs field current
   c) excitation voltage vs armature current
   d) excitation voltage vs field current

Answer: (a)

6. In a synchronous motor [WBUT 2018]
   a) E is always less than V
   b) $E = V$
   c) E is more than V
   d) E may be more or less than V

Answer: (d)

7. A 3-phase synchronous motor has [WBUT 2019]
   a) high starting torque
   b) no starting torque
   c) low starting torque
   d) low starting torque

Answer: (b)

8. In the *V*-curves for alternator, the parameters of *x* and *y* coordinators are, respectively **[WBUT 2019]**

a) armature current and field current **b) power factor and field current**
c) armature current and torque **d) torque and field current**

Answer: (a)

Short Answer Type Questions

1. Explain why a synchronous motor is not self-starting. **[WBUT 2008, 2009]**

Answer:

If in a two pole (say N_s and S_s) stator of synchronous motor, is fed by a p-phase supply then a magnetic flux of constant magnitude but rotating at synchronous speed (say clockwise) will be produced. At any instant of rotor position, the stator poles will also be at that position. The two similar poles, N (of rotor) and N_s (of stator) as well as S and S_s will repel each other, with the result that the rotor tends to rotate in anticlockwise direction. But half a period later stator poles having rotated round, interchange their position and under these circumstances N_s attracts S and S_s attracts N. Hence rotor tends to rotate which is just the reverse of the first. Hence due to continuous and rapid rotation of stator poles, the rotor is subjected to a torque which is rapidly reversing i.e. in quick succession, i.e. the rotor is subjected to a torque which tends to move it first in one direction and then in the opposite. Owing to its large inertia, the rotor cannot instantaneously respond to such quickly reversing torques with the result that it remains stationary. Hence synchronous motor is inherently not self-starting.

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2. What is a synchronous condenser? Explain its operation and utility with phasor diagram. **[WBUT 2011, 2013, 2015]**

OR,

Write short note on Synchronous condenser. **[WBUT 2014, 2016]**

Answer:

Synchronous condenser is a synchronous motor running without a mechanical load. A synchronous motor takes a leading current when overexcited and therefore behaves as a capacitor. It is connected in parallel to the supply or load as shown in fig. It generates leading current to neutralize the lagging component of the load current, results improve the power factor.

Let $P_1 \rightarrow$ the active power of load

$\cos\phi_1 \rightarrow$ pf of load without synchronous condenser

$\cos\phi_2 \rightarrow$ pf of load after using synchronous condenser

$P_S \rightarrow$ active power taken by S.C from the supply.

The rating and the pf at which the Synchronous Condenser is operating can be calculated as follows.

Reactive power of load $Q_1 = P_1 \tan\phi_1$

When Synchronous Condenser is connected in the circuit

Total load (active power) $P = P_1 + P_S$

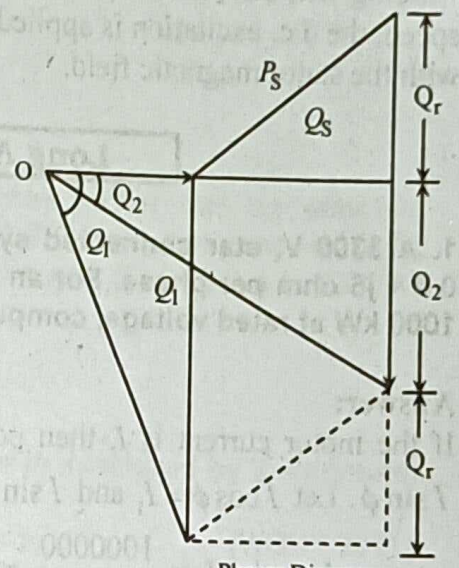
Total reactive power $Q_2 = P \tan \phi_2$

Reactive power supplied by the synchronous condenser $Q = Q_1 - Q_2$

From fig the rated KVA of Synchronous Condenser

$P_1 = \sqrt{P_r^2 + Q_2^2}$

Power factor of Synchronous Condenser $\cos \phi_2 = \frac{P}{P_S}$



Phasor Diagram

Advantages:

- A synchronous condenser has an inherently sinusoidal wave form and the voltage does not exist.
- It can supply and absorb kVAr.
- The pf can be varied in smoothly.
- It allows the overloading for short periods.
- The high inertia of the synchronous condenser reduces the effect of sudden changes in the system load and improves the stability of the system.
- It reduces the switching surges due to sudden connection or disconnection of lines in the system.

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3. How does the synchronous motor start? Explain clearly. **[WBUT 2016]**

Answer:

As the synchronous motor is required to be brought to a speed sufficiently close to the synchronous speed to lock into synchronism with the rotating field, the means by which it is brought up to speed are:

a) Starting with an External Prime-mover

In this method, an external motor drives the synchronous motor and brings it to synchronous speed. The synchronous machine is then synchronized with the bus bar as a synchronous generator. The prime-mover is then disconnected. Once in parallel the synchronous machine will work as a motor. Now the load can be connected to the synchronous motor. Since load is not connected to the synchronous motor before synchronizing, the starting motor has to overcome the inertia of the synchronous motor at no load. Therefore the rating of the starting motor is much smaller than the rating of the synchronous motor.

At present most large synchronous motors are provided with brush less excitation system mounted on their shafts. These exciters are used as starting motors.

b) Motor Starting with Damper Winding

This method is most widely used. A damper winding consists of heavy copper bars inserted in slots of the pole faces of the rotor. These bars are short circuited by end rings at both ends of the rotor. Thus, these short circuited bars forms a squirrel cage winding.

When a 3-phase supply is connected to the stator, the synchronous motor with damper winding will start as a 3-phase induction motor. As the motor approaches synchronous speed, the d.c. excitation is applied to the field windings. The rotor will then pull into step with the stator magnetic field.

Long Answer Type Questions

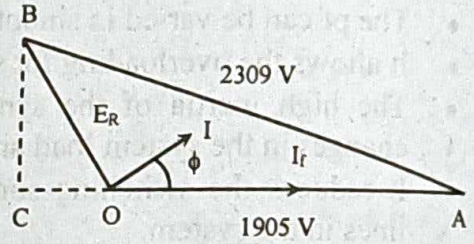
1. A 3300 V, star connected synchronous motor has synchronous impedance of 0.4 + j5 ohm per phase. For an excitation emf of 4000 V and motor input power of 1000 kW at rated voltage, compute line current and power factor.

[WBUT 2007, 2014]

Answer:

If the motor current is I, then power component is $I\cos\phi$ and reactive component is $I\sin\phi$. Let $I\cos\phi = I_1$ and $I\sin\phi = I_2$ so that $I = I_1 + jI_2$

$$I\cos\phi = I_1 = \frac{1000000}{\sqrt{3}\times 3300} = 174.95\text{ A}$$



$$\text{Applied voltage / phase} = \frac{3300}{\sqrt{3}} = 1905.25\text{ V}$$

$$\text{Induced emf / phase} = \frac{4000}{\sqrt{3}} = 2309.40\text{ V.}$$

From the above figure, $OA = 1905$ V and $AB = 2309$ V

IO leads OA by ϕ.

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$$E_R = IZ_s \text{ and } \theta = \tan^{-1}\left(\frac{5}{0.4}\right) = 85.42°$$

BC is perpendicular to AO produced

Now, $E_R = IZ_s = (I_1 + jI_2)(0.4 + j5)$

$$= (175 + jI_2)(0.4 + j5) = (70 - j5) + j(0.4I_2 + 875).$$

From the right angled triangle, ABC, we have: -

$$AB^2 = BC^2 + AC^2 = BC^2 + (AO + OC)^2$$

$$AB^2 = BC^2 + (AO + OC)^2$$

$$(2309)^2 = (875 + 0.4I_2)^2 + (1905 + 70 - 5I_2)^2$$

$$5331481 = 765625 + 350I_2 + 0.16I_2^2 + 3900625 - 9875I_2 + 25I_2^2$$

$$5331481 = 4666250 - 9825I_2 + 25.16I_2^2$$

$$25.16I_2^2 - 9875 - 665231 = 0$$

$$I_2 = \frac{9875 \pm \sqrt{(9875)^2 + 4\times 665231\times 25.16}}{2\times 25.16}$$

$$I_2 = 451.1\text{ A}$$

$$\therefore \quad I = \sqrt{I_1^2 + I_2^2} = \sqrt{(174.95)^2 + (451.1)^2} = 484.2\text{ A}$$

$$P.f = \frac{I_1}{I} = \frac{174.95}{484.2} = 0.36$$

2. A 2 kV, 50 Hz, 3-phase, *Y*-connected synchronous motor has an effective resistance and synchronous reactance of 0.2 Ω and 2.2 Ω per phase respectively. The input is 800 kW at rated voltage and the induced *e.m.f.* (line value) is 2500 V. Evaluate

i) the line current
ii) the power factor
iii) the motor speed (if it is a 6-pole machine) and
iv) the readings of the two wattmeters if the power is measured by 2-wattmeter method.

Draw the per-phase phasor diagram at this condition. **[WBUT 2011]**

Answer:

i) Supply voltage/phase, $V = \frac{2000}{\sqrt{3}} = 1154.7344\text{ V}$

Induced emf/phase, $E = \frac{2500}{\sqrt{3}} = 1443.4180\text{ V}$

Since induced emf is greater than supply voltage therefore, the motor must operate with a leading power factor.

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[In a star connected synchronous motor, phase current I = line current]

$$R_s = 0.2\Omega \qquad X_s = 2.2\Omega$$

$$Z_s = \sqrt{R_s^2 + X_s^2} = \sqrt{0.2^2 + 2.2^2} = 2.209\Omega$$

or, $$I\cos\phi = \frac{\text{Power input}}{\sqrt{3}V_L} = \frac{800 \times 1000}{\sqrt{3} \times 2000} = 230.94688\text{ A}$$

$$\theta = \text{Internal angle}$$

$$\theta = \tan^{-1}\frac{2.2}{0.2} = \tan^{-1}\frac{22}{2} = \tan^{-1}11 = 84.8055°$$

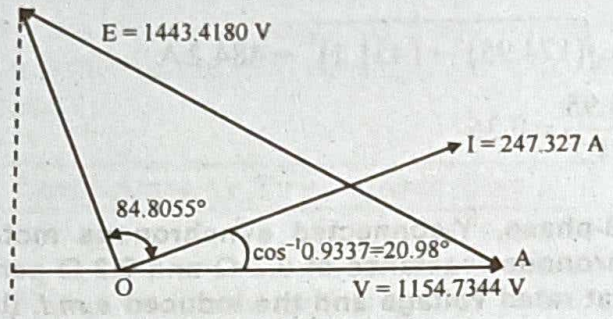
Impedance drop $E_R = IZ_s = 2.209I$

$$AC = \sqrt{E^2 - (E_R\cos\phi)^2} = \sqrt{1443.4180^2 - (2.209I\cos\phi)^2}$$

$$= \sqrt{1443.4180^2 - (2.209 \times 230.9468)^2}$$

$$= \sqrt{2083455.522724 - 260264.7369}$$

$$= \sqrt{1823190.785824} = 1350.2558\text{ V}$$



ii) $OC = AC - AO = 1350.2558 - 1154.7344 = 195.5214\text{ V}$

Now, $E_R = \sqrt{BC^2 + OC^2} = \sqrt{(2.209 \times 230.9468)^2 + (195.5214)^2}$

$= \sqrt{260264.7369 + 38228.6178} = \sqrt{298493.354796} = 546.3454\text{ V}$

Line current $I = \dfrac{E_R}{Z_s} = \dfrac{546.3454}{2.209} = 247.327\text{ A}$

Power factor $\cos\phi = \dfrac{I\cos\phi}{I} = \dfrac{230.94688}{247.327} = 0.9337$ leading

iii) 6 pole machine $P = 6$, $f = 50$ Hz

motor speed $N_s = \dfrac{120f}{P} = \dfrac{120 \times 50}{6} = 1000$ r.p.m.

iv) In case of two wattmeter method the formula is

$\phi = \tan^{-1}\sqrt{3}\dfrac{P_1 - P_2}{P_1 + P_2}$

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$P_1 + P_2 = 800\text{ kW}$ ...(1)

$\Rightarrow \quad \tan\phi = \sqrt{3}\dfrac{P_1 - P_2}{P_1 + P_2}$

$\Rightarrow \quad \tan\left(\cos^{-1}0.9337\right) = \sqrt{3}\dfrac{P_1 - P_2}{P_1 + P_2}$

$\Rightarrow \quad 0.38348 = \sqrt{3}\dfrac{P_1 - P_2}{P_1 + P_2}$

$\Rightarrow \quad \dfrac{0.38348}{1.732} = \dfrac{P_1 - P_2}{800}$

$\Rightarrow \quad P_1 - P_2 = \dfrac{800 \times 0.38348}{1.732}$

$\Rightarrow \quad P_1 - P_2 = 177.736\text{ kW}$ ....(2)

Solving (1) & (2) we get

$\Rightarrow \quad P_1 = 488.868\text{ kW}$

$\Rightarrow \quad P_2 = 311.164\text{ kW}.$

3. A 3-phase star connected 400 V synchronous motor takes a power input of 5472 Watts at rated voltage. Its synchronous reactance is 10 ohms per phase and resistance is negligible. If the excitation voltage is adjusted equal to the rated voltage 400 V, compute the load angle, power factor and armature current.

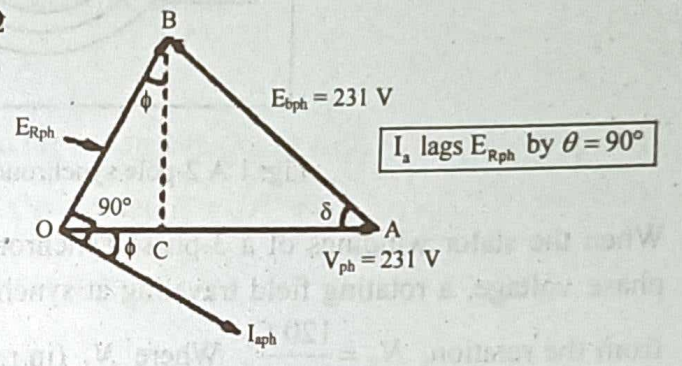
[WBUT 2015]

Answer:

$V_L = 400$ volts, $V_{ph} = 231$ volts

Power input = 5472 watts

$$Z_s = R_a + jX_s = 0 + j10 = j10\,\Omega$$



Power input $= \sqrt{3} \cdot V_L \cdot I_L \cos\phi$

$$5472 = \sqrt{3} \times 400 \times I_L \times \cos\phi$$

$$I_L \cos\phi = 7.9$$

$$E_{Rph} = I_L \cdot Z_s = I_L \cdot 10 = 10 I_L$$

$$BC = 10 I_L \cos\phi = 10 \times 7.9 = 79$$

In ΔABC, $\quad AB^2 = AC^2 + BC^2$

$$AC^2 = AB^2 - BC^2 = (231)^2 - (79)^2$$

$\therefore \quad AC^2 = 47120$

$\therefore \quad AC = 217.07$

$\therefore \quad OC = OA - AC = 231 - 217.07 = 13.93 = 14$

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In ΔOCB, $\quad (OB)^2 = (OC)^2 + (BC)^2 = (14)^2 + (79)^2 = 196 + 6241 = 6437$

$\therefore \quad OB = 80.2309$

But $\quad OB = E_{Rph} = 10 I_L$

$$10 I_L = 80.2309$$

$$I_L = 8.023\text{ A}$$

$$\tan\phi = \frac{OC}{BC} = \frac{14}{79} = 0.1772$$

$\therefore \quad \phi = 10.049°$

$$\text{p.f.} = \cos\phi = 0.9846 \text{ (lag)}$$

Load angle, $\quad \tan\delta = \dfrac{BC}{AC} = \dfrac{79}{217.07} = 0.3639$

$$\delta = 20°$$

4. a) Discuss the working principle of 3-phase synchronous motor. [WBUT 2019]

Answer:

A 2-pole synchronous motor is shown below in Fig. (1)

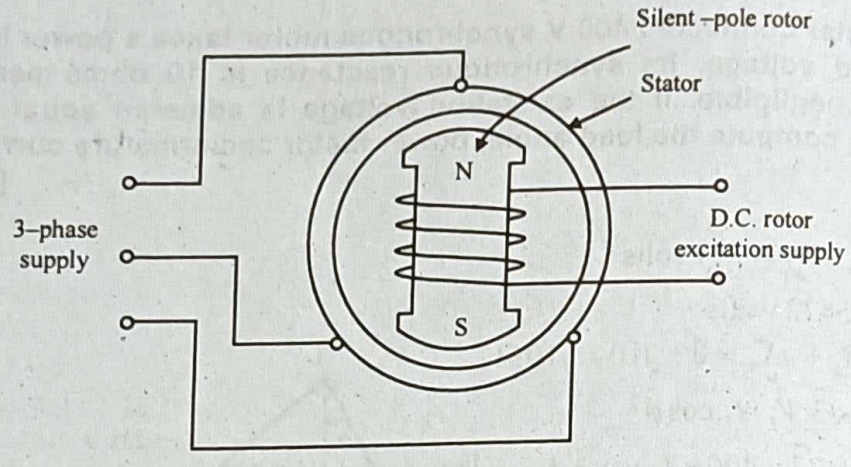

Fig: 1 A 2-pole synchronous motor

When the stator windings of a 3-phase synchronous motor are supplied with rated 3ϕ phase voltage, a rotating field traveling at synchronous speed is set up, which is found from the relation, $N_S = \frac{120f}{P}$. Where N_S (in r.p.m.), f and P are synchronous speed, frequency and number of poles respectively. The rotating magnetic field cuts across the squirrel cage type of winding of the rotor and induces voltages and currents in the bars of this winding. The resultant magnetic field of squirrel cage winding embedded in the rotor field poles reacts with the stator field in such a manner as to cause rotation of the stator. The rotor will increase its speed to a point slightly below the synchronous speed of the stator field. The rotor of the typical synchronous motor accelerate to about 95 to 97% of synchronous speed when started as an induction motor with amortisseur or squirrel cage windings. The field circuit is now excited from an outside source of D.C and magnetic poles of fixed polarity are set up in the rotor field cores. The fixed magnetic poles of the rotor are attracted to unlike poles of the rotating magnetic field set up by the stator windings. The rotor when runs at the same speed as that of the stator field i.e. N_S.

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b) Why synchronous motor is called a condenser? What is the function of synchronous condenser? **[WBUT 2019]**

Answer:

1st Part:

A overexcited synchronous motor acts like a capacitor boosting the power factor of the system. Since a capacitor is static component and a overexcited synchronous motor performs the same action as that of static capacitor it called as a condenser.

2nd Part:

Synchronous condenser is a synchronous motor running without a mechanical load. A synchronous motor takes a leading current when overexcited and therefore behaves as a capacitor. It is connected in parallel to the supply or load as shown in figure below. It generates leading current to neutralize the lagging component of the load current, results improve the power factor.

Let $P_1 \rightarrow$ the active power of load

$\cos\phi_1 \rightarrow$ pf of load without synchronous condenser

$\cos\phi_2 \rightarrow$ pf of load after using synchronous condenser

$P_S \rightarrow$ active power taken by S.C from the supply.

The rating and the pf at which the Synchronous Condenser is operating can be calculated as follows.

Reactive power of load $Q_1 = P_1 \tan\phi_1$

When Synchronous Condenser is connected in the circuit

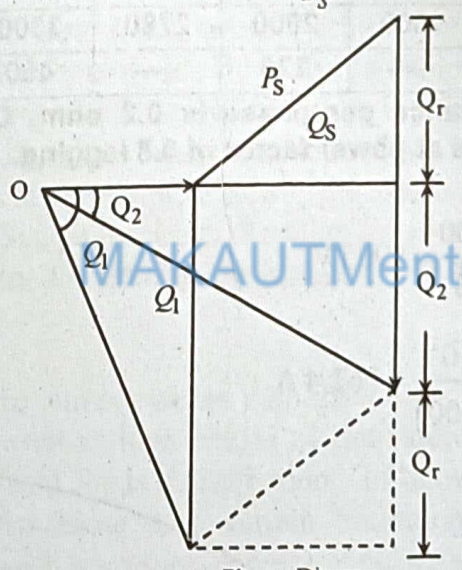
Total load (active power) $P = P_1 + P_S$

Total reactive power $Q_2 = P\tan\phi_2$

Reactive power supplied by the synchronous condenser $Q = Q_1 - Q_2$

From fig the rated KVA of Synchronous Condenser $P_1 = \sqrt{P_r^2 + Q_2^2}$

Power factor of Synchronous Condenser $\cos\phi_2 = \dfrac{P}{P_S}$



Phasor Diagram

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c) Write down the function of Damper winding of synchronous machine.

[WBUT 2019]

Answer:

Synchronous motors are not self starting machines. These machines are made self starting by providing a special winding in the rotor poles, known as damper winding or squirrel cage windings. The damper winding consists of short circuited copper bars embedded in the face of the rotor poles

When an ac supply is provided to stator of a 3-phase synchronous motor, stator winding produces rotating magnetic field. Due to the damper winding present in the rotor winding of the synchronous motor, machine starts as induction motor (Induction machine works on the principle of induction. Damper windings in synchronous motor will carry out the same task of induction motor rotor windings. Therefore due to damper windings

synchronous motor starts as induction motor and continue to accelerate). The exciter for synchronous motor moves along with rotor. When the motor attains about 95% of the synchronous speed, the rotor windings is connected to exciter terminals and the rotor is magnetically locked by the rotating magnetic field of stator and it runs as a synchronous motor.

Functions of Damper Windings:

- Damper winding helps the synchronous motor to start on its own (self starting machine) by providing starting torque.
- By providing damper windings in the rotor of synchronous motor "Hunting of machine" can be suppressed. When there is change in load, excitation or change in other conditions of the systems rotor of the synchronous motor will oscillate to and fro about an equilibrium position. At times these oscillations become more violent and resulting in loss of synchronism of the motor and comes to halt.

5. A 3-phase, 1500 kVA, 3300 V, 50 Hz star-connected alternator gave the following data for open-circuit and short circuit:

Field current (*A*)	5	10	15	20	25	30
O.C. voltage (*V*)	1000	2000	2780	3300	3664	3923
S.C. current (*A*)	-----	225	-----	450	-----	-----

Effective armature resistance per phase is 0.2 ohm. Calculate the full voltage regulation by mmf method at power factor of 0.8 lagging. [WBUT 2019]

Answer:

$$\text{Normal phase voltage} = \frac{3300}{\sqrt{3}} = 1905\ \text{V}$$

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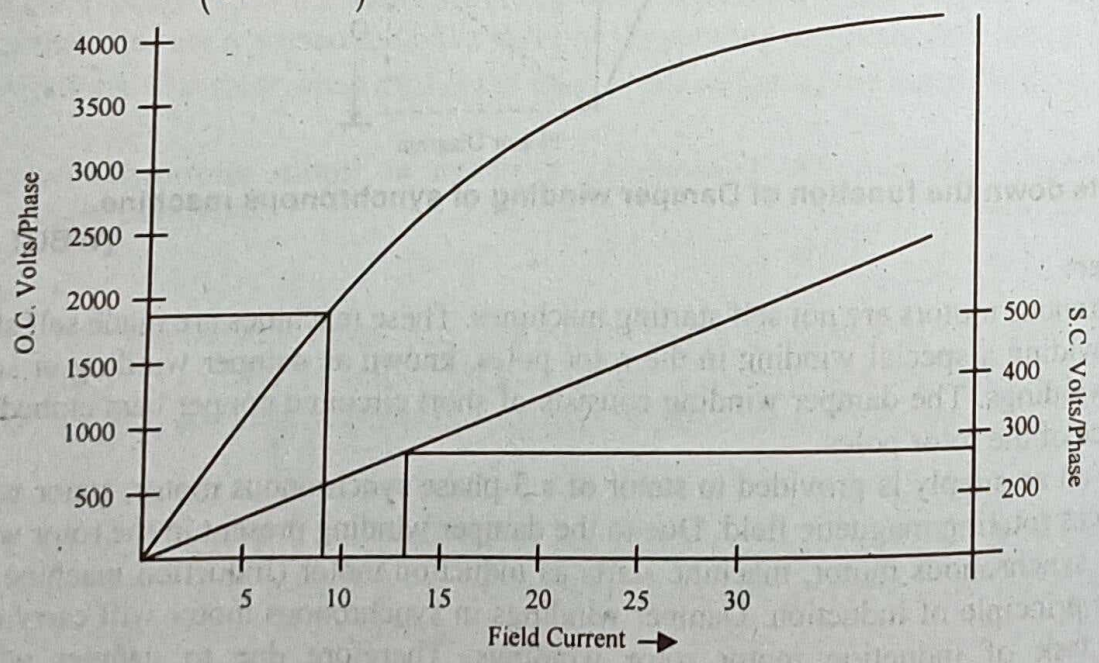
$$\text{Full load current} = \frac{1500 \times 10^3}{\left(\sqrt{3} \times 3300\right)} = 262.4\ \text{A}$$



0.8pf lagging $E_{ph} = \sqrt{(V\cos\phi + IRa)^2 + (V\sin\phi + Ix_s)^2}$

$$z_s = \frac{OC \text{ voltage per phase}}{SC \text{ current per phase}} = \frac{1905}{262.4} = 7.25\Omega$$

$$E_{ph} = \sqrt{(1905\times0.8 + 262.4\times0.2)^2 + (1905\times0.6 + 262.4\times7.25)^2} = 3429.2$$

$$\text{Voltage regulation} = \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100 = \frac{3429.2 - 1905}{1905} \times 100 = 80\%$$

6. Write short notes on the following:

a) Salient pole synchronous machine and its particular applicability in synchronous motors. [WBUT 2011]

b) V-curve of a synchronous motor [WBUT 2016]

c) Synchronous condenser [WBUT 2018]

Answer:

a) The field structure of salient pole synchronous machine is almost entirely for slow and moderate speed machine and frequently provided with a damper winding on the rotor to damp rotor oscillations during transient conditions and to facilitate operation under unbalanced load conditions. In case of a synchronous motor the field structure is to be energised by direct current as in alternator, where as the armature winding is connected to a 3-phase a.c. supply mains. Such a machine, therefore, requires to sources of supply viz. an a.c. source to supply power for driving the armature and a d.c. source to excite the field.

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b) The magnitude of armature current varies with excitation. The armature current has large values both for low as well as high values of excitation and the armature current lags for low excitations, but lead for high excitation. In between, the armature current has certain minimum (corresponding to a certain excitation) for a given load. The variation of armature current with excitation is represented by a curve known as V-Curve which is shown in Fig. 1 below.

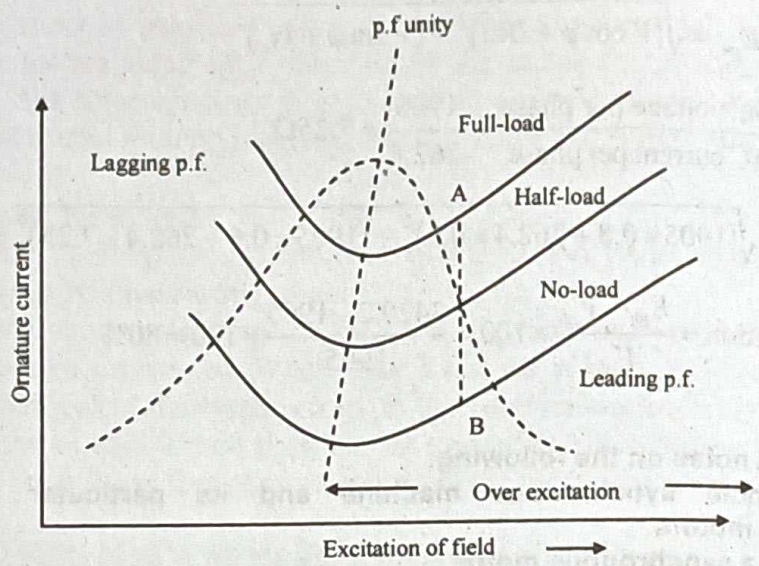

Fig: 1 V- curves

c) Synchronous condenser:

Refer to Question No. 2 of Short Answer Type Questions.

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SPECIAL ELECTRO MECHANICAL DEVICES

Multiple Choice Type Questions

1. What type of motor is most suitable for a computer printer drive? [WBUT 2007, 2013]

a) Reluctance motor
b) Hysteresis motor
c) Shaded pole motor
d) Stepper motor

Answer: (d)

2. Which motor has the starting torque proportional to iron loss? [WBUT 2007, 2015]

a) stepper motor
b) hysteresis motor
c) permanent magnet motor
d) switch reluctance motor

Answer: (b)

3. The motor generally used in a tape recorder is [WBUT 2008, 2015]

a) universal motor
b) reluctance motor
c) split-phase motor
d) hysteresis motor

Answer: (d)

4. A single phase hysteresis motor can run at [WBUT 2008, 2018]

a) synchronous speed
b) subsynchronous speed
c) synchronous and supersynchronous speed
d) synchronous and subsynchronous speed

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Answer: (a)

5. Induction generator runs at [WBUT 2009, 2011, 2012, 2015]

a) super-synchronous speed
b) sub-synchronous speed
c) synchronous speed
d) none of these

Answer: (a)

6. In brushless dc motor we have [WBUT 2011]

a) no mechanical commutator
b) no brushes
c) no arcing
d) all of these

Answer: (d)

7. A stepper motor is [WBUT 2012]

a) a dc motor
b) a single phase ac motor
c) a two phase motor
d) a multi-phase motor

Answer: (c)

8. A synchro has [WBUT 2012]
   a) 3-phase winding on rotor and l-phase winding on stator
   b) 3-phase winding on stator and commutator winding on rotor
   c) 3-phase winding on stator and l-phase winding on rotor
   d) 1-hase winding on stator and commutator winding on rotor

Answer: (c)

9. A 6 pole, 50 Hz single phase induction motor runs at a speed of 900 r.p.m. The frequency of current in the cage rotor will be [WBUT 2012]
   a) 5 Hz b) 55 Hz c) 95 Hz d) 100 Hz

Answer: (a)

10. The ac tachometer is [WBUT 2013]
   a) nothing but a synchronous motor
   b) nothing but a two-phase induction motor
   c) nothing but a single-phase induction motor
   d) none of these

Answer: (b)

11. The motor generally used in a tape recorder is [WBUT 2013]
   a) universal motor b) reluctance motor
   c) split-phase motor d) hysteresis motor

Answer: (d)

12. A compensated winding in an ac commutator motor [WBUT 2013]
   a) reduces reactance drop and improves commutation
   b) reduces reactance drop
   c) reduces reactance drop but retards commutation
   d) improves commutation only

Answer: (d)

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13. The direction of rotation of universal motor can be reversed by [WBUT 2017]
   a) reversing the supply terminals b) switching over from ac to dc
   c) interchanging the brush leads d) any of the above

Answer: (c)

14. The disadvantage of shaded pole motor is [WBUT 2017]
   a) low starting torque b) low efficiency
   c) very little over load capacity d) all of these

Answer: (d)

15. Which motor is generally used in tape recorders? [WBUT 2017]
   a) Universal motor b) Reluctance motor
   c) Split phase motor d) Hysteresis motor

Answer: (d)

16. The amount of torque required to move a stepper motor one full step is called [WBUT 2017]

a) holding torque
b) residual torque
c) detent torque
d) developed torque

Answer: (a)

17. In a BLDC motor, we have [WBUT 2017]

a) no mechanical commutator
b) no brushes
c) no arcing
d) all of these

Answer: (d)

18. For the same no. of poles which stepper motor produces largest stepping angles? [WBUT 2018]

a) Variable reluctance type
b) Hybrid type
c) Permanent magnet type
d) All of these

Answer: (a)

19. The stepping angle for a 3-phase, 24 pole permanent stepper motor is [WBUT 2018]

a) 15 degree
b) 8 degree
c) 5 degree
d) 4 degree

Answer: (c)

20. Which of the following motors has the largest starting torque? [WBUT 2019]

a) Shaded pole motor
b) Split phase motor
c) Repulsion motor
d) Capacitor start motor

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Answer: (d)

Short Answer Type Questions

1. Explain the operating principle of a stepper motor. [WBUT 2009, 2010, 2013]

Answer:

Stepper motor is a form of a.c motors and are used extensively in open loop positioning system. The input given to this motor is in the form of electric pulses. For every input pulses, the motor shaft turns through a specified number of degrees, called a step. The name stepping given to this motor is based on its working principle. One step of rotation for one input pulse. Thus, this motor is an ac motor whose shaft moves through one angular step for each input pulse. The range of step size may vary from 0.72° to 90°. Thus a stepping motor can be regarded as a digital electro-mechanical devices and it translates the input digital information in the form of electric pulses into discrete steps of shaft rotation without any rotor position sensor and an expensive feed back loop.

Operation

The currents so received by the stator winding of the motor is used to make the axis of air gap field around in coincidence with the input pulses. The rotor follows the axis of air

gap magnetic field by virtue of the permanent magnet torque and/or the reluctance torque, depending upon the pulse rate and load torque (including inertia effects).

The step angle as already stated may be very small (0.72°) or very large (90°). The usual step sizes are (1.8°), (2.5°) (7.5°) and (15°). The step angle is expressed by the formula:

$$\beta = \frac{360°}{m\ N_r}$$

where m is the number of stator phases and N_r is the number of rotor poles or teeth.

Resolution of stepper motor is equal to the number of steps per resolution:

$$\text{Resolution} = \frac{360°}{\beta}$$

The shaft speed of stepper is $n = \frac{\beta \times f}{360}$ where f is pulse rate or stepping frequency.

2. Describe the principle of operation of an induction generator. Can it be classified as a synchronous generator or as an asynchronous generator? [WBUT 2011]

OR,

Discuss construction and working principle of an induction generator. [WBUT 2012]

Answer:

1st Part: *Inductor Alternator*

This machine is built to generate a.c supplies of frequencies from 250 c/s. to 200 kc./s. for industrial high-frequency-heating loads. For a given speed and number of rotor "poles" (or teeth), the machine will produce a frequency twice that of a comparable synchronous machine. The absence of rotor windings allows the speed to be raised to the safe limit of rotor centrifugal stress.

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The *homopolar* machine has two stator and two rotor cores forming a single magnetic circuit, energized by an annular d.c exciting winding, as shown in Fig. 1 below:

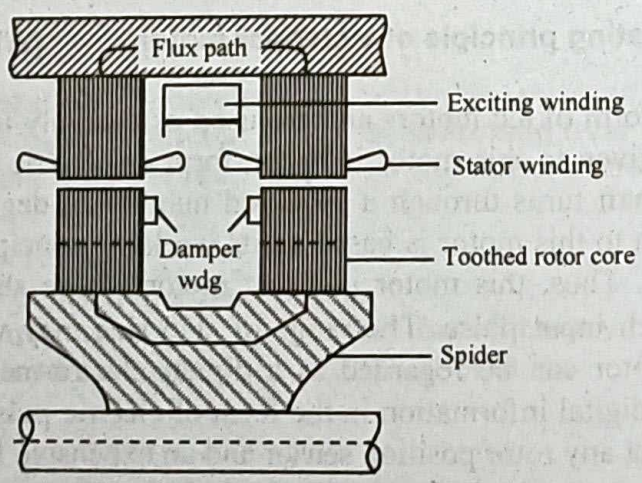

Fig: 1 Homopolar inductor alternator

The *heteropolar* type has a single stator and rotor core. The short shaft makes possible a very short gap, an important advantage in determining the output. The stator and rotor carry varieties of slotting, and the stator periphery is divided into heteropolar zones, Fig. 2.

Both types have the same basic principle, i.e., the pulsation or variation of the magnetic flux linking the stator coil system, resulting from cyclic changes of gap permeance round the stator bore. The permeance is most effectively varied by use of rectangular rotor teeth and a short gap. Movement of the rotor through on tooth-pitch then produces one complete cycle of gap-permeance variation.

If S_2 is the number of rotor slots (or teeth), and n is the rotor space in r.p.s., then the frequency generated is $f = nS_2$. This is independent of the stator tooth arrangement.

To utilize fully the variation of flux, the stator coils should have a pitch of one-half the rotor pitch. Fig. 1(a) and 1(b) show two arrangements for homopolar machines. One has a substantially conventional winding: the other has coils round individual stator teeth. A type of heteropolar arrangement is shown at Fig. 1(c). Here the *total* working flux remains substantially constant so that no appreciable alternating e.m.f. is induced in the d.c exciting coils.

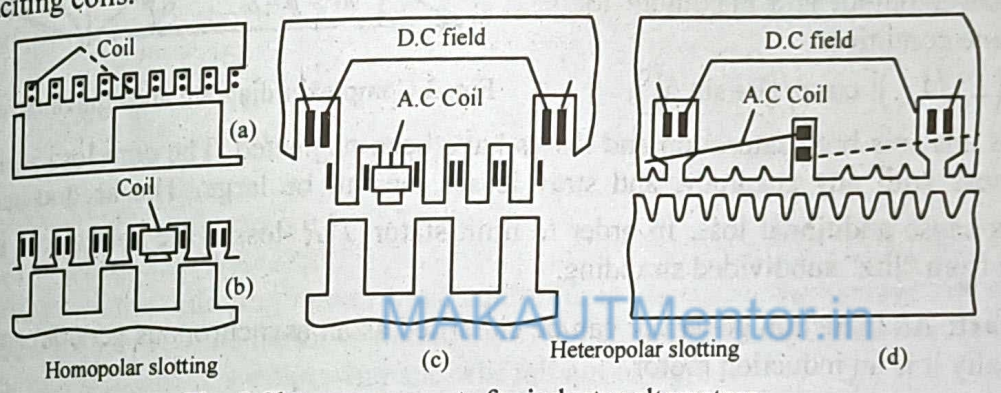

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Fig: 2 Slot arrangements for inductor alternators

The rotor slot-pitch in a machine of rotor diameter D is $y_2 = \pi D/S_2 = \pi Dn/nS_2 = u/f$, so that with the peripheral speed u limited mechanically by centrifugal stress, the slot-pitch must be very small for high frequencies. It then becomes necessary to use stator and rotor teeth of equal pitch, Fig. 2(d), producing a pulsating flux; with the stator coils housed in larger slots of span equal to any suitable number of the smaller teeth.

Theory: The gap permeance fluctuates as the stator and rotor teeth move in and out of register. Let it be represented by $\Lambda_0 + \Lambda_1 \cos\theta$, with θ the electrical angle of rotor displacement from the position of maximum permeance. Neglecting iron-circuit reluctance, the no-load flux will be $\Phi_0 = F_f(\Lambda_0 + \Lambda_1 \cos\theta)$ for a d.c excitation F_f ampere-turns. On load the stator carries a current $i\sin(\theta - \phi - \alpha)$ corresponding to an armature reaction $F_a \sin(\theta - \phi - \alpha)$, where ϕ is the (lagging) power-factor angle of the external load, and α is an additional angle of lag caused by a shift in the angular position of the maximum flux caused by armature reaction. The load flux is then $\Phi = [F_f + F_a \sin(\theta - \phi - \alpha)][\Lambda_0 + \Lambda_1 \cos\theta]$ This product gives a constant term (the average flux), a second-harmonic term (neglected for simplicity) and the term giving the fundamental alternating flux $\Phi_m = F_f\Lambda_1 \sin(\theta + 90°) + F_a\Lambda_0 \sin(\theta - \phi - \alpha) = \Phi_f + \Phi_a$ to

which two e.m.f's E_t and E_a correspond, giving the output e.m.f E as their resultant. The complexor diagram in Fig. 3 shows the relation between these quantities. The machine can be represented by the equivalent circuit comprising an e.m.f source E_t with a synchronous reactance $x_s = E_a/I$ and a load Z of phase-angle ϕ.

The volt-ampere output is

$$EI = E_t^2 Z \Big/ \left[(Z\cos\phi)^2 + (Z\sin\phi + x_s)^2 \right]$$

which is a maximum when $Z = x$. The power output is a maximum for the same condition:

$$P_m = \left(E_t^2/4x_s\right)\left[\cos\phi/(1+\sin\phi)\right].$$

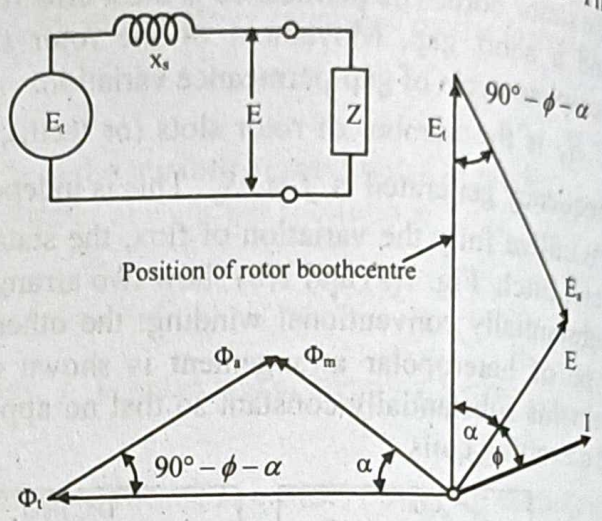

Fig: 3 Complexor diagram and equivalent circuit

In this analysis both saturation and losses have been neglected. The core loss is difficult to assess with any accuracy, and stray losses tend to be large. The second-harmonic fluxes cause additional loss. In order to limit stator I^2R losses the conductors may be made from "litz" subdivided stranding.

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2nd Part: An induction generator can be classified as an asynchronous generator because basically it is an induction motor.

3. Explain the operation of a variable-reluctance type stepper motor. Why does it fall out of step if the pulsing rate of logic controller is increased? [WBUT 2011]

Answer:

1st Part: Variable reluctance stepper motor

The stator of this motor consists of equally spaced projected poles on its inner periphery. The poles or teeth are wound with exciting coils. The exciting coils are supplied from dc through switch.

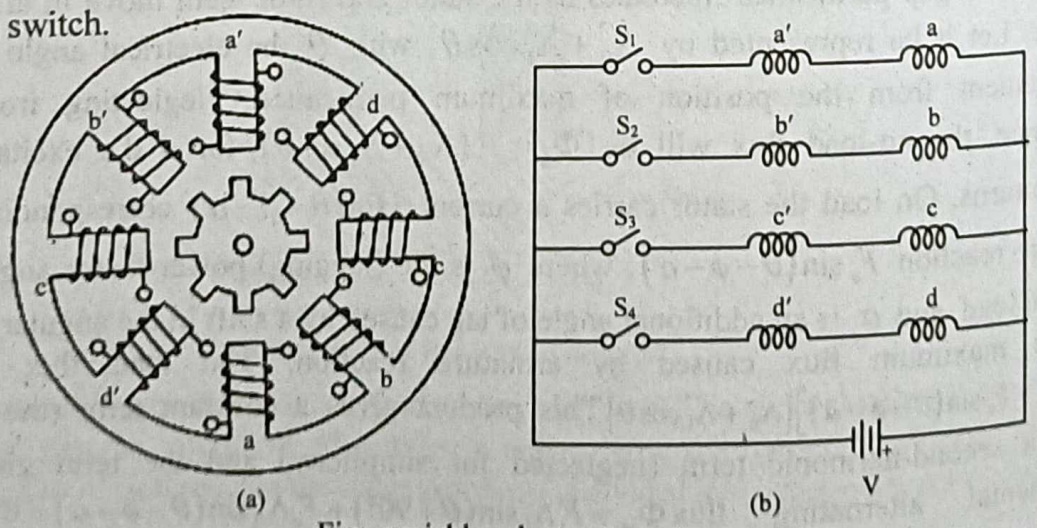

Fig: variable reluctance motor

The switches are closed in proper sequence. The stator windings that are in diametrically opposite are connected in series so that when one pole is South Pole, the opposite pole is North Pole. The stator is laminated to avoid eddy current losses.

The rotor consists of teeth projected from its outer periphery. The teeth are of same width as that of the stator teeth. The rotor may be laminated or some times it may be solid piece.

If there are N no of stator coils, they are connected in two coil groups to form $\frac{N}{2}$ circuits, these circuits are called phases.

The stator coils are excited in proper sequence using S_1, S_2, S_3, and S_4. This makes the rotor to move in steps in order to occupy the minimum reluctance position. Since the rotation is due to the variation in reluctance between the stator and rotor teeth, the motor is called as variable stepper motor. The direction of rotation can be reversed by reversing the sequence of switching the windings.

The step angle for the above motor with 4 No. of stator phases and 6 no. of rotor teeth is

$$\beta = \frac{360°}{m \times N_r} = \frac{360}{4 \times 6} = 15°$$

The operation of variable reluctance stepper motor can be:

a) Full step operation.
b) Half step operation.
c) Micro step operation.

2nd Part: When the pulsating rate of logic controller is increased, the average velocity of the rotor increases and the motor is said to slow. When the pulse rate is further exceeded the rotor may pull out of synchronism and will fall out of step.

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4. With appropriate circuit diagram explain the operation of a brushless D.C. motor. Can it run without motor position feedback? [WBUT 2011]

Answer:

1st Part: ***Refer to Question No. 4.a) of Long Answer Type Questions.***

2nd Part: In the case of brushless DC motors, the feedback is with some electronic feedback sensor such as magnetic Hall sensors, encoders or resolvers. The key point is that the windings are sequentially switched with the drive electronics in Brushless DC motors. Without the electronics, the motor cannot even run. Conversely since the Brushless DC motors have electronics any way, they can use to accomplish speed control and many other useful functions.

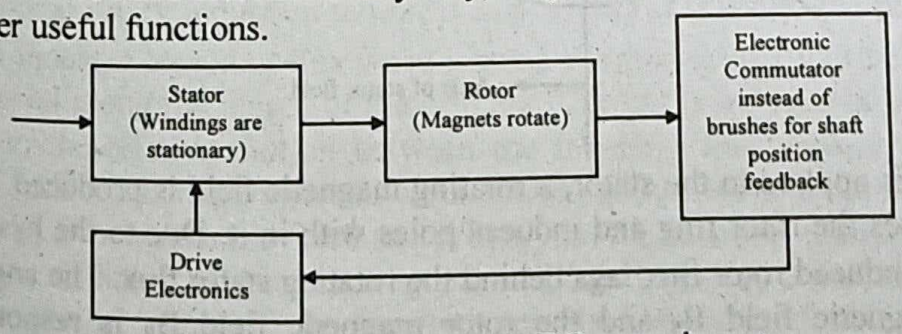

Fig: Brushless type DC motor layout

5. The number of poles or teeth in the stator and rotor of a stepper motor are different. Why? **[WBUT 2018]**

Answer:

Stepper motor move in discrete steps when current is applied to the stator. The size of the step is determined by the no. of phases in the stator. The stator of a stepper motor consists of poles with teeth and each pole has a winding. Phases are made up of poles connected by their windings. When current is applied to a phase, each pole in that phase is energized and magnetized. Poles are 180° opposite to each other and are magnetized with same polarity.

The rotor of a stepper motor is made up of two parts, each part has a set of teethes and the teeth of one part are magnetized as north poles, while the teeth on the other part are magnetized as south pole, when the rotor moves so that its teeth line up with the magnetized teeth of the stator.

6. Write down the working principle of hysteresis motor with necessary diagram. **[WBUT 2018]**

Answer:

A hysteresis motor is a synchronous motor with a uniform air gap and without DC excitation. It operates both in single and three phase supply. The torque in a hysteresis motor is produced due to hysteresis and eddy current induced in the motor by the action of rotating flux of the stator windings. The working of the motor depends on the working of the continuously revolving magnetic flux.

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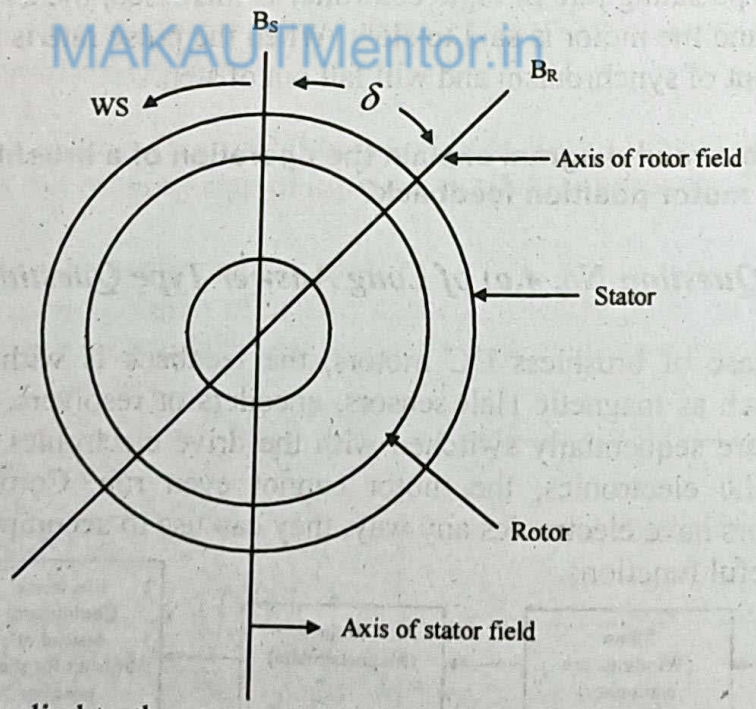

When supply is applied to the stator, a rotating magnetic field is produced. The magnetic field magnetises the rotor ring and induces poles with in it. Due to the hysteresis loss in the rotor, the induced rotor flux lags behind the rotating stator flux. The angle δ between the stator magnetic field B_S and the rotor magnetic field B_R is responsible for the production of the torque.

Long Answer Type Questions

1. Explain the principle of operation of Linear Induction motor. [WBUT 2006, 2007]

OR,

Write short note on Linear induction motor [WBUT 2011, 2012, 2013, 2015, 2016]

OR,

Explain the constructional feature and operating principle of linear induction motor. State its important application. [WBUT 2014, 2017]

Answer:

Linear induction motor gives linear motion instead of rotational motion as in the cape of conventional induction motor. in this motor the movement of the field is rectilinear and so the movement of conductors.

To explain the principle of operation of LIM. Fig. 1(a) and Fig. 1(b) as shown below may be referred to:

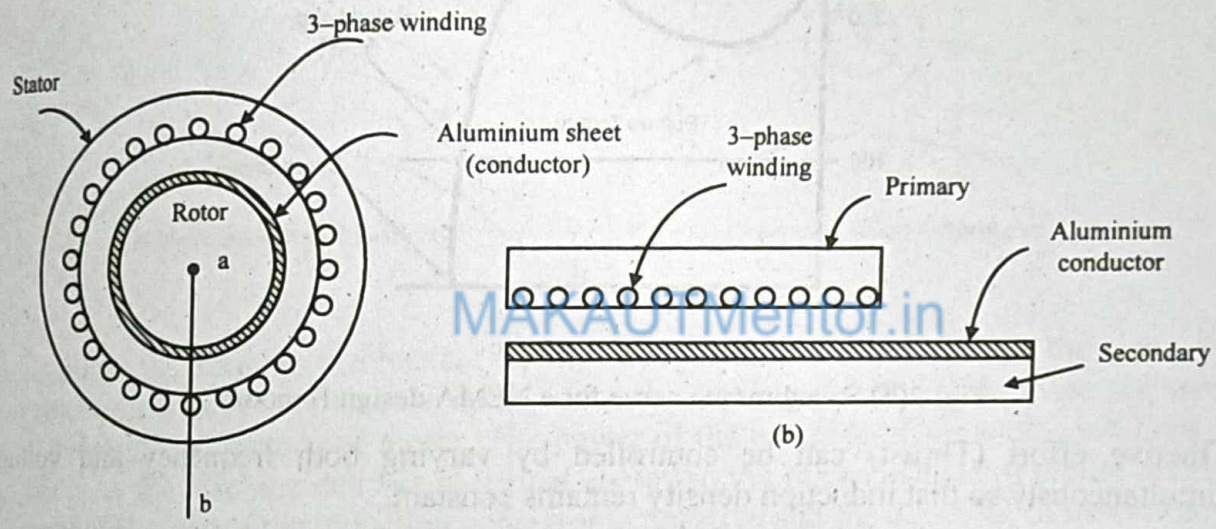

Fig: 1 (a) Rotary induction motor (b) Linear induction motor

If the stator of the poly phase rotary induction motor as shown in Fig. 1(a) as above cut along the line ab and spread out flat as shown in Fig. 1(b), then this forms primary of the linear induction motor and in this motor, the stator and rotor are called primary and secondary respectively. Secondary of LIM consists of a flat aluminum conductor with ferromagnetic core.

As in a conventional rotary induction motor, if 3-ϕ supply is given to the primary of the linear induction motor, a traveling flux wave instead of rotating flux will be produced in it, which will travel along the length of the primary. Current is induced in the aluminum conductor due to the relative motion between the traveling flux wave and aluminum conductor. The induced current interacts with traveling flux wave to produce a linear force (or, thrust F). If secondary is fixed and primary is free to move, the force will move the primary in the direction of the traveling wave. While Fig. 1(b) is called single sided linear induction motor, Fig. 2(a) as shown below is known as double sided linear induction motor (DLIM) which has primary on both the sides of the secondary.

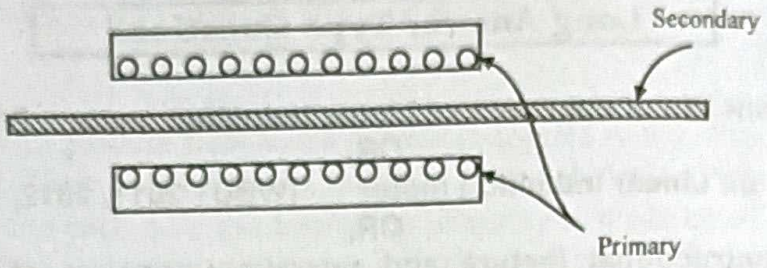

Fig: 2(a) Double-sided linear induction motor (DLIM)

The Thrust (or tractive effort) – speed characteristics of this type of motor is shown in Fig. 2(b) below.

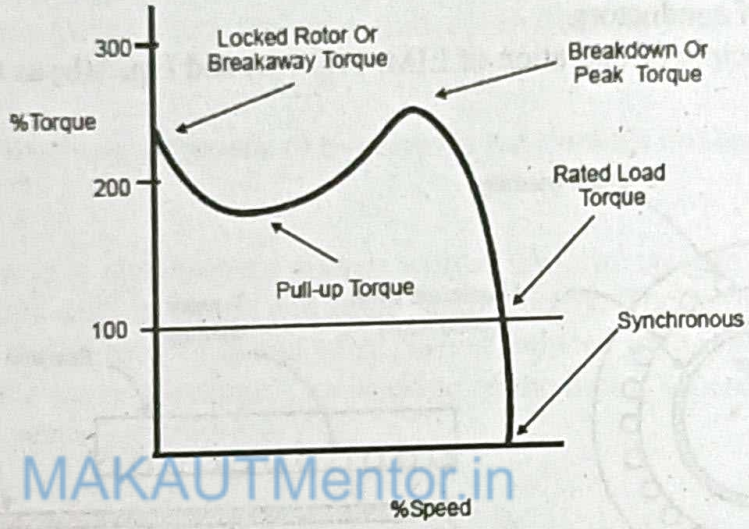

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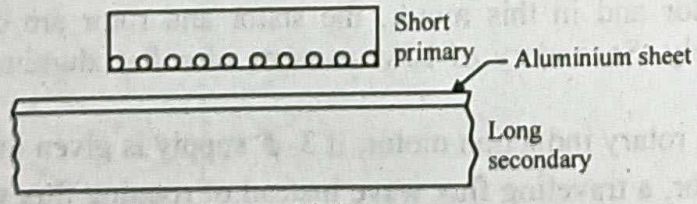
Fig: 2(b) Speed/torque curve for a NEMA design B motor

Tractive effort (Thrust) can be controlled by varying both frequency and voltage simultaneously so that induction density remains constant.

Application

An important application of a LIM is in transportation. Usually a short primary is on the vehicle and a long secondary is on the track as shown in figure below.



LIM for a vehicle

A LIM can also be used in other applications, such as materials handling, pumping of liquid metal, sliding-door closers and curtain pullers.

2. a) Describe the principle of operation and torque-speed characteristic of induction generator. **[WBUT 2010, 2016]**

Answer:
The induction generator only generates when the stator of a polyphase induction motor is connected at constant voltage and frequency and its rotor is mechanically coupled to a prime-mover and is driven by it at a speed higher than the synchronous speed. The rotor over takes the rotating magnetic field and the rotor conductors cut the magnetic flux in a reverse direction to motor rotation. As a result, the emfs and currents in the rotor will reverse their direction.
Consequently the reaction force between rotating field and rotor current also changes its direction and oppose the rotation as shown in Fig. (1).

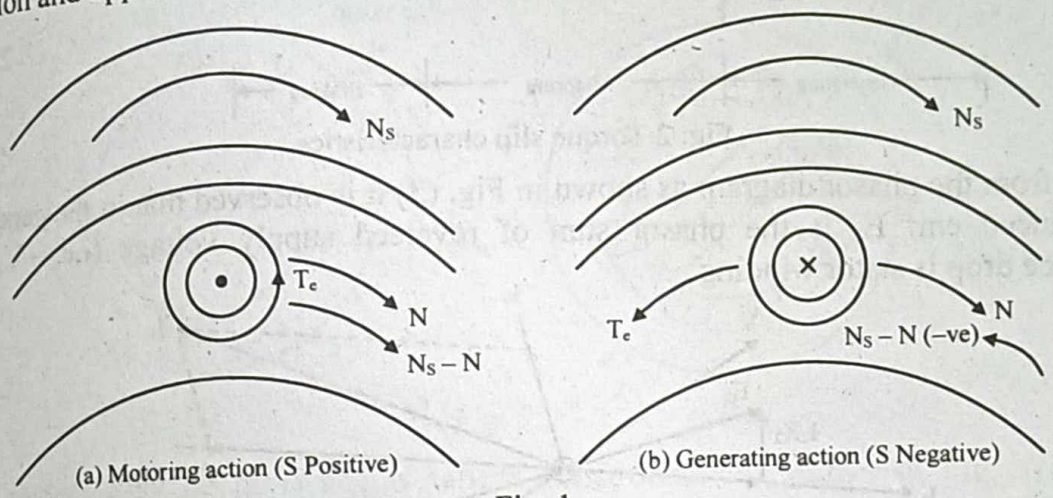


Fig: 1

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To maintain this rotation mechanical energy is required to be delivered to the rotor, the magnetising current remaining the same, since the rotating field conditions are the same in an induction generator and motor. The power of the machine under such conditions is negative i.e. the machine delivers electrical energy to the mains instead of taking it from the mains. The slip of the induction generator is negative and the direction of its emf now coincides with the active component of current instead of being opposed to it, as is the case of a motor. At super synchronous speed. The condition of an induction generator are electrically similar to those at sub-synchronous speed for induction motor.
From what have been stated it is clear that an induction generator supplies an active current to the mains but at the sometime, it receives from the mains a lagging reactive current (magnetising current), in the same way as a motor. That is why it requires a source of reactive energy to obtain this current. Such a source may be synchronous generator operating in parallel with an induction generator and feeding in to a common mains. Therefore, an induction generator cannot operate independently and operating in parallel and feeding into the mains, it reduces the power factor through its reactive current. However, the necessary reactive current may be supplied to an induction generator by static capacitors connected in parallel with it.
The torque slip characteristics of the induction generator resemble to those of the motor as shown in Fig. (2). The maximum value of torque that the induction generator can develop, limits its range of operation.

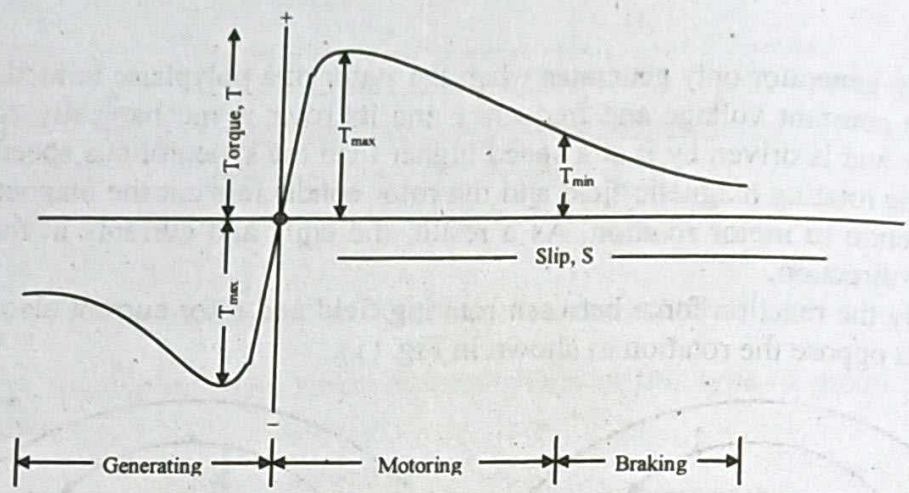

Fig: 2 Torque slip characteristics

Further, from the phasor diagram as shown in Fig. (3) it is observed that in the generating case induced emf E_1 is the phasor sum of reversed supply voltage (i.e. $-V_1$) and impedance drop is stator winding.

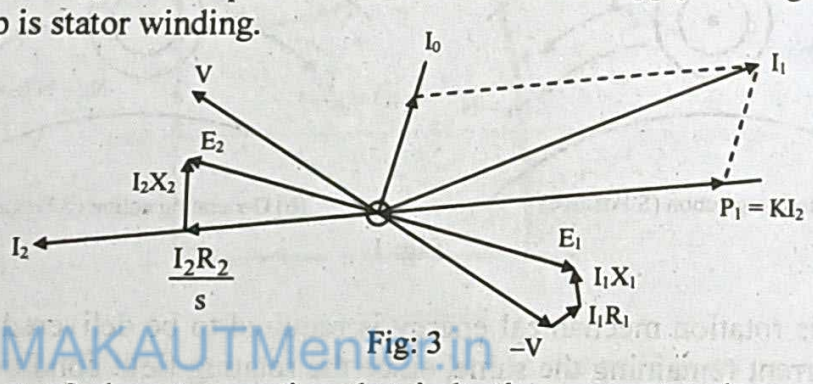

Fig: 3

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It will not be out of place to mention that induction generator does not have definite speed for a given frequency but speed with constant frequency varies with load, the load (active power) being practically proportional to the slip, S.

So it is essential that the prime-mover driving. The induction generator should have a rising characteristic. The prime-mover must be provided with automatic control to increase the speed of the generator when it is required to supply the increased load.

The induction generator is very useful for installation in small power station where it can be operated in parallel and feeding into a common mains without attendant. It is also very useful for braking purposes in railway work.

b) Explain the principle of operation of Linear Induction Motor and performance of LIM. **[WBUT 2010]**

Answer: ***Refer to Question No. 1 of Long Answer Type Questions.***

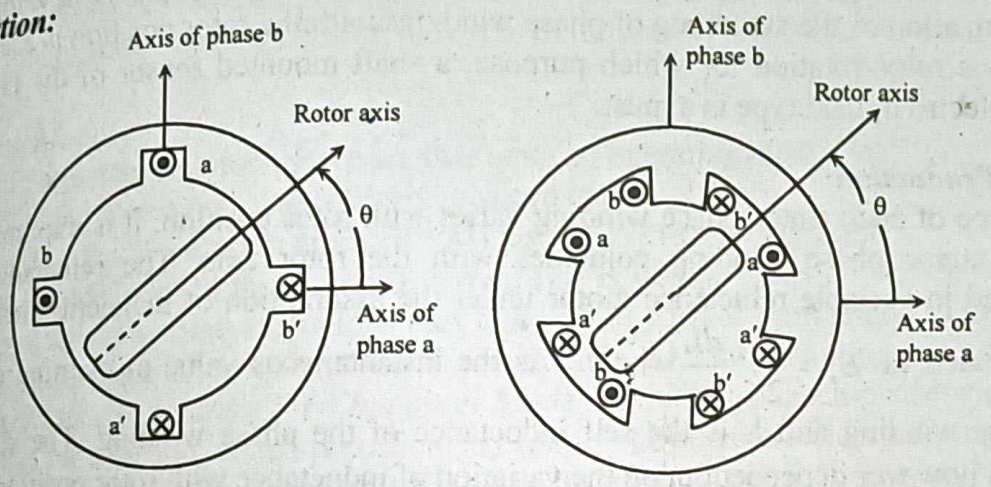
c) Explain the power developed in reluctance motor with the phase diagram. **[WBUT 2010]**

Answer:

Switched reluctance motor is also known as variable-reluctance motor (VRM). The name switched reluctance motor is just to indicate that switching inverter is required to drive a VRM. It has concentrated windings on stator poles and no winding on the rotor teeth and

should not be confused with synchronous motor which in fact has cylindrical stator with distributed windings and salient pole rotor with concentrated field winding. It is designed for continuous rotation and required a rotor position sensor. Further, it can be operated from unidirectional drive circuits resulting reduction of cost of micro and power electronics. As these motors can be manufactured with a large number of stator and rotor teeth, they give large torque per unit volume.

Construction:



(a) Fig: 1 (b)

These motors may be of i) single salient construction as shown in Fig. 1(a) above consisting of a non-salient stator and a two pole salient rotor which has no winding but the cylindrical stator has two phase winding and ii) doubly salient construction as shown in Fig. 1(b) consisting of four salient poles on stator and the rotor has two salient poles with no winding. The concentrated windings on radially opposite poles are connected in either series or parallel to result in two phases winding on stator. This shows that both motors of Fig. (1) have two-phase stator winding and a two pole salient rotor.

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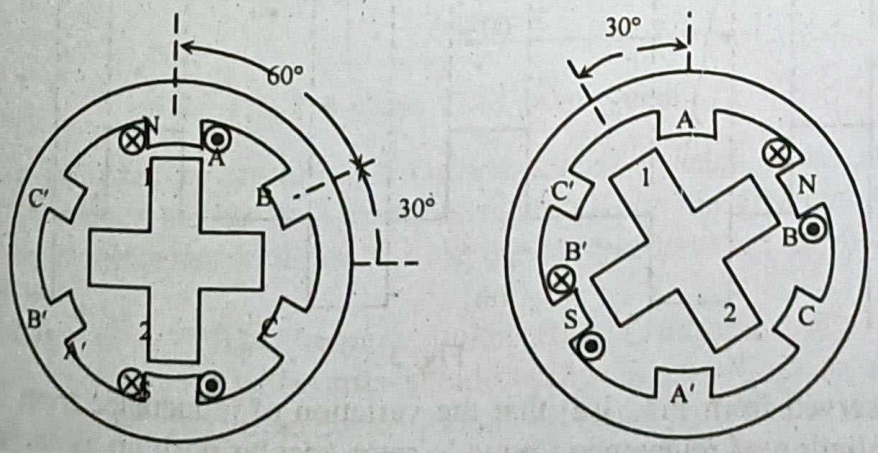
Principle of Operation:



(a) (b)

Fig: 2

With phase winding 'A' excited, the rotor orientation is shown in Fig. 2(a) and the flux linkages are maximized with phase A. When phase winding A is de-energized and phase winding B is excited, the rotor moves counter clockwise (CCW) so as to maximize the flux linkages with phase B Fig. 2(b). For further counter clockwise rotation, phase winding B is de-energized and phase winding C is energized. In fact, the phase current to stator phases are switched on and off in synchronism with rotor position so that continuous rotor position is achieved and a steady average torque is developed. The synchronization of the switching of phase windings with the rotor position is essential for continuous rotor rotation for which purpose, a shaft mounted sensor of the Hall effect type or electro optical type is a must.

Torque Production:

Inductance of each stator phase winding varies with rotor position; it is maximum when axis of stator phase winding coincides with the rotor axis. The reluctance torque developed in variable reluctance motor under the assumption of magnetic linearity, can be expressed as $E_e = \frac{1}{2} i^2 \frac{dL}{d\theta}$ where i is the instantaneous value of exciting current in the phase winding and L is the self inductance of the phase winding. The sign of the torque is however dependent upon the variation of inductance with rotor position θ.

Inductance variation of stator phase winding with respect to θ and torque angle characteristics are shown in Fig, 3(a) and 3(b).

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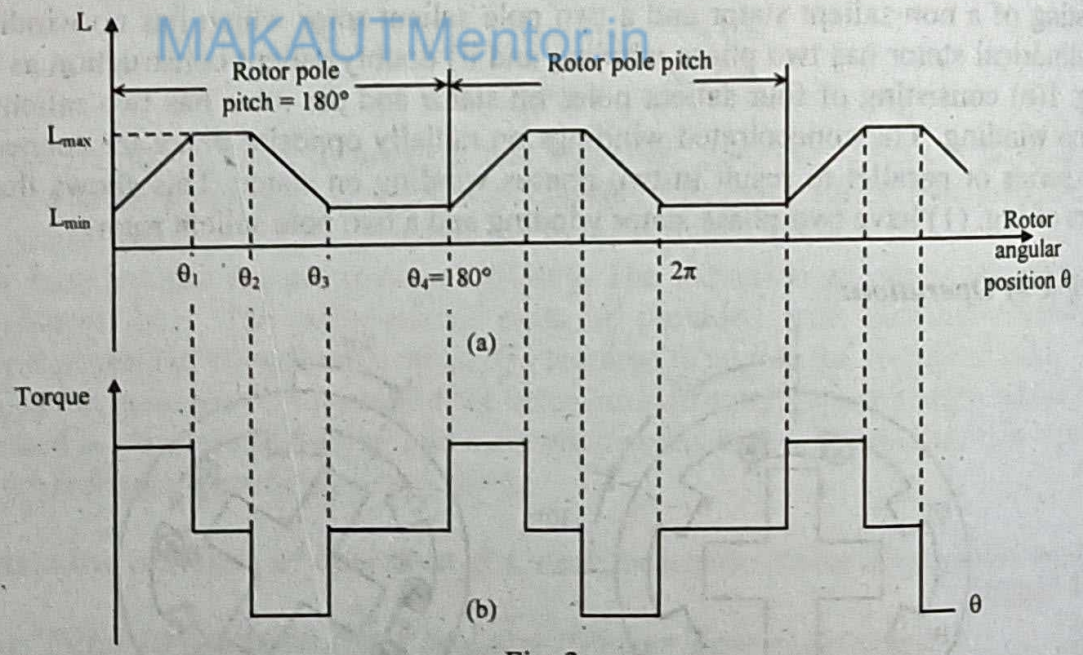

Fig: 3

It may be observed from Fig. 3(a) that the variation of inductance from L_{min} to L_{max} is linear. The variation of reluctance torque is rotor angular position as shown in Fig. 3(b) for a constant stator current in the phase winding. It may be observed further that

reluctance torque is positive when $\frac{dL}{d\theta}$ is positive and torque is negative for negative value of $\frac{dL}{d\theta}$.

No reluctance torque is produced when L is constant. Operation of motor for the condition of negative torque leads to regenerative process of VRM drive system. This shows that torque in VRM can be controlled by shifting the switching "ON" and "OFF" instants of the phase windings during the cycle of inductance variation.

Operating Mode:

In variable reluctance motors, there are two types of operating modes viz:-

i) Single pulse mode also called high speed mode

ii) Pulse width operation mode (PWM) also called low speed mode.

i) Single Pulse mode: In this case the current rise is within limits during the small time interval of each phase excitation. This build up of current limit is due to the winding inductance and motional counter emf generated in the stator winding.

ii) Pulse Width Modulation (or Chopping) Mode: In this mode each phase winding gets excited for a period, which is sufficiently long. The current build up during this long period of time may be prohibitively high. In order to keep the current rise within acceptable ratings of the motor and the inverter components, device is incorporated before variable reluctance motor as shown below in Fig. (4).

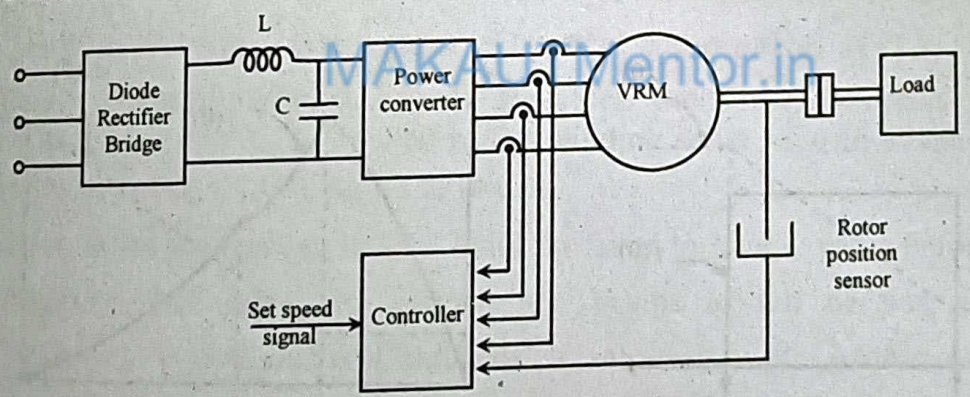

Fig: 4 4-phase VRM drive system

The above is achieved by installing a current sensor in each phase so as to monitor current. This current sensor then controls alternatively the ON and OFF instants of power inverter components in order to hold the current between permissible upper and lower levels.

Phase windings of a VRM, require unidirectional current pulse when rotor is approximately positioned. The inverter should apply direct voltage to phase winding at such rotor orientations that phase current builds up rapidly. When it is required to turn-off the phase winding, the inverter configuration should provide an alternative path for the rapid fall of phase current.

The inverter drive circuit configuration for VRMs is shown below in Fig. (5) in which connection it may be mentioned that the controlled switching device is either a thyristor, a GTO, power transistor, IGBT, MOSFET.

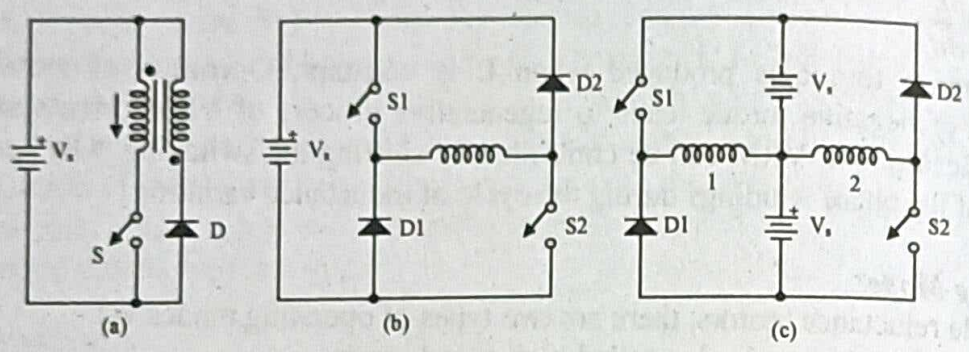

Fig: 5 Inverter drive circuit configuration for VRM

Fig. 5(a) and 5(b) are shown for one phase winding. Fig 5(a) uses bifilar phase windings consisting of two separate windings so that they are closely coupled magnetically.
Fig. 5(b) requires two switching devices and two feed back diode each phase.
Fig. 5(c) requires two d.c. sources and each phase needs one switch and one diode.
The circuit of Fig 5(c) is so arranged that phase 2 is connected opposite to phase 1.
Ideal current waveform for operation of VRM is shown in Fig 5(a) and waveforms for phase current and phase voltage for single phase and chopping mode of operations are shown in Fig. 5(b) and 5(c) below:

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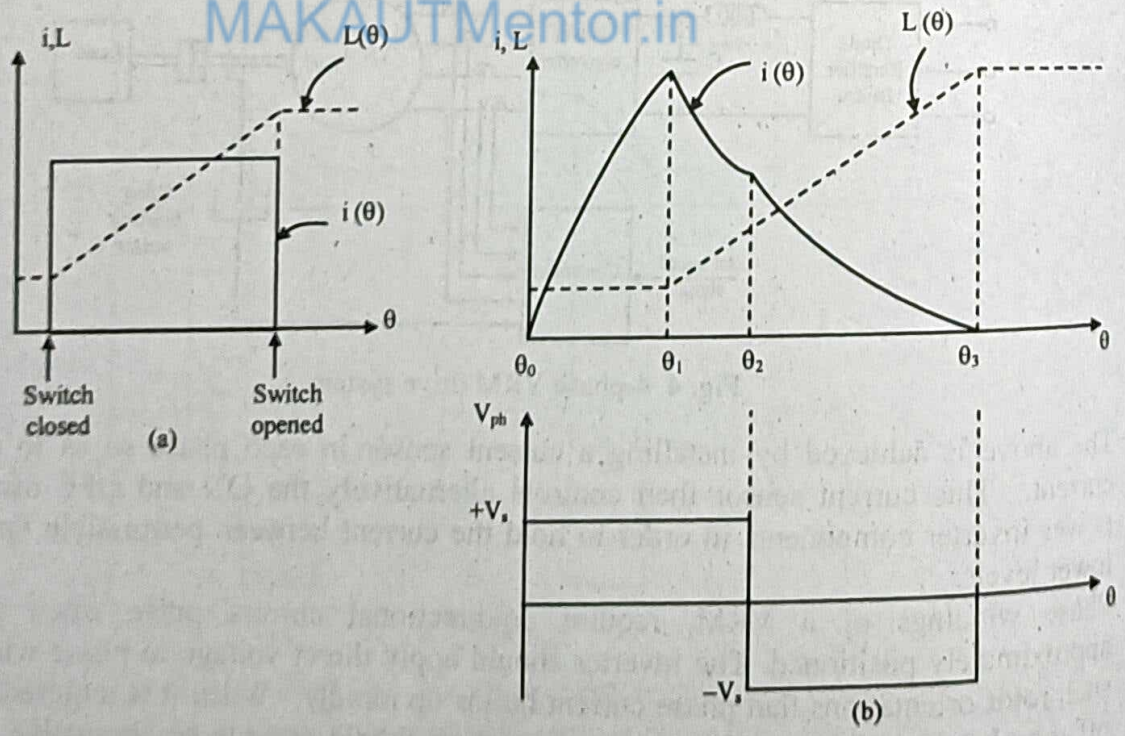

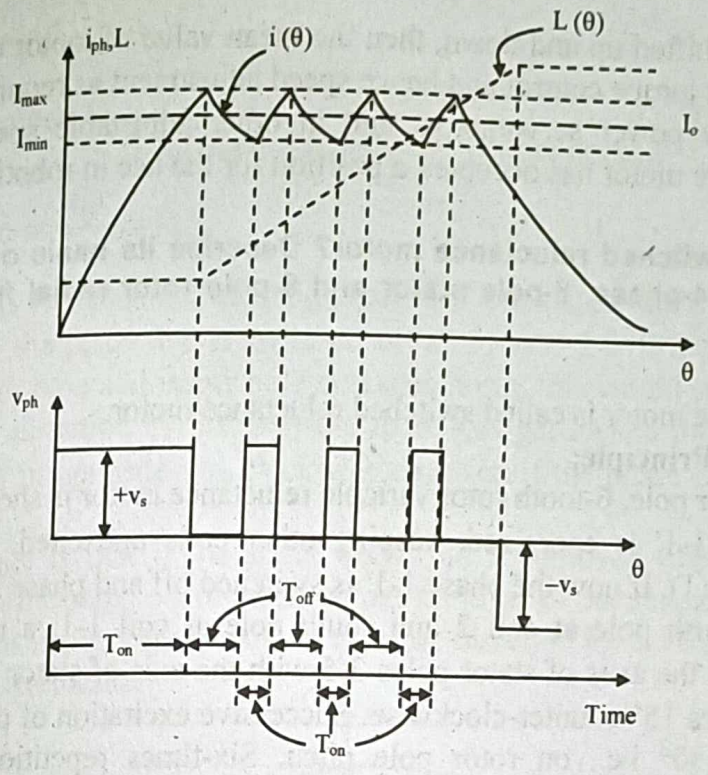

(c) Fig: 6

In Fig. 6(a) when inductance begins to rise, switch is closed and current at once reaches a constant value. When $L(\theta)$ stops rising, switch is opened and current decays to zero immediately. During the time current pulse is constant and positive, $L(\theta)$ is rising and therefore positive torque is produced. Actually such ideal waveforms are non-existent.

In Fig. 6(b), source voltage V_S is applied to the winding some what in advance of the instant when the inductance $L(\theta)$ begins to rise.

Low inductance allows the current $i(\theta)$ to build up faster to a large value before torque producing region begins. After θ_1, current $i(\theta)$ begins to fall because of rising inductance $L(\theta)$ and the motional emf until switch is opened at θ_2. At this rotor angle θ_2, negative voltage is applied to the phase winding. This causes rapid fall of current and finally $i(\theta)$ reduces to zero at extinction angle θ_3. Angle $(\theta_2 - \theta_0)$ is the transistor (or thyristor) conduction angle and $(\theta_3 - \theta_2)$ is the diode conduction angle of an inverter. Source delivers energy to motor during $(\theta_2 - \theta_0)$ and the energy is fed back by the motor to source during $(\theta_3 - \theta_2)$. The angle $(\theta_3 - \theta_0)$ is called conduction angle θ_C, is an important control parameter. The angle θ_0 is called the switch-on-angle and θ_2 is the switch off angle. Angle $(\theta_1 - \theta_0)$ is called angle of advance.

The chopped phase current as a function of rotor position θ is shown in Fig. 6(c). It may be seen from Fig. 6(c) that I_{max} and I_{min} are the upper and lower prescribed levels of chopped phase current and I_o is its mean value. If the upper and lower limits of each

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phase current are shifted up and down, then the mean value of motor current would alter which will result in torque control and hence speed adjustment as required.

Applications: Low power servomotors and in other adjustable speed drive systems. Switched reluctance motor has occupied a position for the use in robotics.

3. a) What is a switched reluctance motor? Describe its basic operating principle with regard to a 4-phase, 8-pole stator and 6-pole rotor radial flux (conventional) S.R. motor. [WBUT 2011]

Answer:

Variable reluctance motor is called switched reluctance motor.

Basic Operating Principle:

A 4-phase, 8-stator pole, 6-tooth rotor variable reluctance motor is shown in Fig. (1). When the phase 1-1′ is energized, keeping other coils unexcited, the rotor aligns as shown in the Fig. (1). If now the phase 1-1′ is switched off and phase 2 -2′ is switched on to develop north pole at coil 2 and south pole at coil 1-1, a reluctance torque is produced to align the axes of stator poles 2-5 with the axis of stator poles of phase 2-2′. The rotor advances 15° counter-clockwise. Successive excitation of phases 3, 4, 1′ yields a total advance 30° i.e., on rotor pole pitch. Six-times repetition of this sequence completes one revolution of the shaft. Rotor can be made to rotate in clockwise direction reversing the switching sequence.

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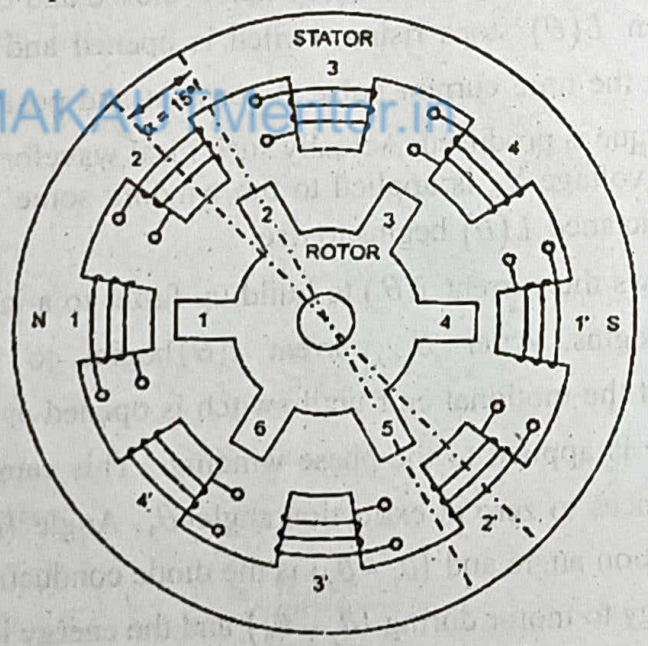

Fig: 1 4-phase, 8-pole stator, 6-tooth rotor variable reluctance stepper motor

b) What is the step-angle in the above case and what should be the interval (in mechanical degrees) after which the 4 phases of the above motor should be switched on sequentially, in case one phase is excited at a time? [WBUT 2011]

Answer:

Stepping angle is given as, $\alpha = \dfrac{360°}{\text{Number of phases} \times \text{number of poles}} = \dfrac{360}{np}$

In the above case $\alpha = \dfrac{360°}{4 \times 6} = 15°$

When phase 1-1′ is switched on, keeping phase 2-2′ unexcited, the rotor aligns as shown in Fig. (2). If now the phase 1-1 is switched off and phase 2-2′ is closed such that lower pole becomes south pole and upper pole becomes north, this would cause rotor to turn in counter-clockwise direction by 30° and the rotor will get locked into the new position. The rotor will turn in opposite i.e., clockwise direction if the phase 2-2′ wore oppositely excited.

The main advantage is that if the stator excitation is removed, the rotor continues to remain locked into the same position, as before removal of excitation. This is due to the reason that the rotor is prevented to move in either direction by the torque because of the permanent magnet excitation.

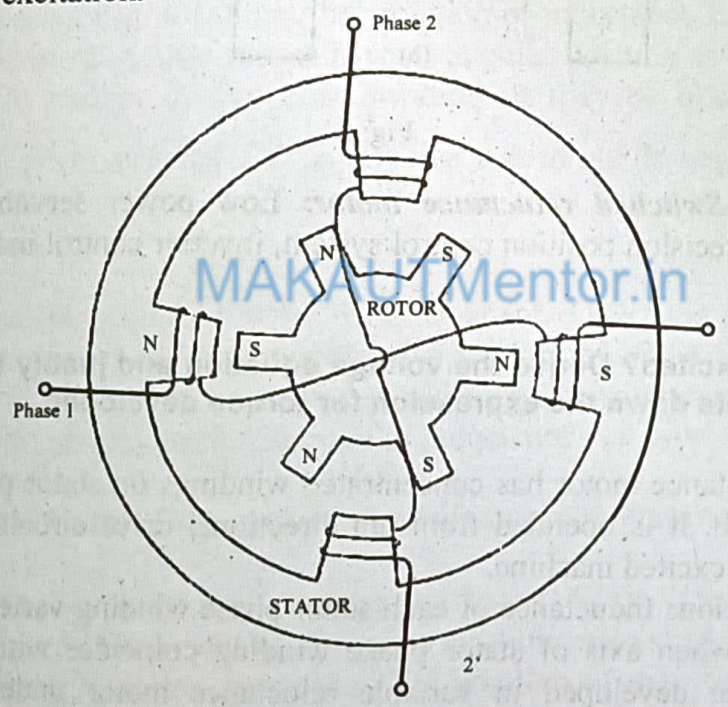

Fig: 2

c) What is the nature of the torque-speed characteristic? What are the application areas of this motor? **[WBUT 2011]**

Answer:

1st part:

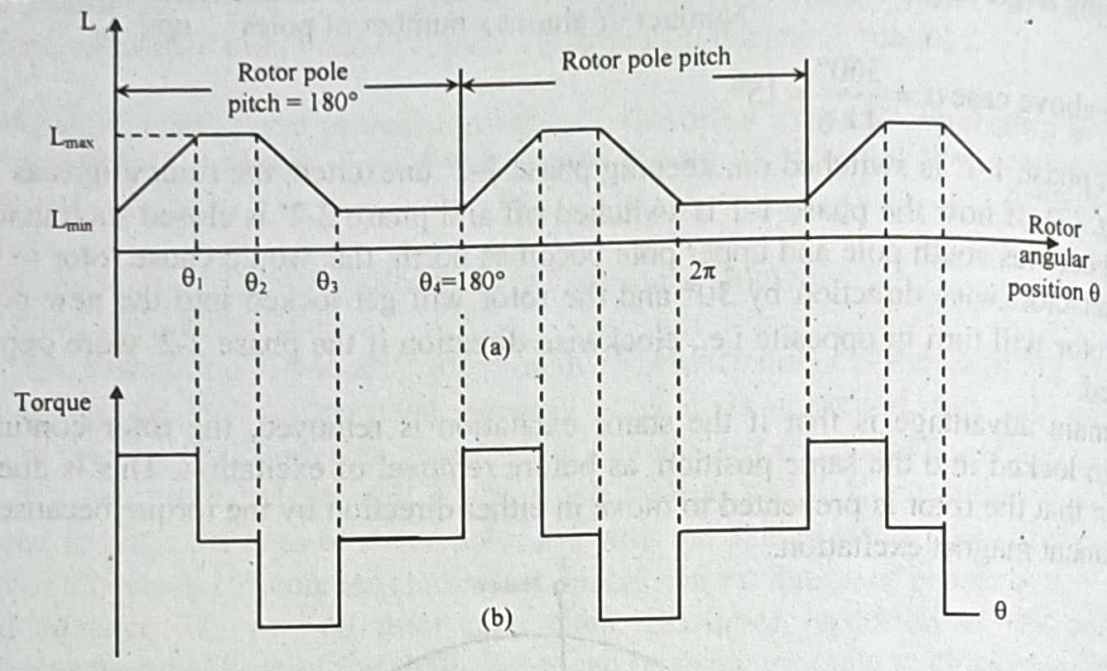

Fig: 3

2nd Part:

Applications of Switched reluctance motor: Low power servomotors, high power traction drives, precision position control system, inverter control induction motor drives etc.

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d) Is it doubly excited? Derive the voltage equation and justify the role of the term 'reluctance'. Write down the expression for torque developed. [WBUT 2011]

Answer:

A switched reluctance motor has concentrated windings on stator poles and no winding on the rotor teeth. It is operated from uni-directional drive circuits and this cannot be turned as doubly excited machine.

Torque Production: Inductance of each stator phase winding varies with rotor position; it is maximum when axis of stator phase winding coincides with the rotor axis. The reluctance torque developed in variable reluctance motor under the assumption of magnetic linearity, can be expressed as $E_e = \frac{1}{2} i^2 \frac{dL}{d\theta}$ where i is the instantaneous value of exciting current in the phase winding and L is the self inductance of the phase winding. The sign of the torque is however dependent upon the variation of inductance with rotor position θ.

Inductance variation of stator phase winding with respect to θ and torque angle characteristics are shown in Fig, 1.(a) and 1.(b).

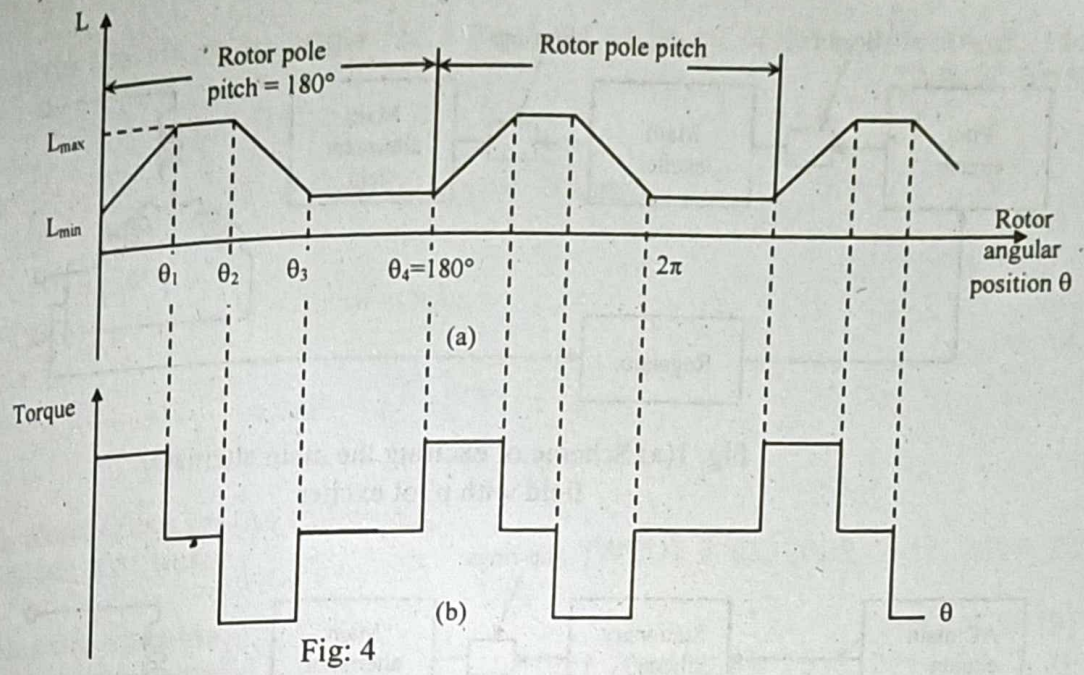

Fig: 4

It may be observed from Fig. 4 (a) that the variation of inductance from L_{min} to L_{max} is linear. The variation of reluctance torque is rotor angular position as shown in Fig.4(b) for a constant stator current in the phase winding. It may be observed further that reluctance torque is positive when $\frac{dL}{d\theta}$ is positive and torque is negative for negative value of $\frac{dL}{d\theta}$.

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No reluctance torque is produced when L is constant. Operation of motor for the condition of negative torque leads to regenerative process of VRM drive system. This shows that torque in VRM can be controlled by shifting the switching "ON" and "OFF" instants of the phase windings during the cycle of inductance variation.

4. Discuss the different excitation system of alternator with diagram. [WBUT 2019]

Answer:

One scheme of exciting the rotor field winding is illustrated Fig. 1(a). The pilot exciter and the main exciter are driven by the synchronous machine main shaft. The pilot exciter, which is small dc shunt generator, feeds the field winding of main exciter which is a separately-excited dc generator. The dc output from main exciter is given to the field winding of the main alternator through slip-rings and brushes. The function of the regulator is a keep the alternator terminal voltage constant at a particular value.

(a) Another scheme of exciting the main alternator field is excited in Fig. 1(b). It consists of main ac exciter and stationary solid-state rectifier. The ac main exciter, which is coupled with the shaft of the synchronous machine, has rotating field and stationary armature. The armature output from the ac exciter has a frequency of about 400 Hz. This output is given to the stationary solid-state controlled rectifier. After rectification, the dc power is fed to the main alternator field, through slip-rings and brushes.

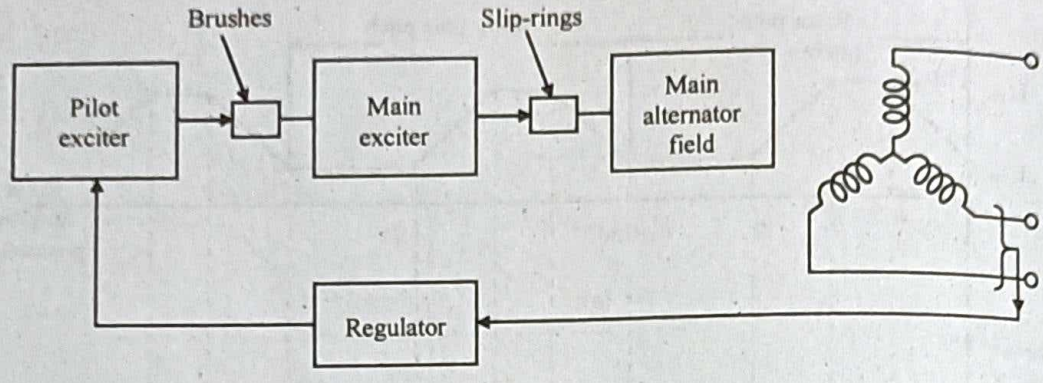

Fig: 1(a) Scheme of exciting the main alternator field with pilot exciter

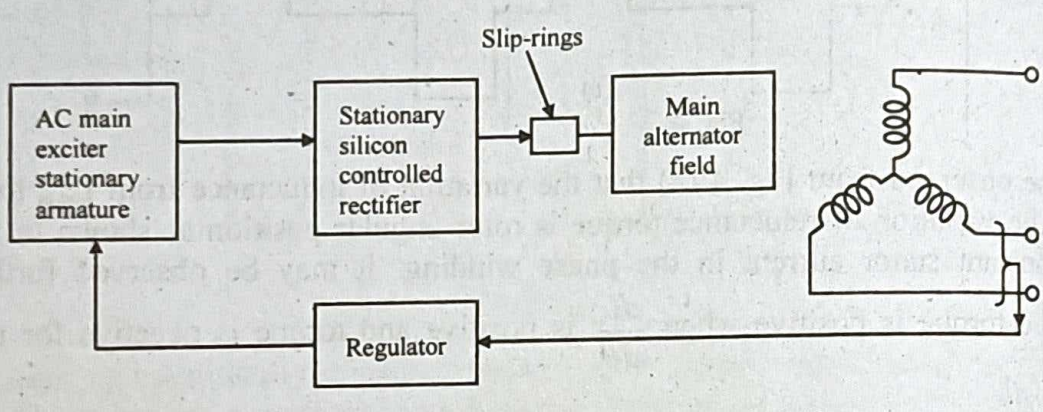

Fig: 1(b) Scheme of exciting the main alternator field with ac main exciter

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(b) The third scheme of supplying dc power to the rotating field winding is illustrated in Fig. 1(c). The a.c. exciter driven by the main synchronous machine has stationary field and rotating 3-phase armature. The 3-phase power from the ac exciter is fed, along the main shaft, to the rotating silicon-diode rectifiers mounted on the same shaft, to the main alternator field, without any slip-rings and brushes. In other words, the power flows along the wires mounted on the main shaft, from the ac exciter to the silicon diode rectifiers and then to the main alternator field. Since the scheme does not require any sliding contacts and brushes, this arrangement of exciting the synchronous machines has come to be called as **brushless excitation system.**

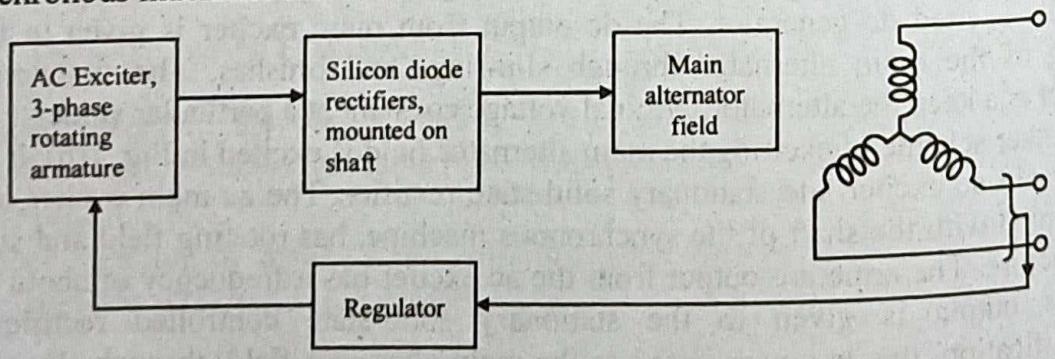

Fig: 1(c) Brushless-excitation system for a synchronous machine

5. Calculate the stepping angle for a 3-stack, 16-tooth variable reluctance stepper motor. **[WBUT 2019]**

Answer:

$$T_p = \frac{360°}{N_r} \qquad T_p = \text{Tooth pitch},\ N_r = \text{teeth}$$

$$\text{Step angle} = \frac{360°}{m N_r} \qquad m = \text{no. of stacks}$$

$$= \frac{360°}{3 \times 16} = \frac{360°}{48} = 7.5°$$

6. Write short notes on the following:

a) Brushless d.c. motor **[WBUT 2008, 2009, 2013, 2015, 2017]**

OR,

Brushless d.c machine **[WBUT 2019]**

b) Induction generators **[WBUT 2008, 2009, 2013, 2014, 2017, 2018]**

c) Switched reluctance motor **[WBUT 2008, 2013, 2014]**

d) Tacho-generator **[WBUT 2008, 2016, 2018]**

e) Stepper motor and "microstepping" or Stepper Motor **[WBUT 2009, 2010, 2012, 2014, 2015, 2017, 2020]**

f) Servomotor or A.C Servomotor **[WBUT 2009, 2010, 2011, 2012, 2015, 2018]**

g) Resolver OR Synchro **[WBUT 2009, 2012]**

h) Permanent magnet motor **[WBUT 2010]**

i) Hysteresis motor **[WBUT 2010, 2012, 2015, 2016]**

j) A.C. servo motor **[WBUT 2017]**

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Answer:

a) Brushless d.c. motor:

A brushless d.c motor is a motor drive system that combines into one unit polyphase ac synchronous motor, solid-state inverter and a rotor position sensor. The solid-state inverter uses transistors for low power drives and thyristors for high power drives. It is also viewed as "Inside - out" d.c. motor because its construction is opposite to that of a conventional d c motor. It has a permanent magnet field poles on the rotor and poly phase armature winding on the stator. The function of mechanical commutator in a conventional d c motor is now performed by electronic commutator.

Rotor position sensor monitors the shaft position and sends the control signals for turning on the controlled switches of the inverter in an appropriate sequence.

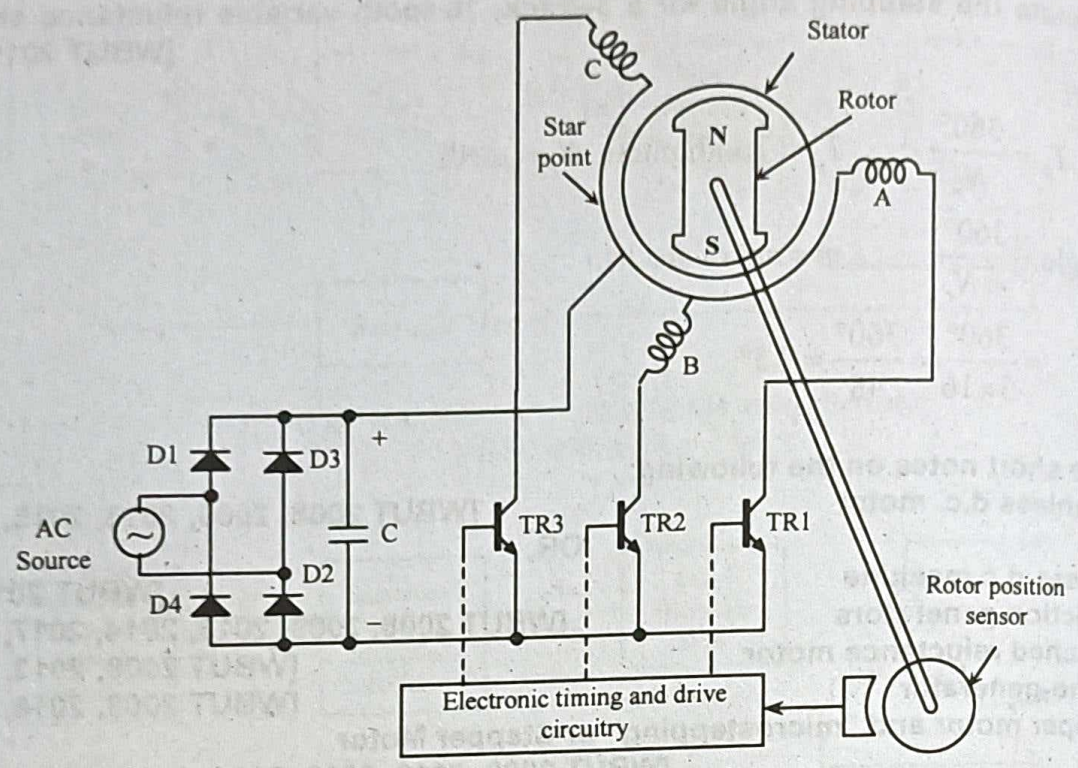

Fig: (1) 3-phase 3-pulse brushless dc motor

The above Fig. 1 shows a 3-phase, 3-pulse brush less d c motor along with its electronic controller, and the stator has 3ϕ winding connected in star. The neutral is connected to positive terminal of d c supply. Full-bridge diode converts ac to dc and the capacitor C serves as a filter circuit.

When transistor TR_1 is turned on, phase A is energized and when TR_2 is on, phase B is energized and so on. If the phase windings are energized in sequence ABC, the rotor rotates clockwise and with sequence ACB, the rotor revolves anti clockwise.

The commonly used rotor position sensors are Hall effect sensor and electro-optical sensor, which consists of a light emitting diode (LED), Phototransistor and a shaft mounted slotted wheel.

b) Induction generators:

Refer to Question No. 2.(a) of Long Answer Type Questions.

c) Switched reluctance motor:

Refer to Question No. 2.(c) of Long Answer Type Questions.

d) Tacho-generator:

It consists of a squirrel cage rotor and a pair of phase windings in space quadrature as shown in Fig. 1 below.

One stator phase winding is called reference field winding r and the other stator phase winding is referred to as control winding 'C'.

The reference winding is energized from a constant voltage and constant frequency source. As a result, emf of the same line frequency is generated in the control winding C.

The magnitude of generated emf winding C is, however, proportional to rotor speed. As control winding is connected to a high impedance amplifier, winding C can be considered as open circuited. It means that winding C does not effect winding r in any way.

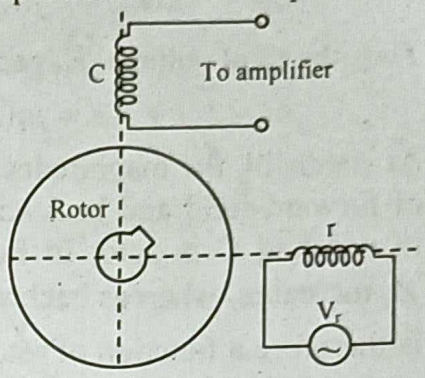

Fig: 1

Thus, the tachogenerator as viewed from the reference winding r is equivalent to a single-phase induction motor and therefore equivalent circuit is based on double-revolving field theory, can be employed for its analysis. Emfs E_f and E_b are generated in winding r by the forward and backward flux waves respectively. As these flux waves come across winding C, emfs are also generated in this winding C.

If $\dfrac{\text{effective turns in winding } C}{\text{effective turns in winding } r} = a$

then $\dfrac{\text{emf generated in winding } C,\ E_{cf}}{\text{emf generated in winding } r,\ E_{rf}} = a$

or, $E_{cf} = a \cdot E_{rf}$ .... (1)

In Fig.1 forward field is assumed to rotate clockwise.

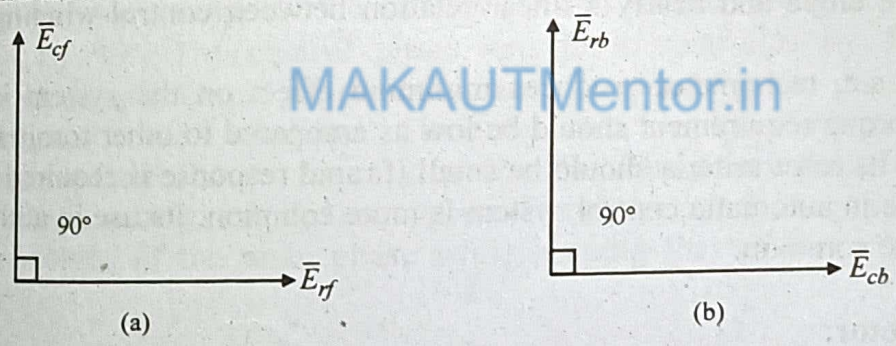

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Fig: 2 Emfs generated in 2-phase

This means that forward field comes across winding C first and a quarter cycle of time later, it comes across winding r. Thus emf $\overline{E}_{cf}$ generated by the forward field in winding C leads by 90° the corresponding emf $\overline{E}_{rf}$ generated in winding r by the forward field, Fig. 6. In complex notation, with the help of Eqn. (1) and Fig. 2, it can be expressed as

$$\overline{E}_{cf} = ja\overline{E}_{rf} = ja\overline{I}_f Z_f \quad \text{.... (2)}$$

where I_f is the phasor current in winding r and can be determined from the equivalent circuit. The backward field revolves in the opposite direction. Therefore, emf $\overline{E}_{rb}$ generated in the reference winding by backward field leads by 90° and emf $\overline{E}_{cb}$ generated in the control winding C by the same backward field, Fig. 6. In complex notation,

$$\overline{E}_{cb} = -ja\overline{E}_{rb} = -jaI_1 Z_b \qquad \text{.... (3)}$$

Thus the total voltage $\overline{E}_c$ generated in control winding C, as per equivalent circuit is:

$$\overline{E}_c = \overline{E}_{cf} + \overline{E}_{cb} = ja(E_{rf} - E_{rb}) = jaI_1(Z_f - Z_b) \qquad \text{.... (4)}$$

At standstill, the magnitudes of forward and backward fields are equal or the magnitudes of forward-field and backward-field impedances are equal. Therefore, emf E_c generated in winding C is zero, In Eqn. (4). When the rotor revolves, forward-field impedance Z_f increases, whereas backward-field impedance Z_b decreases; the difference $(Z_f - Z_b)$ is therefore a function of rotor speed and as a result emf in winding C is generated which is proportional to rotor speed. The phase of the voltage in control winding is reversed with the reversal direction of rotor rotation.

The ideal characteristics of ac tachogenerator are: (i) emf in control winding C is linearly proportional to rotor speed and (ii) the phase of voltage across winding C fixed with respect to the phase of voltage supplied to reference winding r.

The variation of voltage from control winding and its phase angle can be plotted as a function of rotor speed. The shapes of these curves depend upon the speed range and on the ratio of rotor self-reactance to rotor resistance, i.e. on $Q_2 = X_2 / r_2$, where X_2 = rotor self-reactance and r_2 = rotor resistance. It can be proved that either a low value of Q_2 (less than about 0.1) or a high value of Q_2 (more than about 10) will provide almost a constant phase angle and nearly a linear relation between control-winding voltage and speed.

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In order that a.c. tachometer produces minimum effect on the system in which it is inserted, its torque requirement should be low as compared to other torques acting in the system. Also, its rotor criteria should be small if rapid response is required in the control system. Its use in automatic control system is more common. Its use in automatic control system is more common.

e) Stepper motor:

Refer to Question No. 1 of Short Answer type Questions.

Microstepping:

In this method, current is divided unequally in 2 phases. Current in one phase is kept constant; current in next phase is increased in small values until maximum current flow in the phase. Then current in first phase is decreased in same small steps to zero value. Hence the steps obtained will be very small which is called as micro step. This leads to smooth operation and therefore the resolution will be very high. For example VR stepper motor with resolution 12 steps/rev. can be made to have resolution of 120 steps/rev (with $\beta = 3°$) with micro step operation.

f) Servomotor or A.C Servomotor:

Most of the a.c. servomotors are of the two-phase squirrel cage induction type Fig. (a) and are used for low power applications. However, 3ϕ induction motor have been

modified for high power servo system which had so far been using high power d.c. servomotors.

Two-phase A.C. Servomotors

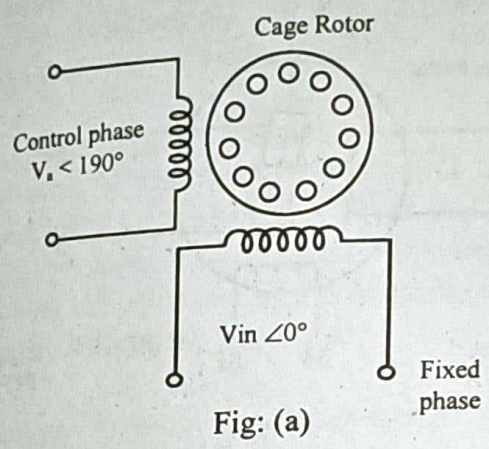

Fig: (a)

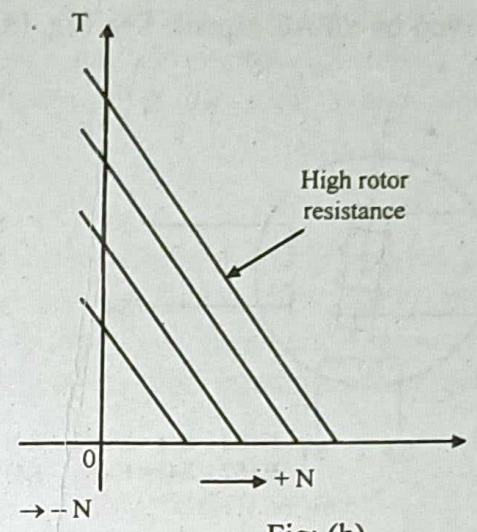

Fig: (b)

This type of motors generally runs on a frequency of 60Hz or 400 Hz. In this motor, the stator has two distributed windings, which are displaced from each other by 90° (electrical). The main winding, which is called reference or fixed phase is supplied from a constant voltage source $V_m \angle 0°$. The other winding also called the control phase is supplied with a variable voltage of the same frequency as the reference phase but its phase displaced by 90°. The control phase voltage is controlled by an electronic controller. The speed and torque of the rotor are controlled by the phase difference between the main and control windings. Since the rotor bars have high resistance, the torque speed characteristics Fig. (b) for various armature voltages are almost linear over a wide speed range particularly near the zero speed. The motor operation can be controlled by varying the voltage of the main phase while keeping that of the reference phase constant.

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Three Phase A.C. Servomotors

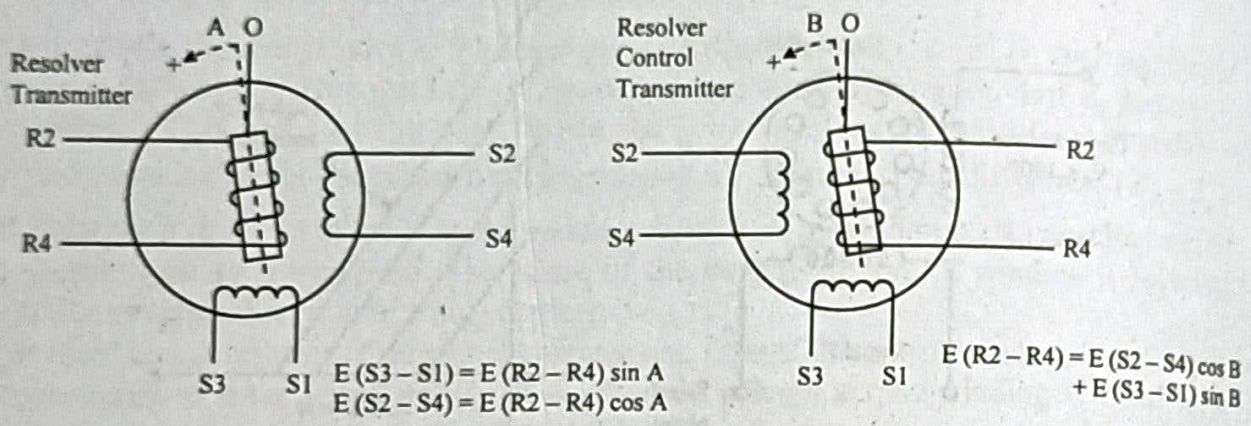
Normally such a motor is a highly non-linear coupled circuit device. Recently this machine has been operated successfully as a linear decoupled machine by using a control method called vector control or field oriented control. In this method, the current fed to the machine are controlled in such a way that its torque and flux become decoupled. This results in a high speed and high torque response.

g) Resolver:

Synchros and Resolvers have traditionally been the transducer of choice where reliability is important and where difficult environment conditions exist. Systems based on such devices are unsurpassed in reliability and cost effectiveness.

Synchros and Resolvers are very similar and the term synchro is often used to refer to both. Both are rotating, transducing devices used to convert shaft angle position to electrical signals, or the reverse. Synchros are typically three-phase devices with one or

two-phase primary windings and 3 secondary windings, each mechanically oriented 120° apart. Resolvers have 2 secondary windings oriented at 90° to each other. The primary of each is driven by an AC signal. See Fig. (a).



While synchros and resolvers are essentially transformers, they are mechanically more like a motor. The primary winding in a synchros can be physically rotated with respect to the secondary windings. The magnitude of the mechanical coupling between the primary and secondary varies according to the position of the rotating element. This, in turn, varies the magnitude of the output voltage. In some systems, a mechanical input, such as a shaft rotation, is converted to a unique set of output voltages. In others, a set of input voltages is used to turn a synchros rotor to a desired position.

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Typical synchro / resolver applications include:

- Fire control systems
- Inertial navigation reference units such as a gyro or compass
- Automatic direction finders
- Distance measurement equipment
- Cockpit simulators
- Jet engine control systems
- Antenna pedestal control
- Cockpit indicators
- Landing gear positioning and control
- Flap actuators

Synchro / Resolver Operation

Synchros are designed to operate with AC input voltages from less than 1.0 Vrms to 115 Vrms, over a wide range of frequencies from 60 Hz to 100 kHz. There are some standard voltages used such as 11.8, 26, 90 and 115 Vrms. They are commonly operated at 26 Vrms and below and at 60 Hz or between 400 and 2600 Hz.

Depending on the size of the synchro, the input voltage and/or frequency may have to be limited such that excessive input current does not saturate the core. Reducing the size and weight of a synchro reduces the size of its magnetic core. However, a small magnetic core easily saturates when driven with 60 Hz. For that reason, for aircraft applications, synchros are commonly excited with 400 Hz signal.

Accuracy
The accuracy of a synchro is based on the ability of its output voltages to define the rotor angle. This is probably the most important of all synchro parameters. It is an exact measure of the performance of the synchro. For any given rotor posotion, the output voltages are designed to provide precise electrical information which corresponds uniquely to that rotor position.

h) Permanent Magnet Motors:
It is a one type of d.c motor and consists of an armature and one or several permanent Magnets encircling the armature. Field coils are not required usually. However, some of these motors do have coils wound on the poles. If they exist, these coils are intended only for recharging the magnets in the event that they loose their strength schematically, this motor appears as only an armature.

Fig. 1 as shown below a 2-pole permanent magnet DC (PMDC) motors

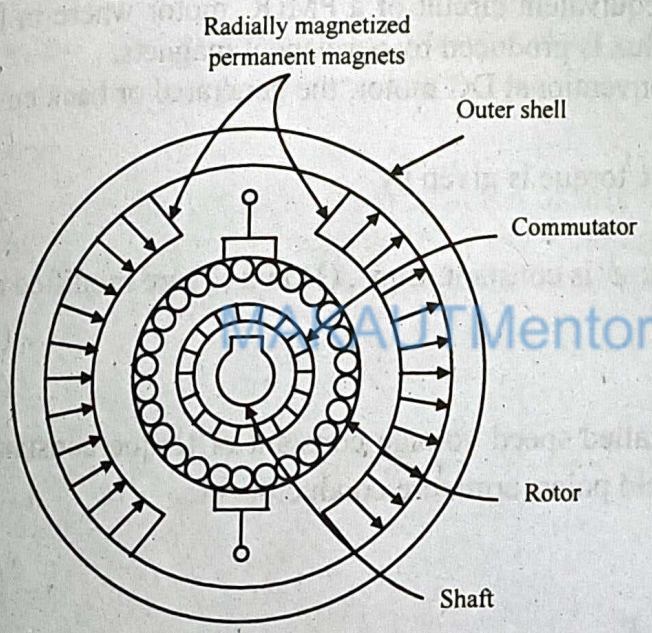

Fig: 1 Cross-sectional view of a PMDC motor

It may be seen from above that the permanent magnets are radially magnetized and mounted on the inner periphery of the cylindrical steel stator, which also serves as a return path for the magnetic flux. The rotor has a conventional dc armature, with commutator segments and brushes.

Types of Permanent Magnet Materials
There are three types of permanent materials used for PMDC motors viz.: -

i) ***Alnico:*** Due to its low coercive magnetizing intensity and high residual flux density, they are used in low current, high voltage application.
ii) ***Ferrites:*** They are used in cost sensitive applications such as air conditioners, compressors, and refrigerators.

iii) ***Rare earths:*** Rare earth magnets are made of samarium – cobalt, neodymium – iron – boron.

They have high residual flux and high coercive magnetizing intensity. The rare earth magnets are largely immune to demagnetizing problems due to armature reaction. Such magnetic materials are costly. Neodymium-iron-boron is cheaper than samarium cobalt. However, the latter can stand higher temperatures than the former. Rare earth magnets are used for size-sensitive applications.

Torque Production

Torque production is achieved by interaction between axial current – carrying rotor conductors and magnetic flux produced by the permanent magnets

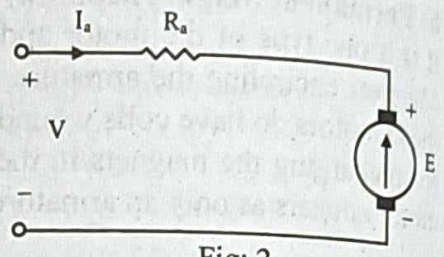

Fig: 2

Fig. 1 as above is an equivalent circuit of a PMDC motor where-in field winding is not shown since the field flux is produced by permanent magnets.

It is known that in a conventional DC motor, the generated or back emf is given by:

$$E = K\phi N \qquad \text{.... (1)}$$

and the electromagnetic torque is given by

$$\tau_e = K\phi I_a \qquad \text{.... (2)}$$

In a PMDC motor, flux ϕ is constant, Eqns. (1) and (2) are modified as:

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$$E = K_1 N \qquad \text{.... (3)}$$

$$\tau_e = K_1 I_a \qquad \text{.... (4)}$$

where $K_1 = K\ \phi$ is called speed voltage constant or torque constant. Its value depends upon the number of field poles, armature conductors etc.

From Fig. 2,

$$V = E + I_a R_a \qquad \text{.... (5)}$$

$$= K_1 N + I_a R_a$$

$$N = \frac{V - I_a R_a}{K_1} \qquad \text{.... (6)}$$

Speed Control:

The speed and torque of PMDC motor can be controlled by armature voltage control, armature rheostat control and chopper control. Flux control method cannot be applied, as flux remains constant. Therefore use of such motor is restricted to motor speeds below base speeds.

Advantages:

a. There is no copper losses in the field circuits as these motors do not require field winding resulting increased efficiency.

b. These motors are smaller than corresponding wound pole motors in absence of field winding.

Disadvantages:

a. Lower induced torque τ_{ind} per ampere of armature current I_a than a shunt motor of same rating in view of the fact that permanent magnets can not produce as high a flux density as an externally supplied shunt field.

b. Magnetic field is always present even when the motor is not in used.

c. There is risk of demagnetization of poles, which may be caused by large armature current. Demagnetization may also be caused by excessive heating, which can occur if the motor is overloaded over a prolonged period.

Uses/Applications:

i) In automobiles to operate windshield wipers and washers, to raise and lower windows.

ii) In computer drives

iii) In toy industries

iv) Portable vacuum cleaners, food mixers, portable electric drives

v) To drive blowers for heaters and air conditioners.

i) Hysteresis Motor:

This motor works on hysteresis principle for production of mechanical torque. The rotor of this motor is smooth cylindrical type with no teeth and windings. The stator is of either 3-phase or single phase. If it is a single phase, it should be of split phase or shaded pole type.

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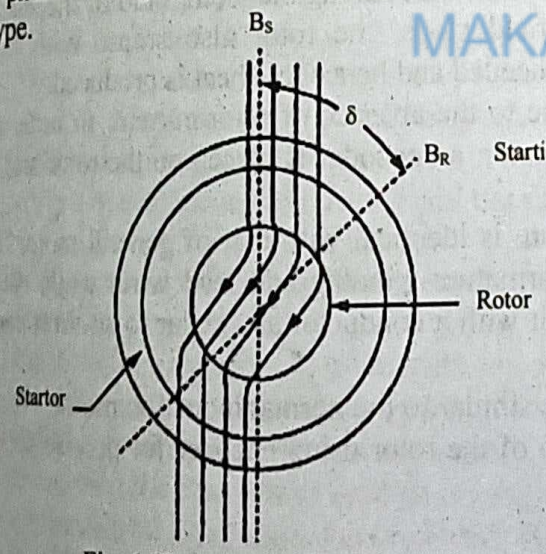

Fig: 1 Hysteresis motor

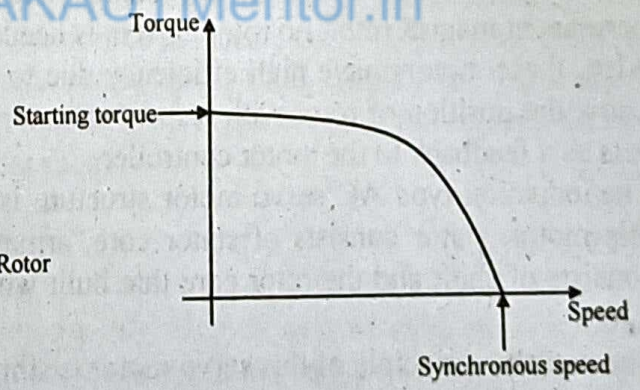

Fig: 2 Torque speed characteristics

When supply is given to stator, it produces rotating magnetic field, which magnetize the rotor, and therefore the poles are induced in the rotor. The flux induced in the rotor lags the rotating magnetic flux of stator by an angle δ due to hysteresis loss in the rotor. A finite torque is produced due to the angle difference between stator and rotor fields. This angle is dependent on shape of hysteresis loop. Hence material with large hysteresis loop

area must be used for rotor. The eddy currents induced in rotor due to stator field also produces its own torque.

The torque speed characteristic is shown above in Fig. 2. The hysteresis torque is almost constant from zero speed to synchronous speed. This is because the hysteresis torque is dependent on flux density of the stator and the rotor material and the eddy current torque is dependent on slip.

Shaded pole type of hysteresis motors are of very small and they are used in electric clocks.

j) A.C. servo motor:

AC servo motors are basically two-phase squirrel cage induction motors and are used for low power applications. Nowadays, three phase squirrel cage induction motors have been modified such that they can be used in high power servo systems.

The main difference between a standard split-phase induction motor and AC motor is that the squirrel cage rotor of a servo motor has made with thinner conducting bars, so that the motor resistance is high

Synchronous-type AC servo motor consist of stator and rotor. The stator consists of a cylindrical frame and stator core. The armature coil wound around the stator core and the coil end is connected to with a lead wire through which current is provided to the motor.

The rotor consists of a permanent magnet and hence they do not rely on AC induction type rotor that has current induced into it. And hence these are also called as brushless servo motors because of structural characteristics.

When the stator field is excited, the rotor follows the rotating magnetic field of the stator at the synchronous speed. If the stator field stops, the rotor also stops. With this permanent magnet rotor, no rotor current is needed and hence less heat is produced.

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Also, these motors have high efficiency due to the absence of rotor current. In order to know the position of rotor with respect to stator, an encoder is placed on the rotor and it acts as a feedback to the motor controller.

The induction-type AC servo motor structure is identical with that of general motor. In this motor, stator consists of stator core, armature winding and lead wire, while rotor consists of shaft and the rotor core that built with a conductor as similar to squirrel cage rotor.

The working principle of this servo motor is similar to the normal induction motor. Again the controller must know the exact position of the rotor using encoder for precise speed and position control.

MISCELLANEOUS

Long Answer Type Questions

1. Will a dc shunt motor operate when energized form an alternating voltage supply? Explain. **[WBUT 2012, 2016]**

Answer:

In a d.c. shunt motor when a d.c. voltage is applied to the brushes of the motor, current flows through the positive brush, commutator, armature winding and finally goes out through the negative brush. The winding in the armature conductors is done in such a way that all the conductors under the N poles carry current in one direction; while all the conductors under the south poles carry current in the opposite direction [Armature conductors under N pole are assumed to carry the current downwards while those under S-pole carry current upwards. The current flowing through the field winding establishes a magnetic field; while the current flowing through the conductors of the armature winding causes these conductors to experience a mechanical force or torque tending to rotate at right angles to the field established in the field winding. All the conductors of the armature tend to rotate the armature in anticlockwise direction and torque is developed to rotate the motor.

But when the motor is energized from single-phase a.c. source, the direction of current in conductors under N-pole is exactly opposite to that in conductors under the influence of S-pole. Consequently, as the conductors exit the influence of a pole of one polarity (N or S) and enter that of reverse polarity (S or N), the direction of current is exactly reversed. The phenomenon of this reversal of direction of induced current in armature conductors actually takes place along the magnetic neutral axis. Consequently the particular coil undergoing reversal of the direction of current gets short-circuited and as such no torque will be developed and the motor will not rotate.

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2. Write short on Induction regulator. **[WBUT 2018]**

Answer:

An induction regulator is a constant voltage transformer, one winding of which can be moved w.r.t the other, there by obtaining a variable secondary voltage. The primary winding is connected across the supply while the secondary winding is connected in series with the line whose voltage is to be controlled. When the position of one winding is changed w.r.t the other, the secondary voltage injected into the line also changes. There are 2 types of Induction Regulators:

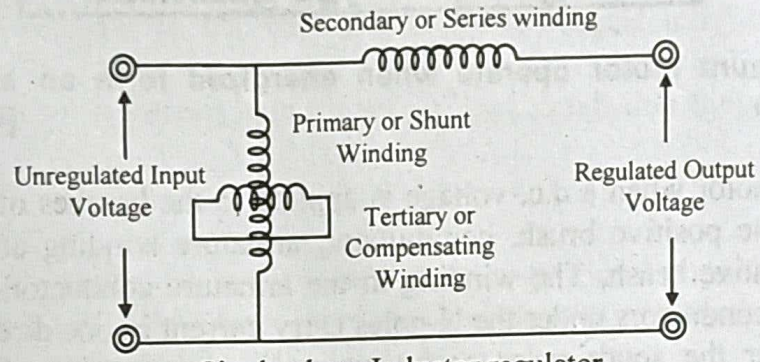
(i) 1-ϕ Induction Regulator

(ii) 3-ϕ Induction Regulator

Single-phase Induction Voltage Regulator

The schematic diagram of the single phase induction voltage regulator is shown in the figure below. The primary winding is connected across the single phase supply , and the

secondary is connected in series with the outgoing lines. The alternating flux is induced in the system and when the axis of the two windings coincide the whole of the flux of primary is linked with the secondary windings and the maximum voltage is induced in the secondary.



Single phase Inductor regulator

When the rotor is rotated through 90°, then none of the primary flux is linked with the secondary windings and hence no flux is linked with the secondary windings. If the rotor further rotates, then the direction of the induced emf becomes negative. Thus the regulator adds or subtracts the circuit voltage depends on the relative position of the two windings of regulators.

Three Phase Induction Voltage Regulator

The three phase induction motors have three primary and three secondary windings and which must be spaced 120° apart. The primary windings are places in the slot of a laminated rotor core and connected across the three phase AC supply. The secondary windings are in slots of a laminated stator core and are connected in series with the load.

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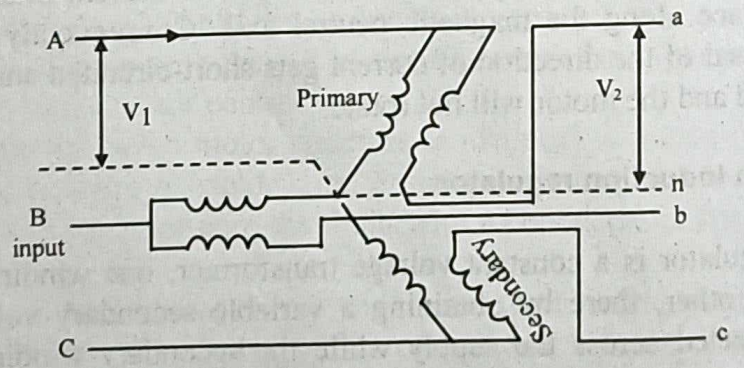

Three Phase induction Voltage Regulator

QUESTION 2015

Group – A
(Multiple Choice Type Questions)

1. Answer all questions:

i) The synchronous-impedance method of finding the voltage regulation by a cylindrical rotor alternator is generally considered as

✓a) a pessimistic method because saturation in not considered
b) an optimistic method because saturation is not considered
c) a fairly accurate method even if power factor is not taken into account while determining synchronous impedance
d) a fairly accurate method even if power factor is taken into account while determining synchronous impedance

ii) A salient pole synchronous machine has maximum power output when power angle δ is

✓a) 90°
b) either 90° or more
c) less than 90°
d) more than 90°

iii) If the power factor of an alternator is zero lagging the armature reaction is

✓a) demagnetizing
b) magnetizing
c) cross magnetizing
d) both demagnetizing

iv) Cylindrical rotor synchronous machines are mainly used in

a) Hydel power plants
✓b) Steam power plants
c) In both hydel and steam power plants
d) None of these

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v) When a 3-phase synchronous motor is running at synchronous speed, the damper winding produces

a) damping torque
b) eddy current torque
c) torque aiding the developed torque
✓d) no torque

vi) In a salient pole synchronous machine, where X_d = d-axis synchronous reactance, Xq = q-axis synchronous reactance

a) $X_q = X_d$
b) $X_q > X_d$
c) $X_q = 0$
✓d) $X_q < X_d$

vii) Which motor has the starting torque proportional to iron loss?

a) Permanent magnet motor
b) Switch reluctance motor
✓c) Hysteresis motor
d) Stepper motor

viii) The function of compensating winding in a single phase series motor is to

a) improve the commutation
b) reduce the reactance drop and degrade the commutation
✓c) reduce the reactance drop and improve commutation
d) none of these

ix) Capacitor start and run induction motor is basically a

✓a) single phase induction motor
b) two-phase induction motor
c) three-phase induction motor
d) single phase reluctance motor

x) The motor generally used in a tape recorder is
a) reluctance motor
b) universal motor
✓c) hysteresis motor
d) split-phase motor

xi) In a double revolving field theory, the slip of the forward motor is S, then the slip of the backward motor is
a) 2S
b) S
✓c) 2 – S
d) S – 2

xii) Induction generator runs at
✓a) super synchronous speed
b) sub-synchronous speed
c) synchronous speed
d) none of these

Group – B
(Short Answer Type Questions)

2. What is a synchronous condenser? Explain its operation and utility with phasor diagram.
See Topic: 3 PHASE SYNCHRONOUS MOTOR, Short Answer Type Question No. 2.

3. What is hunting in an alternator? Discuss the measures to be taken to minimize such hunting.
See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 5.

4. Explain why cylindrical rotor alternators have small diameter and large core length while salient pole alternators have large diameter and small core length.
See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 2.

5. Why is a single phase induction motor not self starting? Name the various methods of starting and mention which mode of starting will provide high starting as well as running torque.
See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 2.

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6. For an universal motor, the performance of the machine is better under d.c. operation than under a.c. operation-justify.
See Topic: SINGLE PHASE INDUCTION MOTORS, Short Answer Type Question No. 2.

Group – C
(Long Answer Type Questions)

7. a) Discuss the nature of armature reaction of an alternator for zero p.f. lagging, zero p.f. leading zero p.f. leading and unit power factor load.
See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 12.

b) Describe the effect of change of excitation and mechanical input of an alternator.
See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 6.

8. a) Explain two reaction field theory for a salient pole synchronous machine. Using this theory, draw the phasor diagram for lagging current for (i) salient pole generator (ii) salient pole motor.
b) A 3-phase star connected 400 V synchronous motor takes a power input of 5472 Watts at rated voltage. Its synchronous reactance is 10 ohms per phase and resistance is negligible. If the excitation voltage is adjusted equal to the rated voltage 400 V, compute the load angle, power factor and armature current.
a) See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 2.
b) See Topic: SYNCHRONOUS MOTOR, Long Answer Type Question No. 3.

9. a) For a single phase induction motor, derive the condition for maximum starting torque during capacitive starting.

b) A 220 V, 4-pole, 50 Hz single phase induction motor gave the following test results:
Blocked Rotor test: 110 V, 10 A, 400 W
No-load test: 220 V, 4 A, 100 W
(i) Find the parameters to develop equivalent circuit. State necessary assumptions.
(ii) Considering the speed of the motor as 1440 rpm, determine (a) line current, (b) power factor.

See Topic: SINGLE PHASE INDUCTION MOTOR, Long Answer Type Question No. 6(a) & (b).

10. a) Explain with reasons why compensating winding is provided in a universal motor for AC operation.
b) What are the modifications that should be done in a dc series motor so that it will run satisfactorily with ac supply?
c) What may happen if one of the 3 – lines of a 3 – phase cage rotor induction motor suddenly gets disconnected? Justify your answer.

See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 15(a), (b) & (c).

11. Write short notes any *three* of the following:
a) Hysteresis motor
b) Servomotor
c) Brushless dc motor
d) Linear Induction Motor
e) Stepping motor.

a) See Topic: SPECIAL ELECTROMECHANICAL DEVICES, Long Answer Type Question No. 6(i).
b) See Topic: SPECIAL ELECTROMECHANICAL DEVICES, Long Answer Type Question No. 6(f).
c) See Topic: SPECIAL ELECTROMECHANICAL DEVICES, Long Answer Type Question No. 6(a).
d) See Topic: SPECIAL ELECTROMECHANICAL DEVICES, Long Answer Type Question No. 1.
e) See Topic: SPECIAL ELECTROMECHANICAL DEVICES, Long Answer Type Question No. 6(e).

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QUESTION 2016

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternatives for any ten of the following:

i) In a shaded pole motor, shading coils are used to
a) reduce windage losses
b) reduce friction losses
✓c) produce rotating magnetic field
d) protect against sparking

ii) The direction of rotation of single phase induction motor can be reversed by
a) reversing the leads of main winding
b) reversing the leads of auxiliary winding
c) reversing the supply leads
✓d) either (a) or (b)

iii) A 230V DC series motor is connected to 230 V AC 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

iv) A 3 phase induction motor, while supplying a constant load, has the fuse of one line suddenly blown off. The motor will run as single phase induction motor with line current nearly increased to

✓a) $\sqrt{3}$ times b) 3 times c) 5 times d) 6 times

v) A capacitor start and run motor is supplied from

✓a) single phase supply b) 3 phase supply
c) 2 phase supply d) none of these

vi) Armature reaction mmf for a synchronous machine cross magnetizes the field mmf in

a) ZPF lagging b) ZPF leading ✓c) UPF d) 0

vii) In case of synchronous generator electromagnetic torque and prime mover torque are in

a) same direction ✓b) reverse direction c) not produced d) none of these

viii) The expression for power (with reference to Power Angle characteristics) for a cylindrical pole rotor synchronous machine is given by

✓a) $\frac{E_f V_t}{X_s}\sin\delta$ b) $\frac{E_f V_t}{X_s}\cos\delta$ c) $\frac{E_f V_t X_s}{\cos\delta}$ d) $\frac{E_f V_t X_s}{\sin\delta}$

ix) The speed of an alternator is

✓a) always same as synchronous speed b) less than synchronous speed
c) above synchronous speed d) none of these

x) Damper winding is used

✓a) for starting a synchronous generator b) for starting a synchronous motor
c) not at all d) in DC machine

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xi) V-curve of a synchronous motor is the curve between

✓a) armature current vs field current b) power factor vs field current
c) excitation voltage vs armature current d) excitation voltage vs field current

xii) Distribution winding

a) gives reduction of harmonics b) gives mechanical strength
c) gives increased harmonics ✓d) both (a) and (b)

Group – B
(Short Answer Type Questions)

2. "A single phase induction motor when excited by a single phase supply produces two equal and opposite revolving fields." – Justify the statement.

See Topic: SINGLE PHASE INDUCTION MOTORS, Short Answer Type Question No. 3.

3. Why are *ac* series motors designed to operate at higher speed? Explain it by drawing phasor diagram.

See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 3.

4. What methods are adopted to start a single phase induction motor? Explain with the help of connection diagram and phasor diagram, the principle of operation of capacitor start & run motor.

See Topic: SINGLE PHASE INDUCTION MOTORS, Short Answer Type Question No. 8.

5. How does the synchronous motor start? Explain clearly.
See Topic: 3 PHASE SYNCHRONOUS MOTOR, Short Answer Type Question No. 3.

6. A 3-phase, wye-connected, round-rotor synchronous generator rated at 10 kVA, 230V has a synchronous reactance of 1.2 Ω per phase and an armature resistance of 0.5 Ω per phase. Calculate the per cent voltage regulation at full-load with 0.8 lagging power factor.
See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 14.

Group – C
(Long Answer Type Questions)

7. a) Explain why single phase induction motor has no starting torque.
b) Why shaded pole motor has starting torque although it has only main winding?
c) The resistance and total inductance of single phase fractional series motor are 30 ohm and 0.5 ohm respectively. It draws 0.8 A current and runs at 2000 rpm when connected to 250 V DC supply. Calculate the speed and power factor when connected to a 250V, 50 Hz supply. Calculate the speed and power factor when connected to a 250V, 50 Hz supply and takes same load current. How much voltage is required for getting 2000 rpm with AC supply? Assume resistance and reactance remain constant.
d) Write down a short note on 'reluctance motor'
a), b) & c) See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 16(a), (b) & (c).
d) See Topic: SPECIAL ELECTROMECHANICAL DEVICES, Long Answer Type Question No. 6(c).

8. a) For single phase induction motor, derive the condition for maximum starting torque during resistor split phase motor.
b) Describe the principle of operation and torque-speed characteristic of induction generator.
c) Will a DC shunt motor operate when energized from alternating voltage supply? Explain.
a) See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 6(a).
b) See Topic: SPECIAL ELECTROMECHANICAL DEVICES, Long Answer Type Question No. 2(a).
c) See Topic: MISCELLANEOUS, Long Answer Type Question No. 1.

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9. a) Clearly explain space phasor diagram and time phasor diagram under lagging power factor load of a cylindrical rotor synchronous generator. State clearly how the armature reaction mmf affects the field mmf.
b) Draw the phasor diagram of a round rotor alternator on short circuit. Discuss why short circuit characteristics is a straight line whereas open circuit characteristics is a curve.
See Topic: SYNCHRONOUS MACHINES, Long Answer type Question No. 13(a), (b) & (c).

10. a) Draw the phasor diagram of a sailent pole synchronous generator based on two reaction theory.
b) A 20 MVA, 3 phase star connected alternator with an impedance of 5 ohm and a resistance of 0.5 ohm, is operating in parallel with constant voltage 11 kV busbars. If its field current is adjusted to give an excitation voltage of 12 kV, then calculate (i) the maximum power output from the alternator (iii) the armature current.
a) See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 9.
b) See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 1.

11. Write short notes on any three of the following
a) Repulsion type motor
b) Hysteresis motor
c) Linear induction motor
d) Tacho-generator

e) Synchronous condenser
f) V-curve of a synchronous motor

a) See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 21(a).
b) See Topic: SPECIAL ELECTROMECHANICAL DEVICES, Long Answer Type Question No. 6(i).
c) See Topic: SPECIAL ELECTROMECHANICAL DEVICES, Long Answer Type Question No. 1.
d) See Topic: SPECIAL ELECTROMECHANICAL DEVICES, Long Answer Type Question No. 6(d).
e) See Topic: 3 PHASE SYNCHRONOUS MOTORS, Short Answer Type Question No. 2.
f) See Topic: 3 PHASE SYNCHRONOUS MOTOR, Long Answer Type Question No. 6(b).

QUESTION 2017

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternatives for any ten of the following:

i) A universal motor is one
a) which can run on any value of supply voltage
b) which has infinitely varying speed
✓c) which can operate on ac as well as dc voltage
d) which can work as single phase or three phase motor

ii) The direction of rotation of universal motor can be reversed by
a) reversing the supply terminals
b) switching over from ac to dc
✓c) interchanging the brush leads
d) any of the above

iii) Fro ceiling fans generally the single phase motor used is
a) split phase type
b) capacitor start type
✓c) capacitor start and run type
d) permanent capacitor type

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iv) The disadvantage of shaded pole motor is
a) low starting torque
b) low efficiency
c) very little over load capacity
✓d) all of these

v) Which motor is generally used in tape recorders?
a) Universal motor
b) Reluctance motor
c) Split phase motor
✓d) Hysteresis motor

vi) In an alternator, voltage drops occurs in
a) armature resistance only
b) armature resistance and leakage reactance
✓c) armature resistance, leakage reactance and armature reaction
d) armature resistance, leakage reactance, armature reaction and earth connections

vii) For an alternator when the power factor of the load is unity
a) the armature flux will have square waveform
b) the armature flux will be demagnetising
✓c) the armature flux will be cross-magnetising
d) the armature flux will reduce to zero

viii) An alternator is supplying 10A to an inductive load at 220V, while running at 1000rpm. Now if the speed of the alternator is reduced to 750 rpm but the field current remains unchanged, the load current will become

a) 18A b) 13.3A ✓c) 10A d) 7.5A

ix) An alternator is rated for 75kW at 0.8 power factor. It means that

a) alternator has 4 poles
✓b) alternator can supply 75kW at 0.8 power factor
c) alternator can supply power only to loads having power factor 0.8 only
d) the peak efficiency of alternator occurs only at 75kW load having 0.8 lagging power factor

x) Two alternators are running in parallel. The excitation of one of the alternator is increased. The result will be

a) machine with excess excitation will burn
b) both machines will start vibrating
c) power output will decrease
✓d) wattless component will change

xi) The back emf in the stator of a synchronous motor depends on

a) speed of rotor ✓b) rotor excitation
c) number of poles d) flux density

xii) The amount of torque required to move a stepper motor one full step is called

✓a) holding torque b) residual torque
c) detent torque d) developed torque

xiii) In a BLDC motor, we have

a) no mechanical commutator b) no brushes
c) no arcing ✓d) all of these

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Group – B
(Short Answer Type Questions)

2. Explain why cylindrical rotor alternators have small diameter and large core length while salient pole alternators have large diameter and small core length?

See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 2.

3. Explain why in a universal motor, the performance of the machine is better under d.c. than in a.c. operation.

See Topic: SINGLE PHASE INDUCTION MOTORS, Short Answer Type Question No. 2.

4. What is Damper winding? Explain its use. Why is damper winding used in salient pole synchronous machine?

1st & 3rd Part: See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 3.
2nd Part: See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 6.

5. What is hunting in an alternator? Explain how hunting can be minimized?

See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 5.

6. Explain the constructional feature and operating principle of linear Induction motor. State its important applications.

See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 1.

Group – C
(Long Answer Type Questions)

7. a) Explain why a 1-phase single winding induction motor produce no starting torque.
b) For a single phase induction motor, derive the condition for maximum starting torque during capacitive starting.
c) Write notes on: Cross-field Theory.

a) See Topic: SINGLE PHASE INDUCTION MOTORS, Short Answer Type Question No. 1.
b) See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 6(a).
c) See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 21(c).

8. a) A 240V, 1-phase induction motor gave the following test result.
Block rotor test: 120 V, 9.6 amp, 460 watt
No load test: 220 V, 4.6 amp, 125 watt.
The stator winding resistance is 1.5Ω and during the block rotor test, the starting winding is open. Find equivalent circuit parameters. Also find the core friction and winding losses.
b) What do you mean by regulation of an alternator? Describe the synchronous Impedance method of determination regulation of an alternator at UPF load. Why is it called a pessimistic method?

a) See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 5(a).
b) See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 4.

9. a) What is distribution factor? What are the advantages of distribution a winding in slots?
b) In a salient pole synchronous machine, the value of X_d is greater than that of X_q; explain with reasons.
c) Describe any synchronizing method of an alternator with infinite bus.

a) See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 4.
b) See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 1.
c) See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 3(b).

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10. a) Explain the power developed in reluctance motor with the phasor diagram.
b) A 75kW, 400V, 3 phase star connected synchronous motor has a resistance and synchronous reactance per phase of 0.04Ω and 0.4Ω respectively. Compute for full load 0.8 pf lead the open circuit emf per phase and gross mechanical power developed. Assume an efficiency of 92.5%.

a) See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 2(c).
b) See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 14.

11. Write short notes on any *three* of the following:
   a) Condition for parallel operation of alternator
   b) A.C. servo motor
   c) Stepper motor and microstepping
   d) Brushless DC motor
   e) Induction generators

a) See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 18(a).
b) See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 6(j).
c) See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 6(e).
d) See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 6(a).
e) See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 6(b).

QUESTION 2018

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternatives for any *ten* of the following:

i) In double revolving field theory, the slip of the forward motor is S, then the slip of the backward motor is

✓a) $2S$ b) S c) $2-S$ d) $S-2$

ii) In a synchronous motor

a) E is always less than V b) $E=V$

c) E is more than V ✓d) E may be more or less than V

iii) In a salient pole synchronous machine, where $X_d = d$-axis synchronous reactance and $X_q = q$-axis synchronous reactance,

a) $X_q = X_d$ b) $X_q > X_d$ ✓c) $X_q < X_d$ d) $X_q = 0$

iv) Negative voltage regulation is observed in an alternator which is

a) over excited ✓b) under excited c) normally excited d) All of these

v) In a synchronous generator operating at zero power factor lagging, the effect of armature reaction is

a) magnetizing ✓b) demagnetizing

c) cross-magnetizing d) both magnetizing and cross-magnetizing

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vi) Short pitch winding results in

a) higher terminal voltage b) higher efficiency

c) higher power factor ✓d) better voltage waveform

vii) During hunting of synchronous motor

✓a) negative phase sequence currents are generated

b) harmonies are developed in the armature circuit

c) field excitation increases

d) damper bar develops torque

viii) The maximum possible speeds in rpm at which an alternator can be driven to generate voltages 60 Hz and 50 Hz are respectively

a) 2000, 2400 b) 3000, 3600 c) 2400, 2000 ✓d) 3600, 3000

ix) A capacitor start and capacitor run induction motor is supplied from

✓a) single-phase supply b) 2-phase supply

c) 3-phase supply d) None of these

x) For the same no. of poles which stepper motor produces largest stepping angles?

✓a) Variable reluctance type b) Hybrid type

c) Permanent magnet type d) All of these

xi) A single phase hysteresis motor can run at
- ✓a) synchronous speed
- b) sub synchronous speed
- c) synchronous and super synchronous speed
- d) synchronous and sub synchronous speed

xii) The stepping angle for a 3-phase, 24 pole permanent stepper motor is
a) 15 degree b) 8 degree ✓c) 5 degree d) 4 degree

Group – B
(Short Answer Type Questions)

2. A purely single phase induction motor does not have starting torque but has running torque. Why?
See Topic: SINGLE PHASE INDUCTION MOTORS, Short Answer Type Question No. 1.

3. Explain the principle of operation of capacitor-start capacitor-run type single-phase induction motor with necessary diagrams and phasor.
See Topic: SINGLE PHASE INDUCTION MOTORS, Short Answer Type Question No. 9.

4. The number of poles or teeth in the stator and rotor of a stepper motor are different. Why?
See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Short Answer Type Question No. 5.

5. Write down the working principle of hysteresis motor with necessary diagram.
See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Short Answer Type Question No. 6.

6. Describe the slip test to determine the d-axis synchronous reactance (Xd) and q-axis synchronous reactance (Xq) of a salient pole synchronous machine.
See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 7.

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Group – C
(Long Answer Type Questions)

7. a) Explain how the equivalent circuit parameters of a single phase induction motor can be determined experimentally. State the assumptions you have made.
See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 13.a).

b) A 6-pole, 50Hz, single phase induction motor, when running at normal speed, has forward field and backward field resistances of 60Ω and 1.4Ω respectively. The stator current at a full-load slip of 5% is 3A. Determine the full-load torque in Nm. Assume rotational losses to be 4% of internal power developed.
See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 17.

8. a) Explain double revolving field theory of 1-phase I/M.
See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 7.

b) A 50 Hz, four pole split-phase induction motor has auxiliary resistance of 5Ω and reactance of 20Ω, both in main and winding. Find the value of resistance and capacitance to be added to the auxiliary winding circuit so that the two winding carry same current and the currents are 90° to each other.
See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 18.

9. a) Explain EMF method of calculation voltage regulation of synchronous generator and state why it leads to pessimistic value at lagging power factor load.

b) The effective resistance of a 3-phase, star connected, 50 Hz, 2200 V, synchronous generator is 0.5 ohms per phase. On short circuit, a field current of 40 A gives full load current of 200 A. An emf (Line to Line) of 1100V is produced on open circuit with the same excitation. Determine synchronous impedance. Hence compute power angle and regulation at full load 0.8 pf lagging.

See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 11(a) & (b).

10. a) A 3-phase motor has synchronous reactance of 12 ohm per phase and negligible resistance. The motor is initially operating at a load of 120 kV with field current adjusted such that the armature current is minimum. The field current is now increased such that the armature current is increased by 50%. With this field current, the load is reduced to 60 kW. Calculate new values of armature current and power factor.

b) A 4-pole, star connected, 50 Hz, 11 kV, 40 MVA turbo-generator, with synchronous reactance of 0.8 pu is connected to a power network. This power network can be represented by 11kV infinite but with a series reactance of j0.5 ohms. A voltage regulator adjusts the field current such that alternator terminal voltage remains constant at 11 kV.

The generator delivers an output of 40 MVA.

i) Draw phasor diagram under condition specified.

ii) Find armature current and alternator P.F.

Find magnitude of excitation emf.

See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 15(a) & (b).

11. a) Show with the help of phasor diagrams that a compensated series motor possesses better speed torque characteristics, better power factor and improved commutation as compared to an uncompensated series motor.

b) A 2-pole, 50 Hz, 300 V, single phase series motor has 800 armature turns and 350 field turns. The total effective resistance is 6Ω and total leakage reactance is 14Ω. For a power input of 350 watts the motor draws 2A and the speed is 3600 rpm.

i) Compute the peak value of field flux per pole.

ii) If the motor is conductively compensated and draws the same amount of current, find the p.f. and speed. The motor has full compensation and the leakage impedance of compensating winding is 1+j2Ω.

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See Topic: SINGLE PHASE INDUCTION MOTOR, Long Answer Type Question No. 19(a) & (b).

12. Write short notes any *three* of the following:

a) Servomotor

b) Induction regulator

c) Tacho-Generator

d) Induction generator

e) Synchronous condenser

a) See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 6(f).

b) See Topic: MISCELLANEOUS, Long Answer Type Question No. 2.

c) See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 6(d).

d) See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 6(b).

e) See Topic: 3-PHASE SYNCHRONOUS MOTOR, Long Answer Type Question No. 6(c).

QUESTION 2019

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternatives for any *ten* of the following:

i) At lagging loads, armature reaction of an alternator is
a) magnetizing ✓b) demagnetizing c) cross-magnetizing d) non-effective

ii) Synchronous machine operates at which power factor?
a) Lagging ✓b) Leading c) Unity d) All of these

iii) Which one of the following methods would give a higher than the actual value of regulation of alternator?
a) zpf method b) mmf method ✓c) emf method d) ASA method

iv) Capacitor in a single phase induction motor is for
a) improving the power factor ✓b) improving the starting torque
c) starting the motor d) reducing the harmonics

v) The direction of rotation of a capacitor start single phase induction motor can be reversed by interchanging terminals of
a) capacitor b) supply
c) centrifugal switch ✓d) starting winding

vi) Shaded pole single phase induction motor can be used for
a) grinders b) food mixture
c) tape recorders ✓d) personal computer as cooling fan

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vii) A 3-phase double layer stator winding has a coil span of 150 deg. Its coil span factor will be
a) 0.96 b) 1.0 ✓c) 0.966 d) 0.98

viii) Which of the following motors has the largest starting torque?
a) Shaded pole motor b) Split phase motor
c) Repulsion motor ✓d) Capacitor start motor

ix) Slip test performed of alternator to determine
a) Slip ✓b) X_d and X_q
c) positive and negative sequence reactance d) sub-transient reactance

x) A 3-phase synchronous motor has
a) high starting torque ✓b) no starting torque
c) low starting torque d) low starting torque

xi) In the *V*-curves for alternator, the parameters of *x* and *y* coordinators are, respectively
✓a) armature current and field current b) power factor and field current
c) armature current and torque d) torque and field current

xii) A ceiling fan uses
a) permanent capacitor motor ✓b) capacitor start and capacitor run motor
c) capacitor motor d) universal motor

Group – B
(Short Answer Type Questions)

2. Write a short note on brushless *dc* machine.
See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 5(a).

3. How is the current phase shift accomplished in the auxiliary winding of a spilt phase induction motor?
See Topic: SINGLE PHASE INDUCTION MOTORS, Short Answer Type Question No. 10.

4. Explain the conditions of parallel operation of alternator. What is the need of parallel operation of alternator?
See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 15.

5. Calculate the distribution factor of fundamental and third harmonics of 3-phase alternator for a stator having 54 slots, 6 poles.
See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 16.

6. Explain the Hunting phenomenon of alternator.
See Topic: SYNCHRONOUS MACHINES, Short Answer Type Question No. 5 (1st Part).

7. How is induced torque developed in a single-phase induction motor according to the double revolving-field theory?
See Topic: SINGLE PHASE INDUCTION MOTORS, Long Answer Type Question No. 7.

Group – C
(Long Answer Type Questions)

8. a) Discuss the different excitation system of alternator with diagram.
b) Why is armature winding of alternator kept stationary and field rotating?
c) What happens, if the field excitation of alternator suddenly get opened during running condition of alternator?
a) See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 4.
b) & c) See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 16(a) & (b).

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9. a) Explain how Potier triangle can be drawn with the help of OCC and any two points from zpfc.
b) A 3-phase, 1500 kVA, 3300 V, 50 Hz star-connected alternator gave the following data for open-circuit and short circuit:

Field current (*A*)	5	10	15	20	25	30
O.C. voltage (*V*)	1000	2000	2780	3300	3664	3923
S.C. current (*A*)	----	225	----	450	----	----

Effective armature resistance per phase is 0.2 ohm. Calculate the full voltage regulation by mmf method at power factor of 0.8 lagging.
c) Why the S.C. characteristics of alternator is straight line?
a) See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 7(b) (2nd Part).
b) See Topic: 3 PHASE SYNCHRONOUS MOTOR, Long Answer Type Question No. 5.
c) See Topic: 3 PHASE SYNCHRONOUS MOTOR, Short Answer Type Question No. 18.

10. a) Discuss the working principle of 3-phase synchronous motor.
b) Why synchronous motor is called a condenser? What is the function of synchronous condenser?
c) Write down the function of Damper winding of synchronous machine.
See Topic: 3 PHASE SYNCHRONOUS MOTOR, Short Answer Type Question No. 4(a), (b) & (c).

11. a) A 250 W, 110 V, 60 Hz, 6-pole, split-phase induction motor has the following impedances:

$$R1 = 1.52\Omega,\ R2 = 3.13\Omega,\ X1 = 2.100\Omega,\ X2 = 1.56\Omega,\ XM = 58.2\Omega$$

The core losses of this motor are 35W and the friction, windage and stray losses are 16W. The motor is operating at the rated voltage and frequency with its starting winding open and the motor's slip is 5 percent. Find the following quantities in the motor at these conditions:

i) Speed in revolutions per minute
ii) Stator current in amperes
iii) Stator power factor
iv) Input power
v) Air-gap power
vi) Output power
vii) Efficiency

b) Write down the working principle of Hysteresis motor.

c) Compare the single phase induction motor with a polyphone induction motor having the same size and speed.

See Topic: SINGLE PHASE INDUCTION MOTORS, Short Answer Type Question No. 20(a), (b) & (c).

12. a) Calculate the stepping angle for a 3-stack, 16-tooth variable reluctance stepper motor.

b) The stator resistance of a 1-phase induction motor is 2.5 ohm and its leakage reactance is 2.0 ohm. On no-load, the motor takes 4A at 96V and at 0.25 lagging power factor. The no-load friction windage loss in negligible. Under the blocked rotor condition the input power is 130W at 6A and 42V. Obtain the equivalent circuit parameters.

c) Write a short note on stepper motor.

a) See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 5.

b) See Topic: SYNCHRONOUS MACHINES, Long Answer Type Question No. 19.

c) See Topic: SPECIAL ELECTRO MECHANICAL DEVICES, Long Answer Type Question No. 6(e).

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