KUESTION

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ELECTRICAL MACHINES

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Manual for Kuestion

Why Kuestion?

It's very overwhelming for a student to even think about finishing 100-200 questions per chapter when the clock is ticking at the last moment. This is the reason why Kuestion serves the purpose of being the bare minimum set of questions to be solved from each chapter during revision.

What is Kuestion?

A set of 40 questions or less for each chapter covering almost every type which has been previously asked in GATE. Along with the Solved examples to refer from, a student can try similar unsolved questions to improve his/her problem solving skills.

When do I start using Kuestion?

It is recommended to use Kuestion as soon as you feel confident in any particular chapter. Although it will really help a student if he/she will start making use of Kuestion in the last 2 months before GATE Exam (November end onwards).

How do I use Kuestion?

Kuestion should be used as a tool to improve your speed and accuracy chapter wise. It should be treated as a supplement to our K-Notes and should be attempted once you are comfortable with the understanding and basic problem solving ability of the chapter. You should refer K-Notes Theory before solving any "Type" problems from Kuestion.

Transformers

Type 1 : Dimensions of a Transformer

For Concept, refer to Electrical Machines K-Notes, Transformers

Sample Problem 1:
A single phase 10 kVA, 50 Hz transformer with 1 kV primary winding draws 0.5 A and 55W, at rated voltage and frequency, on no load. A second transformer has a core with all its linear dimensions $\sqrt{2}$ times the corresponding dimensions of the first transformer. The core material and lamination thickness are the same in both transformer. The primary winding of both the transformers have the save number of turns. If a rate voltage of 2 kV at 50 Hz is applied to the primary of the second transformer, then the no load current and power, respectively, are

(A) 0.7 A, 77.8W
(B) 0.7 A, 155.6W
(C) 1A, 110W
(D) 1A, 220W

Solution: Option (B) is correct.
No-load current of second transformer becomes $\sqrt{2}$ times.
$I_{m2} = \sqrt{2} \times .5 = .707A$
Core Loss becomes $2\sqrt{2}$ times
$P_2 = 2\sqrt{2} \times 55 = 155.6\ W$

Unsolved Problems:

Q.1 Two transformers of the same type, using the same grade of iron and conductor materials, are designed to work at the same flux and current densities, but the linear dimensions of one are $\sqrt{3}$ times those of the other in all respects. The ratio of KVA of the two transformers closely equals
(A) 3 (B) 9 (C) 6 (D) 1

Q.2 A 11000V, 50 Hz transformer has a flux density of 1.2T and a core loss of 3000 watts at rated voltage and frequency. Now all the linear dimensions of the core are doubled, primarily and secondary turns are halved and the new transformer is energised from 22000 V, 50 Hz supply. Both the transformers have the same core material and the same lamination thickness. Core losses of the transformer are

(A) 6000 W (B) 9000 W (C) 12,000 W (D) 24,000 W

Type 2 : Induced EMF in a Transformer

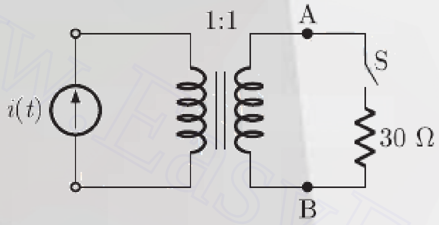
For Concept, refer to Electrical Machines K-Notes, Transformers

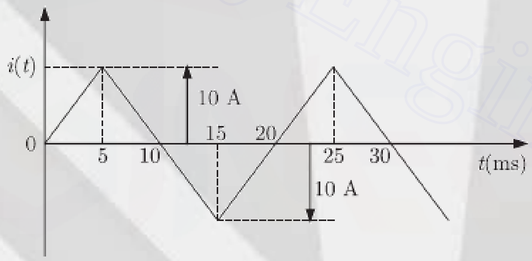
Common Mistake:

Generally we mark the polarities correct and then use Lenz Law again, so we will negative of actual emf so once you know polarities of EMF in primary and secondary just use Faraday's Law instead of Lenz Law.

Sample Problem 2:

The circuit diagram shows a two-winding, lossless transformer with no leakage flux, excited from a current source, *i* (*t*), whose waveform is also shown. The transformer has a magnetizing inductance of 400/π mH.





The peak voltage across A and B, with S open is

(A) 400/π V (B) 800 V (C) 4000/π V (D) 800/π V

Solution : (D) is correct option

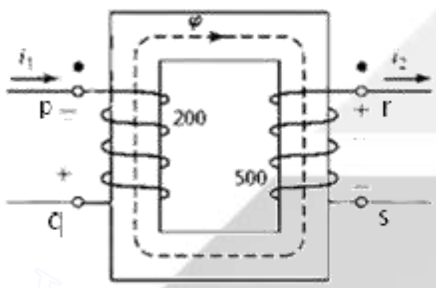
Peak voltage across A and B with S open is

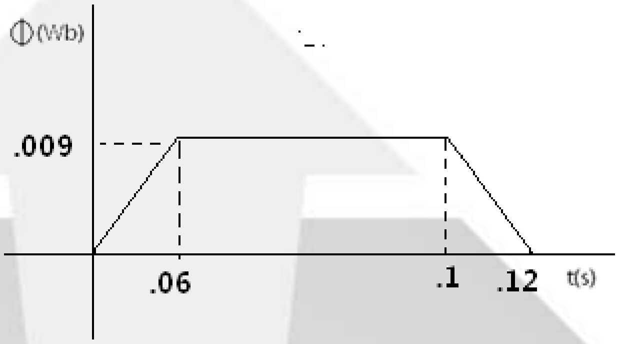
$$V = m\frac{di}{dt} = m \times (slope\ of\ \text{I-t})$$

$$V = \frac{400}{\pi} \times 10^{-3} \times \left[\frac{10}{5 \times 10^{-3}}\right] = \frac{800}{\pi}$$

Unsolved Problems:

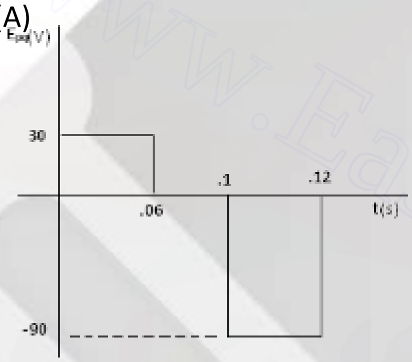
Q.1 The core of a two winding transformer is subjected to a magnetic flux variation as shown in the figure



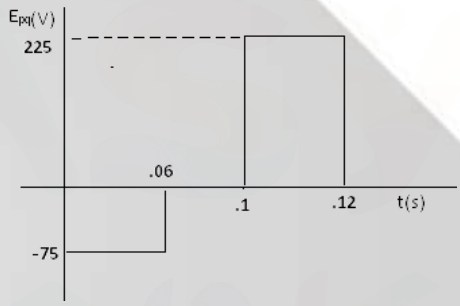


The induced emf (E_{pq}) in the primary winding will be f the form

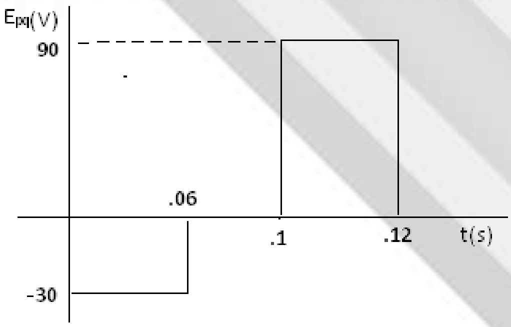
(A)



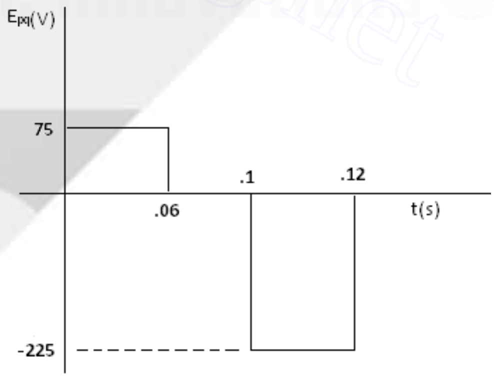
(B)



(C)

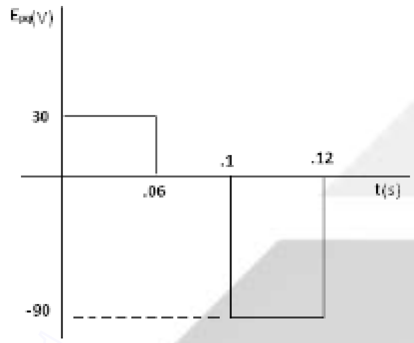


(D)

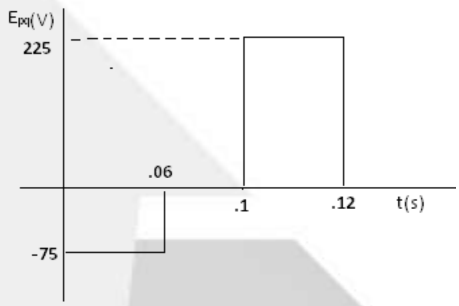


Q.2 In previous question the induced emf (E_{rs}) in the secondary winding will be of the form

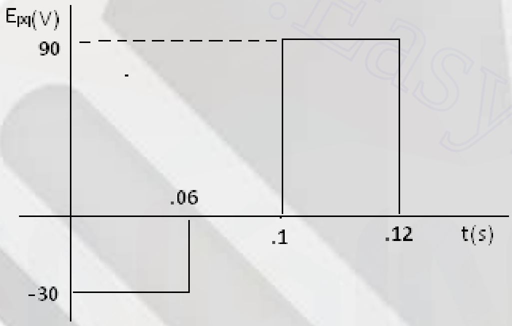
(A)



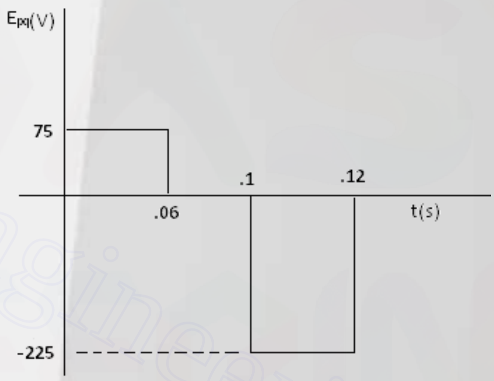
(B)



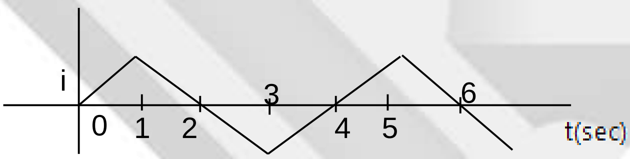
(C)



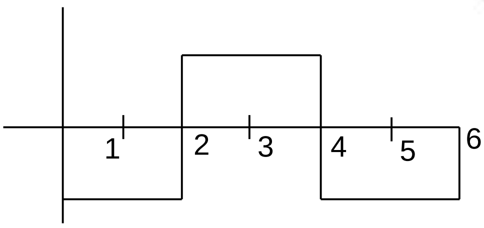
(D)



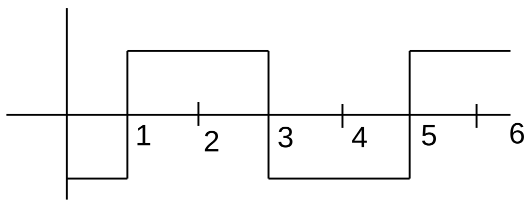
Q.3 An Ideal transformer has Linear B – H curve with finite slope and a turns ratio of 1: 1.The primary of transformer is energized with an ideal current source, producing the signal 'i' as shown in the figure. Then shape of the secondary terminal voltage v_2(t) is



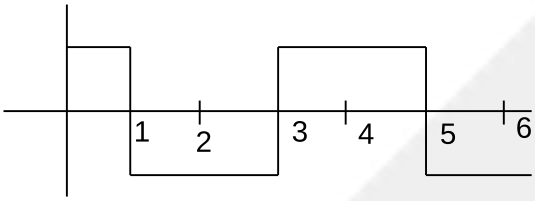
(A)



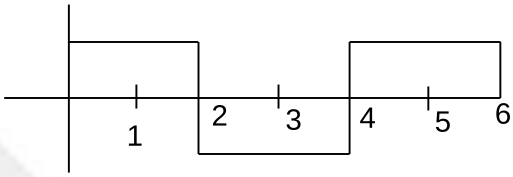
(B)



(C)



(D)

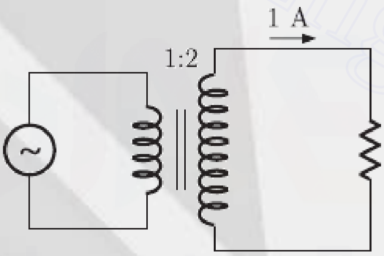


Type 3 : Equivalent Circuit of Transformer

For Concept, refer to Electrical Machines K-Notes, Transformers

Common Mistake:
Sometimes we add primary current to no-load current as scalar though they must be added as phasors.

Sample Problem 3:
A Single-phase transformer has a turns ratio 1:2, and is connected to a purely resistive load as shown in the figure. The magnetizing current drawn is 1 A, and the secondary current is 1 A. If core losses and leakage reactances are neglected, the primary current is



(A) 1.41 A (B) 2 A (C) 2.24 A (D) 3 A

Solution : (c) is correct option
I_0 = 1 amp (magnetizing current)
Primary current IP = ?
I_2 = 1 A
I_{2p} = secondary current referred to Primary

$$= \frac{2}{1} \times 1 = 2 \text{ amp}$$

$$I_p = \sqrt{i_o^2 + i_{2p}^2}$$

$$= \sqrt{1+4}$$

$$= 2.24 \text{ amp}$$

Unsolved Problems:

Q.1 Across the HV side of a single phase 200 V / 400 V, 50 Hz transformer, an impedance of 32 + *j*24Ω is connected, with LV side supplied with rated voltage & frequency. The supply current and the impedance seen by the supply are respectively:

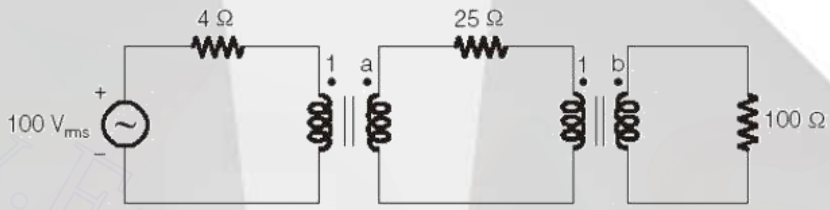
(A) 20 A & (128 + *j*96)Ω

(B) 20 A & (8 + *j*6)Ω

(C) 5 A & (8 + *j*6)Ω

(D) 20 A & (16 + *j*12)Ω

Q.2 Consider the circuit shown below



If the ideal source supplies 1000W, half of which is delivered to the 100 Ω load, then the value of b is____

(A)1.5

(B).89

(C).56

(D).67

Q.3 A 1200/300, turns transformer when loaded, current on the secondary is 100A at 0.8 power factor lagging and primary current is 50A at 0.707 power factor lagging. Determine the no-load current of the transformer with respect to the voltage?

(A) 25.5A

(B) 26.5A

(C) 27.5A

(D) 28.5A

Type 4 : Testing of Transformers

For Concept, refer to Electrical Machines K-Notes, Transformers

Common Mistake:

Before using Iron Losses and Copper Losses obtained from testing we need to verify whether they are obtained at rated conditions before using them in efficiency. If not, we convert them to rated conditions and then only use them.

Sample Problem 4:

The percentage impedance of a 100KVA, 11KV/400V, delta/wye 50 Hz transformer is 4.5% . For the circulation of half the full load current during short circuit test , with low voltage terminals shorted , the applied voltage on the high voltage side will be

(A)200 V (B)247.5V (C)250 V (D)230 V

Solution : (B) is correct option

During S.C. Test to get rated full load current we have to apply 4.5% of rated voltage .

Similarly to get half the rated full load current we have to apply (4.5/2)% rated voltage

$$\therefore \frac{4.5}{2}\times\frac{1}{100}\times 11000 = 247.5\,\text{V}$$

Unsolved Problems:

Q.1 A 230 / 115 V single phase transformer takes a current of 2 A at 0.2 lagging with the l.v. winding open circuited. On load, the l.v. winding delivers a current of 15 A at 0.8 p.f. lagging the primary current is

(A) 9.5 A (B) 9.1 A (C) 6.5 A (D)13A.

Q.2 A 4KVA, 50Hz, 1-ϕ transformer has a ratio 200/400V. The data taken on the l.v side at the rated voltage show that the open circuit wattage is 80w. The mutual inductance between the primary and secondary windings is 1.91H. What value will be the current taken by the transformer if the no load test is conducted on the H.V side at rated voltage, neglect the effect of winding resistances and leakage reactance's.

(A) 0.2A (B) 0.512 A (C) 0.388 A (D) 0.55 A

Q.3 A 20 kVA, 2500 / 250V, 50 Hz, 1-ϕ transformer gave the following test result.

OC test (on LV side): -250 V, 1.4 A, 105 watts

SC test (on HV side): -104 V, 8 A, 320 watts

pf of transformer, if the transformer is operating at maximum regulation is

(A) 0.384 lag (B) 0.923 lag (C) 0.834 lag (D) 0.463 lag

Q.4 A 50 Hz, single – phase transformer draws a short circuit current of 30 A at 0.25 pf lag when connected to 16 V, 50 Hz source. What will be the pf if it is energized from 16 V, 75 Hz source ?

(A) 0.17 lag (B) 0.37 lag (C) 0.25 lag (D) 0.27 lag

Type 5 : Losses in a Transformer

For Concept, refer to Electrical Machines K-Notes, Transformers

Common Mistake:
Before applying expressions for Hysteresis and Eddy Current Losses check whether V/f is constant and nothing is mentioned then we can assume V/f is constant.

Sample Problem 5:
A 50 Hz transformer having equal hysteresis and eddy current losses at rated excitation is operated at 45 Hz at 90% of its rated voltage. Compared to rated operating point the core losses under this condition ;

(A)reduce by 10%
(B)reduce by 19%
(C)reduce by 14.5%
(D)remain unchanged

Solution : (C)is correct option

Given initially the hysteresis loss (W_{h1}) and eddy current loss (W_{h2}) are equal

Total iron loss $W_{i1} = W_{h1} + W_{h1} = 2W_{h1}$

when frequency =45 Hz & applied voltage =90% of rated voltage

$$B_{max} = \frac{V_1}{f_1} = \frac{(.9)V_1}{(.9)f_1} = constant$$

$$W_h \propto f, \quad W_e \propto f^2$$

$$\therefore W_{i2} = W_{h2} + W_{e2}$$

$$\therefore W_{h2} = .9W_{h1} \quad \& W_{e2} = .81W_{e1}$$

$$W_{i2} = .9W_{h1} + .81W_{e1} = 1.71W_{h1}$$

$$[\because W_{h1} = W_{e1}]$$

% reduction core loss = $\frac{2W_{h1} - 1.71W_{h1}}{2W_{h1}} \times 100 = 14.5\%$

Unsolved Problems:

Q.1 A 3-phase alternator is connected to a Dd transformer. The hysteresis and eddy current losses of the transformer are respectively 300 W and 400 W. If the speed of the alternator is reduced by 10%, then the hysteresis and eddy current losses of the transformer will be respectively

(A) 228 W and 262.44 W
(B) 243 W and 324 W
(C) 243 W and 360 W
(D) 270 W and 400 W

Q.2 The iron losses of 1,000 W of a given transformer are equally divided between the hysteresis and eddy current losses, with a certain voltage V impressed at a frequency, if now, the voltage is halved and the frequency is doubled, the iron losses will be

(A) 1000 W (B) 500 W (C) 235 W (D) 470 W

Q.3 A 40 – Hz transformer is to be used on a 50 – Hz system. The losses at the lower frequency are 1.2 %, 0.7 % and 0.5 % for copper, hysteresis and eddy currents, respectively. Find the output at 50 Hz, as a percentage of that at 40 – Hz for the same total losses as on 40 – Hz.

a) 96.5 % b) 107 % c) 93 % d) 103. 5 %

Q.4 For determination of losses a transformer having 400V, 50Hz using test the total iron losses were found to be 2000W at normal V&F. The iron losses were found to be 750W when the applied voltage and frequency were 200V, 25HZ. Determine Hysteresis loss at normal voltage and frequency?

(A) 500W (B) 1000W (C) 2000W (D) 250W

Type 6 : Efficiency of Transformers

For Concept, refer to Electrical Machines K-Notes, Transformers

Common Mistake:
We generally confuse between loading required for maximum efficiency and normal loading the "x" for maximum efficiency has nothing to do with loading in normal cases like if we say half load. That "x" will only be used whenever we talk about Maximum Efficiency.

Sample Problem 6:
A 500kVA, 3-phase transformer has iron losses of 300 W and full load copper losses of 600W. The percentage load at which the transformer is expected to have maximum efficiency is
(A) 50.0% (B) 70.7% (C) 141.4% (D) 200.0%
Solution : (B) is correct option.
Given that,
Transformer rating is 500 kVA
Iron losses = 300 W
Full load copper losses = 600 W
Maximum efficiency condition

$$W_i = X^2 W_2$$

$$X = \sqrt{\frac{W_i}{W_c}}$$

$$X = \sqrt{\frac{300}{600}}$$

= .707
Efficiency% = 0.707x100
= 70.7%

Unsolved Problems:

Q.1 The full load copper loss of a transformer is twice its core loss. At what percent of the full load will the efficiency be maximum
(A) 25% (B) 50% (C) 70.7% (D) 141%

Q.2 A 20 kVA, 220 V / 110 V, 50 Hz single phase transformer has full load copper loss is 200W and core loss is 112.5 W. At what kVA and load power factor the transformer should be operated for maximum efficiency?

(A) 20 kVA & 0.8 power factor (B) 15 kVA & unity power factor
(C) 20 kVA & unity power factor (D) 15 kVA & 0.8 power factor

Q.3 A 500 kVA transformer has constant losses of 500 W and copper losses at full load are 2000 W. The maximum possible efficiency of transformer is

(A) 99.4% (B) 99.6% (C) 98.2% (D) 97.25%

Type 7 : Voltage Regulation

For Concept, refer to Electrical Machines K-Notes, Transformers

Common Mistake:
Mostly the voltage regulation is negative for leading power factor and always it is positive for lagging power factor but if your answer does not comply, please recheck your solution.

Sample Problem 7:
A 415/110 V, single phase transformer has an equivalent resistance of 0.04 pu and equivalent inductance of 0.08 pu. Find the power factor for which the voltage regulation is maximum. Also find the secondary voltage for full loading when primary is excited with 415V?

(A) 0.447, 100V (B) 0.66,110V (C) 0.77,100V (D) 0.66,110V

Solution : (A) is correct option
For maximum regulation the power factor should be lagging with

$$\cos\theta_2 = \frac{r_{e2}}{z_{e2}} = \frac{\varepsilon_r}{\sqrt{\varepsilon_r^2 + \varepsilon_x^2}} = 0.447$$

Maximum voltage regulation $=\varepsilon_r \cos\theta_2 + \varepsilon_x \sin\theta_2 = 0.089$

$$\therefore \frac{E_2 - V_2}{E_2} = 0.089 \Rightarrow V_2 = 100\text{V} \;\text{ as } E_2 = 110\text{V}$$

Unsolved Problems:

Q.1 Percentage resistance and percentage reactance of a transformer are 1% and 4% respectively . what is voltage regulation at power factor 0.8 lagging and 0.8 leading.

(A) 2.4% and -0.8% respectively
(B) 3.2% and -1.6% respectively
(C) 3.2% and -3.2% respectively
(D) 4.8% and 1.6% respectively

Q.2 A 100 MVA, 230/115 KV delta –delta 3 phase transformer has a per unit resistance of 0.02 pu and a per unit reactance of 0.055pu . The transformer supplies a load of 80 MVA at 0.85 PF lagging . What is the percentage voltage regulation of the transformer?

(A)3.5% (B)4.6% (C)3.7% (D)2.4%

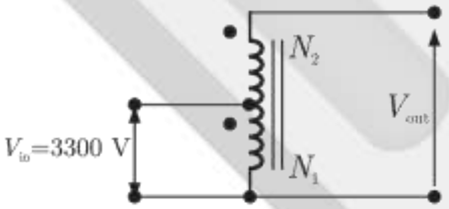
Q.3 A transformer of 400/200 transformation ratio. It required 40V to circulate rated current on short circuit condition and the power factor in case of short circuit is 0.2, find the voltage regulation of transformer at full load 0.8 pf leading?
(A) -2.8% (B)-3.2% (C)-4.26% (D)3.2%

Type 8 : Auto Transformer

For Concept, refer to Electrical Machines K-Notes, Transformers

Common Mistake:
Assume losses as constant between two winding transformer and Auto Transformer.

Sample Problem 8:
A 50 kVA, 3300/230 V single-phase transformer is connected as an auto transformer shown in figure. The nominal rating of the auto- transformer will be



(A) 50.0kVA (B) 53.5kVA (C) 717.4kVA (D) 767.4kVA

Solution : (D) is correct option.
V_{in} = 3300 V

V_{out} = 3300 + 230 = 3530 V
Output current I_2 and output voltage 230 V
So

$$I_2 = \frac{50 \times 10^3}{230} = 217.4 \text{ A}$$

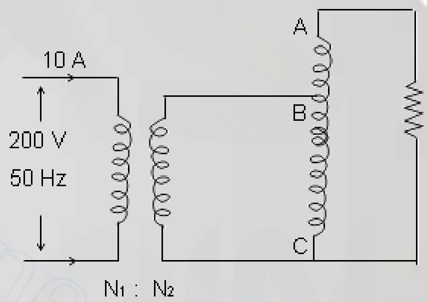
When the output voltage is V_{out} then kVA rating of auto transformer will be
I_2 = 3530x217.4
= 767.42 kVA

Q.1 A 30 kVA, 2700 V / 270 V, two winding transformer is to be used as an auto transformer, with constant source voltage of 2700 V.The secondary voltage of auto transformer is 2430 V. The output power at full load unity pf is
(A) 270 kW (B) 330 kW (C) 297 kW (D) 243 kW

Q.2 The two winding transformer and the autotransformer of the circuit shown in Figure are ideal. The current in the section BC of the autotransformer is

N_1=200 N_2=100

N_{BA}=30 N_{BC}=20



(A) 28 A from B to C
(B) 12 A from C to B
(C) 28 A from C to B
(D) 12 A from B to C

Q.3 A 200KVA , 2300/460V , 50Hz, 2W Transformer is used an auto transformer to step up voltage of 2300 to 2760 V . If transformer has η of 96% at 0.8 pf lag and % regulation of 3%. Then % voltage regulation and KVA rating of auto transformer is
(A).8% ,1500KVA
(B).5%,1200KVA
(C)1% ,1500KVA
(D)1.5%,1200KVA

Answer key

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8
1	B	C	B	B	D	A	B	A
2	D	D	B	C	C	B	C	D
3		B	A	A	D	B	C	B
4				A	B			

DC Machines

Type 1: Induced EMF

For Concept, refer to Electrical Machine K-Notes, DC Machines

Common Mistake:
While Calculating EMF use the value of Armature Current and not the Line Current.

Sample Problem 1:
A 220 V, 15 kW, 100 rpm shunt motor with armature resistance of 0.25 Ω, has a rated line current of 68A and a rated field current of 2.2 A. The change in field flux required to obtain a speed of 1600 rpm while drawing a line current of 52.8 A and a field current of 1.8 A is

(A) 18.18% increase
(B) 18.18% decrease
(C) 36.36% increase
(D) 36.36% decrease

Solution: (D) is correct option

$$E \propto n\phi$$

Where $n \to$ speed, $\phi \to$ flux, $E \to$ back emf

Given that $V_t = 250V,\ R_a = 0.25\Omega,\ n_1 = 100rpm,\ I_{L1} = 68A,\ I_{F1} = 2.2A$

Armature current, $I_{a1} - I_{F1} = 68 - 2.2 = 65.8A$

$E_1 = V_t - I_a R_a = 250 - 65.8 \times 0.25 = 203.55V$

Now, n_2=1600rpm, I_{L2}=52.8A, I_{F2}=1.8A

Armature current, $I_{a2} = I_{L2} - I_{F2} = 52.8 - 1.8 = 51A$

$E_2 = V_t - I_a R_a = 220 - 51 \times 0.25 = 207.25V$

$$\frac{E_1}{E_2} = \left(\frac{n_1}{n_2}\right)\left(\frac{\phi_1}{\phi_2}\right)$$

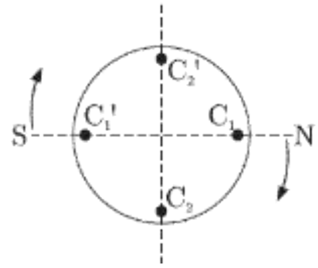
$$\frac{203.55}{207.45} = \left(\frac{1000}{1600}\right)\left(\frac{\phi_1}{\phi_2}\right)$$

$$\phi_2 = 0.6369\phi_1$$

$$\%\text{reduce in flux} = \frac{\phi_1 - \phi_2}{\phi_1} \times 100 = \frac{\phi_1 - 0.6369\phi_1}{\phi_1} \times 100 = 36.3\%$$

Sample Problem 2:

Two magnetic poles revolve around a stationary armature carrying two coil ($c_1 - c'_1$, $c_2 - c'_2$) as shown in the figure. Consider the instant when the poles are in a position as shown. Identify the correct statement regarding the polarity of the induced emf at this instant in coil sides c_1 and c_2.



(A) Θ in c_1, no emf in c_2 (B) $\otimes$ in c_1, no emf in c_2

(C) Θ in c_2, no emf in c_1 (D) $\otimes$ in c_2, no emf in c_1

Solution: (A) is correct option

Given that two magnetic pole revolve around a stationary armature.

Dynamically Induced EMF depends on relative speed so instead of considering rotating poles we assume poles are at rest and armature is rotating with same speed but in anti-clockwise direction.

Now since direction of Magnetic Field is from N-pole to S-pole so field exists from right to left and since armature rotates anti-clockwise the direction of velocity of c2 is right to left and hence parallel to Magnetic field.

$E \propto \sin\theta$, where θ is the angle between velocity of conductor and magnetic field

So, there is no EMF induced in c2.

In case of c1 the angle between magnetic field and velocity is 90^0 and thus emf induced is non-zero and the direction will be upward because if direction is upward the torque on the conductor will be downward whereas the conductor is moving upwards so the induced torque will oppose the motion in accordance with Lenz's Law.

At c_1 the emf induced upward and no emf induced at c_2 and c'_2

Sample Problem 3:

A 8-pole, DC generator has a simplex wave-wound armature containing 32 coils of 6 turns each. Its flux per pole is 0.06 Wb. The machine is running at 250rpm. The induced armature voltage is

(A) 96 V (B) 192 V (C) 384 V (D) 768 V

Solution: (C) is correct option

Given that:

P = 8 Pole, DC generator has wave-wound armature containing 32 coil of 6 turns each. Simplex wave wound flux per pole is 0.06 Wb

N = 250 rpm

So,

Induced armature voltage

$$E_g = \frac{\phi ZNP}{60A}$$

$Z =$ total no. of armature conductor

$Z = 2CN_c = 2 \times 32 \times 6 = 384$

$$E_g = \frac{0.06 \times 250 \times 3.86 \times 8}{60 \times 2}$$

$\because A = 2$ for wave winding

$E_g = 384$ V

Unsolved Problems

Q.1 A 6 – Pole, 1000rpm, DC motor lap wound with 400 conductors. The diameter of armature is 30cm and axial length is 20cm. The average flux density under each pole is 0.5 tesla .The induced emf in the armature is.

(A) 314.16V (B) 153V (C) 104.72V (D) 96.3V

Q.2 A 220V DC generator supplies 4KW at a terminal voltage of 220V.it has an armature resistance of 0.4Ω. If the flux/pole is made to increase by 10%, the machine is now operated as a motor at the same terminal voltage with the same armature current. What is the ratio of generator speed to motor speed?

(A) 1.176 (B) 2.18 (C) 1.056 (D) 2.176

Q.3 A 4-pole D.C. motor runs at 600 rpm on full load and takes 25A at 450 V. The armature is lap wound with 500 conductors and flux per pole is given by $\phi = (1.7 \times 10^{-2})\ I^{0.5}$ webers. Where 'I' is the motor current. If the supply voltage and torque both are halved, The speed at which the motor will run

(A) 378 rpm (B) 369 rpm (C) 389 rpm (D) 372 rpm

Q.4 A 4 pole, 500V DC shunt motor has a wave- wound armature winding containing 720 conductors. The armature resistance is 0.2Ω and the voltage drop across per brush is 1V. If the full load armature current is 60A and the flux per pole Is 30mWb, then what will be full-load rpm speed of the motor?

(A)650rpm (B)675rpm (C)690rpm (D)710rpm

Q.5 A 220V Dc shunt motor takes 5A current on no load while running at a speed of 1000 rpm. It has an armature and a shunt field resistance of 0.3Ω and 200Ω respectively. Now the motor is driving a load drawing 40A current from the supply. If the armature reaction weakness the field by 2.5% on the load, what would be speed of the motor?

(A)962rpm (B)978rpm (C)950rpm (D)976rpm

Q.6 A separately excited D. C. motor has an armature resistance of 0.5 Ω. It is connected to 250 V D. C. supply and drawing an armature current of 20 A at 1500 rpm. The speed of the motor for an armature current of 10 A, for the same field current is

(A) 1520 rpm (B) 1469 rpm (C) 1531 rpm (D) 1475 rpm

Q.7 A 230 V DC series motor develops its rated output at 1500 rpm while taking 20 A. Armature and series field resistances are 0.3 Ω and 0.2 Ω respectively. Neglecting saturation. Resistance that must be added to obtain a rated torque at 1000 rpm is

(A) 4.23 Ω (B) 3.667 Ω (C) 2.87 Ω (D) 4.678 Ω

Q.8 A 220 V, 100 Kw separately excited d.c. generator has an induced e.m.f of 230 V at full load and a brush contact drop of 2 V. the armature resistance is........ ohm.

(A) 0.0167 (B) 0.0176 (C) 0.0716 (D) None

Q.9 A 220 V belt – driven d.c. shunt generator delivering a power of 110 kw at rated voltage continues to run as a motor drawing a power of 11 kw, after the belt breaks. The armature and shunt field resistances are 0.025 and 55 ohms, respectively. The ratio of the induced e.m.f's,E_G : E_M is (G for generator and M for motor), approximately,

(A) 1.063 : 1 (B) 1.082 : 1 (C) 1 : 1.063 (D) 1.085 : 1

Q.10 A 250V DC shunt motor has an armature resistance of 0.5Ω & field resistance of 250Ω when driving constant torque at 600 rpm. The motor draws 21 A. The new speed of the motor if an additional 250Ω resistance is inserted in the field circuit.

(A)1200rpm (B)600rpm (C)780rpm (D)1150rpm

Type 2: Torque equation

For Concept, refer to Electrical Machine K-Notes, DC Machines

Sample Problem 4:
For the motor to deliver a torque of 2.5 Nm at 1400 rpm, the armature voltage to be applied is (Assume R_a = 3.4 Ω)

(A) 125.5 V (B) 193.3 V (C) 200 V (D) 241.7 V

Solution: (B) is correct option
$T = 2.5$ Nm at 1400 rpm
than V=?

$$\because T = \frac{E_b I_b}{\omega}$$

$$2.5 = \frac{186.6 \times I_b}{2\pi \times 1400}$$

$$I_a = 1.963A$$

$$V = E_b + I_a R_a = 186.6 + 1.963 \times 3.4 = 193.34V$$

Unsolved Problems:

Q.1 A 220V series motor running at a certain speed takes 25A. Its armature and series field resistance are 0.3 Ω and 0.1Ω respectively. The motor supplying to a load that the torque varies as the cube of the speed. The resistance to be connected in series with the armature to reduce the speed by 30% is ?

(A) 4.2 Ω (B) 8.73 Ω (C) 1.9 Ω (D) 6.5 Ω

Q.2 A 230 V, 250 rpm, 100 A separately excited D.C. motor has an armature resistance of 0.5Ω . The motor is connected to 230 V D. C. supply and rated D. C. voltage is applied to the field winding. It is driving a load whose torque–speed characteristic is given by$T_L = 500 - 10\omega$, where ω is in rad / sec. Steady state speed at which the motor drive the load, is

(A) 232 rpm (B) 187 rpm (C) 179 rpm (D) 300 rpm

Q.3 A 200 V, 2000 rpm, 10 A separately excited D. C. motor has an armature resistance of 2Ω. Rated D. C. voltage is applied to both the armature and field winding of the motor. If the armature draws 5 A from the source, torque developed by the motor is

(A) 4.3 Nm (B) 4.77 Nm (C) 0.45 Nm (D) 0.5 Nm

Q.4 A 6-pole dc motor has 488 wave wound conductors, length of the armature is 250 mm and diameter is 530 mm. The flux density in the air gap is 0.6 T. The armature current is 243 A and armature resistance is 0.073Ω. The gross mean power developed when the applied voltage is 500 V is

(A) 117.2 KW (B) 112.2 KW (C) 212 KW (D) 132 KW

Q.5 A 4-pole D.C series – motor takes an armature current of 60 Amperes when running steadily at 2000 R.P.M. The four field coils are now connected in two parallel groups of two in series, Now the armature takes a current of 100 A. Assuming that the flux produced as directly proportional to the exciting current and the load torque varies as the square of the speed. The new speed has to be

(A) 2357 rpm (B) 1667 rpm (C) 3333 rpm (D) 1200 rpm

Type 3:Plugging

For Concept, refer to Electrical Machine K-Notes, DC Machines

Common Mistake:
Braking Torque and Plugging Torque are different quantities and should not be interchanged.

Sample Problem 5:
A 240 V, dc shunt motor draws 15 A while supplying the rated load at a speed of 80 rad/s. The armature resistance is 0.5 Ω and the field winding resistance is 80 Ω. The net voltage across the armature resistance at the time of plugging will be

(A) 6 V (B) 234 V (C) 240 V (D) 474 V

Solution: (D) is correct option
Given: V = 240 V, dc shunt motor
I = 15 A
Rated load at a speed = 80 rad/s
Armature Resistance = 0.5 Ω
Field winding Resistance = 80 Ω
So,
E = 240 – 12*0.5
E = 234 V
$V_{plugging} = V + E$
$= 240 + 234$
$= 474$ V

Unsolved Problems

Q.1 A 400 V, 750 RPM, 70 A D.C. shunt motor has an armature resistance of 0.3 Ω.When running under rated conditions, the motor is to be braked by plugging with armature current limited to 90 A. When the speed has fallen to 300 rpm, total braking torque is

(A) 645.3 Nm (B) 538.4 Nm (C) 723.5 Nm (D) 829.4 Nm

Q.2 A 200V DC shunt motor is running at 1000 rpm and drawing a current of 10 A. Its armature winding resistance is 2Ω. It is braked by plugging. The resistance to be connected in series with armature to restrict armature current to 10 A, is?

(A)32Ω (B)36Ω (C)38Ω (D)40Ω

Q.3 A 400V shunt motor supplies the rated load at a speed of 100 rad/sec and drawing a current of 30 A. The armature resistance is 1Ω and the field winding resistance is 200Ω.The breaking torque at the instant of plugging will be?

(A)80.96N-m (B)156.26N-m (C)240.66N-m (D)180.75N-m

Type 4: Power Loss and Efficiency

For Concept, refer to Electrical Machine K-Notes, DC Machines

Common Mistake:
In case of Shunt Machine we consider field losses as constant losses whereas in Series Machine field losses are considered as Variable Losses while calculating maximum efficiency.

Sample Problem 6:

The armature resistance of a permanent magnet dc motor is 0.8 Ω. At no load, the motor draws 1.5 A from a supply voltage of 25 V and runs at 1500 rpm. The efficiency of the motor while it is operating on load at 1500 rpm drawing a current of 3.5 A from the same source will be

(A) 48.0% (B) 57.1% (C) 59.2% (D) 88.8%

Solution: (A) is correct option

Given that the armature of a permanent magnet dc motor is

Ra = 0.8 Ω

At no load condition

V = 25 V, I = 1.5 A, N = 1500 rpm

No load losses = E*I

$\because E = V - IR_a$

So,No load losses = (25 − 1.5*0.8)1.5= 35.7 W

At load condition

I = 3.5 A

Iron losses = I^2R

$(3.5)^2$ 0.8 = 9.8 W

Total losses = No load losses + iron losses = 35.7 + 9.8 = 45.5 W

Total power P = VI

P = 25*3.5 = 87.5 W

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{total power-losses}}{\text{total power}} = \frac{87.5 - 45.5}{87.5} \times 100 = 48\%$$

Unsolved Problems

Q.1 In a D. C. motor running at 1000 rpm, the hysteresis and eddy current losses are 250 W and 100 W respectively. If the flux remains constant, speed at which the total iron losses halved, is

(A) 629 rpm (B) 570 rpm (C) 500 rpm (D) 670 rpm

Q.2 A 250 V d.c. shunt motor takes 1.5 A on no – load. The armature and field resistances are 1.0 and 500 ohms, respectively. The maximum efficiency when acting as a motor is, approximately,

(A) 86.3 % (B) 84.9 % (C) 86.6 % (D) 88.2 %

Q.3 A 10 KW, 250 V, 1200 rpm dc shunt motor has a full load efficiency of 80%.The field and armature resistance are 125 and 0.2 Ω respectively. The speed of the motor is to be reduced to 75% with load torque remaining const. Resistance to be inserted in the armature circuit is?

(A) 1.25 Ω (B) 1.75 Ω (C) 2.25 Ω (D) 1.0 Ω

Q.4 A 230V DC shunt motor has an armature resistance and a field resistance of 0.3Ω and 160Ω respectively. The motor draws a line current of 3.938 A on no load. The armature current at full-load is 40A. What is the power developed by the armature on no laod?

(A)575W (B)572.125W (C)570.56W (D)590W

Q.5 A 200 V dc shunt motor delivers an output of 17 kW with an input of 20 kW. The field winding resistance is 50Ω and armature resistance is 0.04Ω. Maximum efficiency will be obtained when the total armature copper losses are equal to

(A) 2632 W (B) 3000 W (C) 3680 W (D) 5232W

Type 5: DC machine Connections

For Concept, refer to Electrical Machine K-Notes, DC Machines

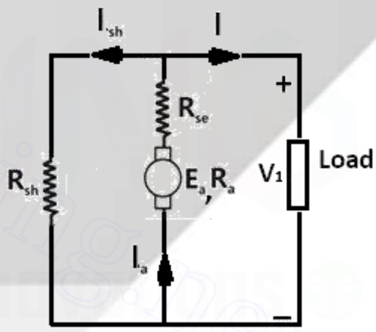
Sample problem:

The armature, shunt and series winding resistance of a 100A, 120V compound generator are 0.06Ω, 25Ω and 0.04Ω respectively. If the generator is connected as long shunt, what will be the induced emf?

(A)130.48V (B)126.28V (C)109.52V (D)129.52V

Solution: (A) is correct option

The generator is connected as long shunt, the equivalent circuit is



Shunt field current, $I_{sh} = \frac{V_t}{R_{sh}} = \frac{120}{25} = 4.8A$

Armature current, $I_a = I + I_{sh} = 100 + 4.8 = 104.8A$

Induced emf $E_g = V_t + I_a(R_a + R_{se}) = 120 + 104.8(0.06 + 0.04) = 130.48$

Unsolved Problems:

Q.1 A 50KW, 120V, long shunt compound generator has armature resistance, shunt field resistance and the series field resistance of 0.05Ω, 40Ω and 0.02Ω respectively. It supplies a load at its maximum efficiency and the rated voltage. The rotational loss is 2KW. The maximum efficiency of the generator is ?

(A)90.24% (B)89.36% (C)83.5% (D)82.11%

Q.2 A 250V shunt short generator has armature, series field and shunt field resistance of 0.4Ω, 0.2Ω and 125Ω respectively. If this generator supplies 10KW at rated voltage. Find the EMF generated in the armature. Ignore the effect of armature reaction and allow 1V per brush for contact drop.

(A)245.5V (B)276.8V (C)278.5V (D)295.5V

Q.3 A 15KW, 230V, 80A, 1000rpm DC series motor has the following full load losses expressed in percentage of motor input. Neglect the armature reaction and magnetic saturation and assume the rotational loss to remain constant.

Armature circuit ohmic loss (including brush loss)=2.8%

Field ohmic loss=2.6%

Rotational loss =2.2%

If the motor draws half the rated current at rated voltage, determine the speed and shaft power output?

(A)2505rpm, 8754W

(B)2055rpm, 8457W

(C)2055rpm, 8547W

(D)2106rpm, 8547W

Answer Key

	1	2	3	4	5	6	7	8	9	10
Type 1	C	A	D	B	D	C	B	B	A	D
Type 2	B	D	A	A	A					
Type 3	A	C	B							
Type 4	B	B	A	B	A					
Type 5	D	B	C							

Synchronous Machines

Type 1: Induced EMF

For Concept, refer to Electrical Machines K-Notes, Synchronous Machines

Common Mistake:

If number of slots are more than 6 then winding is distributed though it may not be explicitly mentioned in the question.

Don't confuse coil span and chording angle while calculating pitch factor.

Sample Problem 1:

A 4-pole, 50 Hz, synchronous generator has 48 slots in which a double layer winding is housed. Each coil has 10 turns and is short pitched by an angle to 36^0 electrical. The fundamental flux per pole is 0.025 Wb. The line-to-line induced emf(in volts), for a three phase star connection is approximately

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

Solution: (C) is correct option

4pole , 50 Hz , Synchronous generator , 48 slots

For double layer winding No. of coils =No. of slots 48

Total number of turns =48*10=480

For 3 phase winding ,

$$\text{Turns / phase} = \frac{480}{3} = 160$$

$$K_p = \cos(\frac{\alpha}{2}) = \cos(\frac{36}{2}) = 0.951$$

$$\gamma = \frac{4 \times 180}{48} = 15^0, \quad \text{slot/pole/phase=m=}\frac{48}{4 \times 3} = 4$$

$$K_d = \frac{\sin(\frac{m\gamma}{2})}{m\sin(\frac{\gamma}{2})} = \frac{\sin(\frac{60}{2})}{4\sin(\frac{15}{2})} = 0.9576$$

$$E_{ph} = 4.44 \times K_p \times K_d \times \phi \times f \times T_{ph}$$

$$=4.44 \times 0.951 \times 0.9576 \times 0.025 \times 50 \times 160 = 808.68V$$

$$E_{L-L} = 1400.67V$$

Unsolved Problems

Q.1 A 3 – phase, 16 – pole synchronous generator has star connected full pitch winding with 144 slots and 12 conductors per slots. The flux per pole is 0.05 wb and the speed is 375rpm. The line induced emf is.

(A) 5316V (B) 4253V (C) 3544V (D) 3069V

Q.2 An electrical machine with 6-poles has 90 slots and 8 conductors / slot, all the coils are full pitched. The flux per pole is 0.03 wb. The relative speed between field flux and armature winding is 1200 rpm. The generated voltage if the machine is operated as a lap connected d.c. generator

(A) 748 V (B) 1296 V (C) 432 V (D) 526 V

Q.3 A single–phase alternator has 6 slots per pole. The induced emf when all the slots are wound is E_1, while that with only four slots / pole wound, the remaining being left unwound is E_2. Then $E_1 : E_2$ = …………

(A) 1 : 1.3 (B) 1.3 : 1 (C) 1 : 1 (D) 3 : 2

Q.4 The number of slots per pole per phase of a 3 phase synchronous machine with double layer winding and a phase spread of 60^0 is 3. Its distribution factor is ___________.

(A)0.86 (B)0.96 (C)0.88 (D)0.75

Type 2: Voltage Regulation

For Concept, refer to Electrical Machines K-Notes, Synchronous Machines

Common Mistake:
While Calculating Induced EMF Terminal Voltage should be in per-phase value. Also while calculating Voltage Regulation either both voltages should be per phase or line values.

Sample Problem 2:
A Single-phase,2000V alternator has armature resistance and reactance of 0.8 ohms and 4.94 ohms respectively .The voltage regulation of the alternator at 100A load at 0.8 leading power factor is
(A)7% (B)-8.9% (C)17% (D)0%
Solution: (B) is correct option
Single phase alternator , V=2000V , R_a=0.8Ω , I_a=100A, X_a=4.94Ω
Power factor =0.8(lead)=cosϕ

$$\text{Induced emf } = \sqrt{\left[(V\cos\phi + I_aR_a)^2 + (V\sin\phi \pm I_aX_a)^2\right]}$$

+ lag p.f.
- lead p.f.

$$E = \sqrt{\left[(2000\times0.8 + 100\times0.8)^2 + (2000\times0.6 - 100\times4.94)^2\right]}$$

$$E = 1822.3V$$

The voltage regulation $= \dfrac{|E|-|V|}{|V|}\times 100 = \dfrac{1822.3-2000}{2000}\times 100 = -8.9\%$

Unsolved Problems

Q.1 A 600V, 60 K.V.A, single phase alternator has an effective resistance of 0.2 Ω. A field current of 10A produces an armature current of 210A on short circuit and an emf of 480V on open circuit. The full load regulation with 0.8 P.F lagging is

(A) 16.67% (B) 28.5% (C) –8.9% (D) 30.2%

Q.2 A 3-ϕ Y-connected synchronous generator is rated at 1.5MVA, 11 K.V. The armature effective resistance and synchronous reactance are 0.015p.u and 0.31 p.u respectively. Find out the p.f at which the regulation becomes zero for a load of 1.4375MVA.

(A) 0.87 lead (B) 0.95 lead (C) 0.98 lead (D) unity

Q.3 A 3-ϕ Y-connected synchronous generator is rated at 1600KVA, 13500V. The armature effective resistance and synchronous reactance are 1.5Ω and 30 Ω respectively per phase. Calculate the percentage regulation for a load of 1280KW at power factors of 0.8 leading?

(A)-10% (B)-11% (C)-12% (D)-13%

Q.4 A 3-ϕ Y-connected alternator is rated at 10KVA, 415V. The synchronous impedance of alternator is (0.4+j5)/phase. The maximum possible voltage regulation at rated condition?
(A)29.1% (B)30% (C)27.5% (D)0%

Type 3: Synchronous Impedance

For Concept, refer to Electrical Machines K-Notes, Synchronous Machines

Common Mistake:
While Calculating Synchronous Impedance per phase value of Open-Circuit Voltage should be considered.

Sample Problem 3:
A 100 kVA, 415 V(line), star-connected synchronous machine generates rated open circuit voltage of 415 V at a field current of 15 A. The short circuit armature current at a field current of 10 A is equal to the rated armature current. The per unit saturated synchronous reactance is
(A) 1.731 (B) 1.5 (C) 0.666 (D) 0.577
Solution: (C) is correct option
Given star connected synchronous machine, P = 100 kVA
Open circuit voltage V = 415 V and field current is 15 A, short circuit armature current at a field current of 10 A is equal to rated armature current.

$\therefore I_{sc}$ for 10A is $I_{a\ rated}$

I_{sc} for 15A $= \frac{15}{10} \times I_{a\ rated}$

$$I_{a\ rated} = \frac{100 \times 10^3}{\sqrt{3} \times 415} = 139.12A$$

$\therefore I_{sc}$ for 15A $= 208.68A$

$$Z_{s(saturated)} = \frac{415}{208.68} = 1.988 \text{ ohm}$$

$$I_{a\ rated} \times Z_s = 139.12 \times 1.988 = 276.66V$$

$$\text{p.u. } Z_s = \frac{276.66}{415} = 0.666$$

Alternate Method:

$$SCR = \frac{\text{Field current required for rated open circuit voltage}}{\text{Field current required for rated short circuit current}}$$

$$SCR = \frac{15}{10} = 1.5$$

$$SCR = \frac{1}{X_{pu}}$$

$$X_{pu} = \frac{1}{SCR} = \frac{1}{1.5} = 0.666 \text{ pu}$$

Unsolved Problems

Q.1 A 25MVA, 13KV, 3 – phase, star connected, 50Hz synchronous machine has a short circuit ratio of 0.52. For rated induced voltage on no - load, it requires a field current of 250A. The adjusted (saturated) synchronous reactance of the machine is.

(A) 13Ω (B) 1.92Ω (C) 6.76Ω (D) 18Ω

Q.2 A 600V, 60KVA single phase alternator has an effective resistance of 0.2Ω. A field current of 10 A produces an armature current of 210A on short circuit and an emf of 480V on open circuit. Then synchronous impedance and reactance is

(A)2.26Ω, 2.27Ω (B)2.28Ω, 2.26Ω (C)2.28Ω, 2.27Ω (D)2.27Ω, 2.28Ω

Q.3 A 3-phase star-connected 1000KVA, 11000V alternator has rated current of 52.5A. The AC resistance of the winding per phase is 0.45Ω .The test results are given below
O.C. test: Field current =12.5A, voltage between lines =422V
S.C. test : Field current =12.5A, line current = 52.5 A
What is the full-load voltage regulation of alternator at 0.8 pf lagging?
(A)2.53% (B)2.63% (C)2.73% (D)2.83%

Type 4: Power Angle Equation

For Concept, refer to Electrical Machines K-Notes, Synchronous Machines

Common Mistake:
If we use per-phase voltages we obtain per-phase power and if we use line voltages we directly obtain 3-phase power.

Sample Problem 4:
For a salient pole alternator excitation voltage is 1.2 p.u. $X_d = 1$, $X_q = 0.6$ p.u. The maximum power developed at rated voltage when the excitation fails.
(A) 1 p.u. (B) 0.5 p.u. (C) 0.33 p.u. (D)1.2 p.u.
Solution: (C) is correct option

$$P = \underbrace{\frac{V_t E_f}{X_d}\sin\delta}_{\text{Excitation power}} + \underbrace{\frac{V_t^2}{2}\left(\frac{1}{X_q}-\frac{1}{X_d}\right)\sin 2\delta}_{\text{Reluctance power}}$$

When excitation fails, there is no excitation power. Only reluctance power will left
for maximum reluctance power $\delta = 45^0$

$$P = \frac{1}{2}\left(\frac{1}{0.6}-\frac{1}{1}\right)\sin(2\times 45) = 0.33 \text{ p.u.}$$

Unsolved Problems

Q.1 A cylindrical rotor synchronous motor with induced emf = 1.5 pu is connected to an infinite bus bar. The machine has a synchronous reactance of 1.2 pu and output power delivered to load is 0.5 pu. With all losses neglected, the reactive power is

(A) 0.3125 pu delivered (B) 0.3125 pu absorbed

(C) 0.4167 pu delivered (D) 0.4167 pu absorbed

Q.2 A 3.5 MVA, salient pole, 3–phase synchronous generator rated at 6.6 KV has 32–poles. Its direct axis and quadrature axis synchronous reactance's are 9.6 Ω and 6 Ω per phase respectively. The total maximum power can the generator supply at the rated voltage if the field become open circuited (neglect armature resistance) is

(A) 0.978 MW (B) 1.362 MW (C) 8.2 MW (D) 2.78 MW

Q.3 A synchronous generator is running over excited with E_f=1.4p.μ. This machine, with a synchronous reactance of 1.2p.u.is delivering a synchronous power of 0.5p.u.to the bus. If the prime mover torque is increased by 1%, by how much will the reactive power change

(A) –0.5% (B) 0.37% (C) –0.475% (D) 0.345%

Q.4 A 3-phase star-connected 50 Hz synchronous generator has direct axis synchronous reactance of 0.65 pu and quadrature axis synchronous reactance of 0.5 pu. The generator delivers rated kVA at 0.8 lagging power factor. Resistance drop at full load is 0.02 pu. Open circuit voltage is

(A) 1.372 pu (B) 0.832 pu (C) 1.492 pu (D) 0.637 pu

Q.5 A 3 phase star-connected alternator with Z_s=j8Ω , deliver 200A at a power factor 0.8 lagging to 11KV infinite bus, with steam supply unchanged, find the percentage increase or decrease in the excitation emf necessary to raise the p.f. to unity. Assume rotational losses to remain constant.

(A)12.12% (B)8.84% (C)20.04% (D)15.08%

Type 5: Salient Pole Synchronous Machines

For Concept, refer to Electrical Machines K-Notes, Synchronous Machines

Common Mistake:
While using EMF – Terminal Voltage Equation direct axis and quadrature axis currents, make sure that you treat them as phasors and use their phase angles as well.

Sample Problem 5:
The direct axis and quadrature axis reactance's of a salient pole alternator are 1.2 p.u and 1.0 p.u respectively. The armature resistance is negligible. If this alternator is delivering rated kVA at upf and at rated voltage then its power angle is
(A) 30^0 (B) 45^0 (C) 60^0 (D) 90^0
Solution: (B) is correct option
Power angle for salient pole alternator is given by

$$\tan\psi = \frac{V_t \sin\phi + I_a X_q}{V_t \cos\phi + I_a R_a}$$

Since the alternator is delivering at rated kVA rated voltage

$I_a = 1$ pu , $V_t = 1$ pu,

$\phi = 0^0, \sin\phi = 0, \cos\phi = 1$

X_q = 1 pu, X_d = 1.2 pu

Since $\phi = 0^0$, $\psi = \delta$

$$\tan\delta = \frac{1\times 0 + 1\times 1}{1+0} = 1$$

$\delta = 45^0$

Q.1 A 1500KVA, star connected 6.6KV salient pole synchronous motor has X_d = 23.2Ω and X_q= 14.5Ω/ph respectively. Armature resistance is negligible. The excitation emf (line value) when the motor is supplying rated load at 0.8 lead P.F. is.

(A) 6.1KV (B) 10.57KV (C) 15KV (D) 18.3KV

Q.2 A 50-Hz, 3-phase, 480-V, delta connected salient pole synchronous generator has x_d = 0.1 ohm and x_q = 0.075 ohm. The generator is supplying 1200 Amp. at 0.8 p.f. lagging. The load angle is

(A) 41.5° (B) 14.5° (C) 4.6° (D) 6.4°

Q.3 A 10KVA, 380V, 50Hz, 3-ϕ star connected salient pole alternator has direct axis and quadrature axis reactance's of 12Ω and 8Ω respectively. The armature has a resistance of 1Ω per phase. The generator delivers rated load at 0.8 p.f lagging with the terminal voltage being maintained at rated value. Find the direct axis component of armature current, if the load angle is 16.15°

(A) 12.14A (B) 9.14A (C) 14.21A (D) 5.37A

Q.4 In a 3 phase, salient pole synchronous generator with the 'a' phase terminal voltage of $V\angle 0^0$ volts, the phase current delivered by the machine is 30A, lagging the terminal voltage by 30^0. The induced emf per phase is at angle 15^0 from the terminal voltage. The currents I_q and I_d are, respectively

(A) $15\angle -90^0$ A, $26\angle 0^0$ A (B) $30\angle -30^0$ A, 0A

(C) $29\angle -15^0$ A, $7.76\angle -105^0$ A (D) $21.21\angle -75^0$ A, $21.21\angle 15^0$ A

Type 6: Synchronous Motor

For Concept, refer to Electrical Machines K-Notes, Synchronous Machines

Common Mistake:

Don't confuse between EMF-Terminal Voltage Equations of Generator and Motor.
Always the EMF-Terminal Voltage Equation (KVL) is applied on phase quantities so first convert terminal voltage to per phase before applying that equation.

Sample Problem 6:

A synchronous motor is connected to an infinite bus at 1.0 pu voltage and draws 0.6 pu current at unity power factor. Its synchronous reactance is 1.0 pu resistance is negligible. Keeping the excitation voltage same, the load on the motor is increased such that the motor current increases by 20%. The operating power factor will become

(A) 0.995 lagging (B) 0.995 leading

(C) 0.791 lagging (D) 0.848 leading

Solution: (A) is correct option

A synchronous motor is connected to an infinite bus at 1.0 p.u. voltage and 0.6 p.u. current at unity power factor. Reactance is 1.0 p.u. and resistance is negligible.

So,

$V = 1\angle 0^0$ p.u.

$I_a = 0.6\angle 0^0$ p.u.

$Z_s = R_a + jX_s = 0 + j1 = 1\angle 90^0$ p.u.

$V = E\angle\delta + I_a Z_s = 1\angle 0^0 - 0.6\angle 0^0 \times 1\angle 90^0$

$E\angle\delta = 1.166\angle -30.96$ p.u.

Excitation voltage $= 1.17$ p.u.

Load angle $(\delta) = 30.96^0$ (lagging)

$$|I_a X_a|^2 = E^2 + V^2 - 2EV\cos\delta \qquad \{\because I_a = 1.2\times 0.6 = 0.72 \text{ p.u.}\}$$

$$(.72\times 1)^2 = 1^2 + (1.662)^2 - 2\times 1\times 1.1662\cos\delta$$

$$\cos\delta = 0.789 \Rightarrow \delta = 37.85^0$$

$$I_a = \frac{V\angle 0^0 - E\angle -\delta}{jX_s} = \frac{1\angle 0^0 - 1.1662\angle -37.85^0}{1\angle 90^0}$$

$$I_a = 0.712\angle -6.31^0$$

$\therefore$ New power factor $= \cos(-6.31^0) = 0.994$ Lag

Unsolved Problems:

Q.1 A 3300 V delta connected synchronous motor having a synchronous reactance per phase of 18 Ω. It operating at a lead P.F of 0.707 when drawing 800 KW. The excitation emf (E) and load angle (δ) is

(A) 4973 V, 17^0 lead (B) 4973 V, 17^0 lag

(C) 8614 V, 17^0 lag (D) 8614 V, 17^0 lead

Q.2 A 3–phase star connected 400 V synchronous motor takes a power input of 5472 watts at rated voltage. Its synchronous reactance is 10 Ω per phase and resistance is negligible. If its excitation voltage is adjusted equal to the rated voltage of 400 V. Power factor of the motor is?

(A) 0.867 lag (B) 0.9848 lag (C) 0.892 lag (D)0.978 lag

Q.3 A 4 – pole star connected, 50 Hz, 11 kV, 40 MVA turbo generator, with a synchronous reactance of 0.8 p.u is connected to a power network. This power network can be represented by 11 kV infinite bus with a series reactance of 0.5 Ω. A voltage regulator adjusts the field current such that alternator terminal voltage remains constant at 11kV. The generator delivers an output of 40 MVA. Excitation emf (line to line) is

(A) 1372 V (B) 14644 V (C) 13832 V (D) 14727 V

Q.4 A 100 h.p, 500 V, 3-ϕ, star connected synchronous motor has a resistance and reactance per phase of 0.03 ohm and 0.3 ohm respectively. Calculate the electromotive force per phase for full load p.f if 0.8 lagging, assume an efficiency of 93%.

(A) 266 V (B) 309 V (C) 34.47 V (D) none

Type 7: Parallel Operation

For Concept, refer to Electrical Machines K-Notes, Synchronous Machines.

Common Mistake:
While Calculating Synchronizing current consider both emf in per-phase values and consider total reactance as sum of two reactances.

Sample Problem 7:
Two 550KVA alternators operate in parallel to supply the following loads
(1) 250KW at 0.95 p.f. lag
(2) 100KW at 0.8 p.f. lead
One machine is supplying 200KW at 0.9 p.f. lag. The power factor of the other machine must be ?
(A)0.89 lead (B)0.95 lead (C)0.95 lag (D)0.89 lag

Solution: (A) is correct option
KW demand of load = 250+100KW = 350KW
KVAR demand of load =
$$\frac{250K}{0.95}\times\sin\left[\cos^{-1}0.95\right]+\frac{100K}{0.8}\times\sin\left[\cos^{-1}0.8\right]=82.17\ (\text{lag})+75\ (\text{lead})=7.17\ (\text{lag KVAR})$$
KW supplied by machine 1=200KW
KW supplied by machine 2=demand-200KW=150Kw
KVAR supplied by machine 1= $\frac{250K}{0.9}\times\sin\left[\cos^{-1}0.9\right]=96.86$ lag
Hence machine 1 supplied the reactive power to machine 2 and machine 2 supplied the active power to machine 1.

$\therefore$ KVAR consumed by machine 2 =96.86-7.17=89.69 KVAR

$$\tan\phi = \frac{VI\sin\phi}{VI\cos\phi} = \frac{89.69\ KVAR}{150\ KW} = 0.5979$$

ϕ=30.87 $\Rightarrow$ cosϕ=0.858 lead

Unsolved Problems:

Q.1 Two 3-phase, Y-connected alternators are to be paralleled to a set of common bus bars. The armature has a per phase synchronous reactance of 1.7 Ω and negligible armature resistance. The line voltage of the first machine is adjusted to 3300 V and that of the second machine is adjusted to 3200 V. The machine voltages are in phase at the instant they are paralleled. Under this condition, the synchronizing current per phase will be

(A) 16.98 A (B) 29.41 A (C) 33.96 A (D) 58.82 A

Q.2 Two similar 3-phase, 6.6 kV star – connected alternators running parallel, supply a load of 4000 kW at 0.8 pf lagging. The synchronous impedance per phase for the first machine is 0.6 + j 10Ω and for the second machine is 0.5 + j 12Ω. The total load is shared equally between the two machines. Without changing their driving torques, the excitation of first alternator is adjusted that delivers 200 A at a lagging power factor. Excitation voltage of Alternator 1 and load angle of second alternator are?

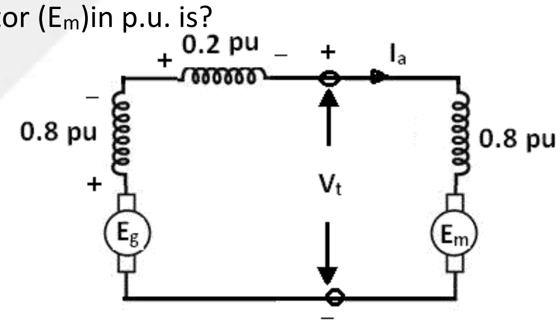
(A) 6.78 kv / phase, 22° (B) 5.16 kV / phase, 15.3°
(C) 8.93 kv / phase, 19° (D) 5.16 kV / phase, 19°

Q.3 A number of alternators are working in parallel with their terminal voltage equal to the rated value. One of the machine, which has a synchronous reactance of 50% and a resistance of 1%, deliver a power output in KW equal to 70% of its rated KVA. If the emf of this unit equals 1.2 times the terminal voltage, find out the power factor at which the machine is operating.

(A)0.76 lag (B)0.9 lag (C)0.78 lag (D)0.8 lag

Q.4 In the circuit shown in figure below a synchronous generator is feeding a synchronous motor through a transmission line. Both the motor and generator are rated as 10KVA, 400V, 50Hz. The field currents of the two machines are maintained such that the motor terminal voltage is V_1=400V and its pf is 0.8 leading.

The magnitude of the induced voltage of the motor (E_m)in p.u. is?



(A)1.28

(B)0.894

(C)1.61

(D)1.79

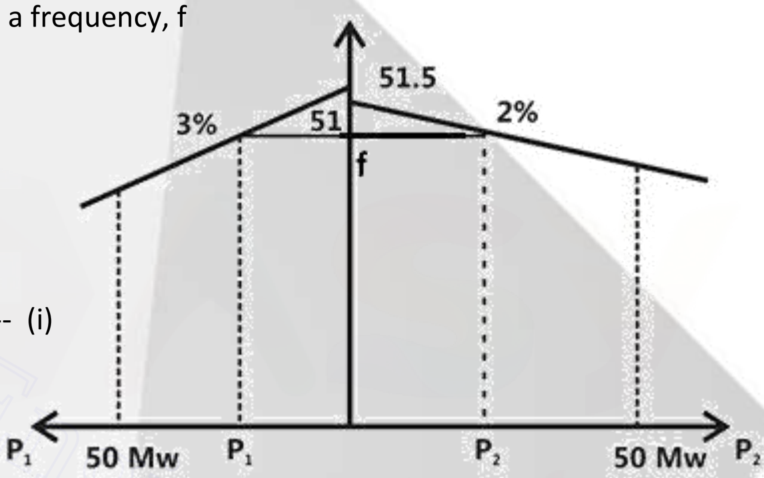
Type 8: Droop Characteristics

For Concept, refer to Electrical Machines K-Notes, Synchronous Machines

Sample Problem 8:

Two $3-\phi$ alternators of 50 MW capacities each operate in parallel. The settings of governors are such that rise in speed from full load to no – load is 2% in one machine & 3% in other machine. If machine is fully loaded at rated frequency when total load is 100MW, what would be load on each machine when total load is 60MW?

Solution: Assume both machines operate at a frequency, f



$$\frac{P_1}{50} = \frac{51.5 - f}{51.5 - 50}$$

$$P_1 = \frac{50}{1.5}(51.5 - f)$$

$$P_1 = \frac{100}{3}(51.5 - f) \text{ --------- (i)}$$

$$\frac{P_2}{50} = \frac{51 - f}{51 - 50}$$

$$P_2 = 50(51 - f) \text{ --------- (ii)}$$

$$P_1 + P_2 = 60MW \text{ -------- (iii)}$$

Solving these 3 equations, we get

$$P_1 = 34MW, \; P_2 = 26MW$$

Unsolved Problems:

Q.1 Two similar alternators operating in parallel have the following data:
Alternator 1 – Capacity 700KW, frequency drops from 50 Hz at no load to 48.5 Hz at full load
Alternator 1 – Capacity 700KW, frequency drops from 50.5 Hz at no load to 48 Hz at full load
Speed regulation of prime movers -linear in each case. Calculate how a total load of 1200KW is shared by each alternator

(A) 600KW, 600KW
(B) 540KW, 660KW
(C) 537.6KW, 662.4KW
(D) 620KW, 580KW

Q.2 Two identical 3 MVA alternators A and B are to operated in parallel. The governors of alternators A and B are such that frequencies drop uniformly from 50 Hz to 48.5 Hz and 50 Hz to 48 Hz respectively, on full-load. If a load of 3500KW is shared by the machine, then load taken by A and respectively are?

(A)1.75 MW, 1.75 MW (B)2 MW, 1.5 MW

(C)2.5 MW, 1 MW (D)3 MW, 0.5 MW

Q.3 A generator with the frequency-power characteristic shown in the figure 1, supplying a load. Now a second load is connected in parallel with the first one as shown in figure 2 . Load 1 consumes a real power of 1000KW at 0.8 pf lagging. While load 2 consumes a real power of 800KW at 0.707 pf lagging. The operating frequency of the system before and after the second load is connected are respectively?

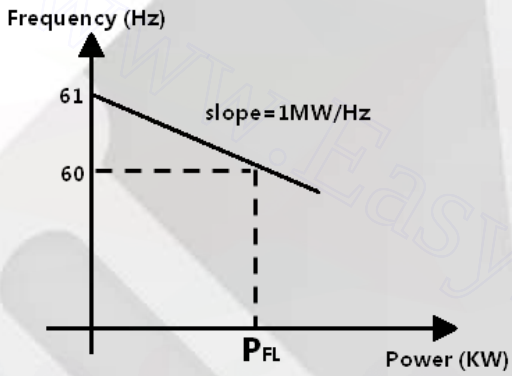


Fig. 1

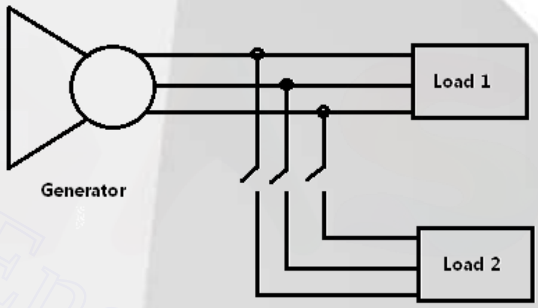


Fig.2

(A)60Hz, 61Hz (B)61Hz, 60Hz (C)60Hz, 60Hz (D)60Hz, 59.2Hz

Type 9: Losses and Efficiency

For Concept, refer to Electrical Machines K-Notes, Synchronous Machines

Common Mistake:

While Calculating efficiency we need to consider field losses but if we are calculating electrical power or shaft power we will not consider the field losses while traversing power flow diagram.

Sample Problem 9:

A 400 V, 50 kVA, 0.8 p.f. leading 3-connected,50 Hz synchronous machine has asynchronous reactance of 2 Ω and negligible armature resistance. The friction and windage losses are 2kW and the core loss is 0.8 kW. The shaft is supplying 9kW load at a power factor of 0.8leading. The line current drawn is

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

Solution: (C) is correct option

Given a 400 V, 50 Hz and 0.8 p.f. loading delta connection 50 Hz synchronous machine, the reactance is 2 Ω. The friction and windage losses are 2 kW and core losses is 0.8 kW and shaft is supply 9 kW at a 0.8 loading power factor

So,

Input power=$P_{mech\ output}$ + friction loss + core loss

= 9 kW+ 2 kW+ 0.8 kW

= 11.8 kW

$\because$ Input power = $\sqrt{3}\ V_L I_L \cos\phi$ = 11.8 kW

$$= \sqrt{3}\ 400 \times I_L \times 0.8 = 11800 \Rightarrow I_L = 21.29A$$

Unsolved Problems:

Q.1 A 6.6KV, star connected,3 – phase, synchronous motor operate at constant voltage and excitation. Its synchronous impedance is (2 + j20) Ω/ph. The motor operate at 0.8 lead P.F when drawing 800KW from the mains. If the load on the motor is increased such that the power input is 1200KW. Then line current and power factor respectively are?

(A) 87.5A, 0.92 lag
(B) 195A, 0.54 lead
(C) 113A, 0.92 lead
(D) 113A, 0.85 lead

Q.2 The excitation of a 415 – V, 3 – phase, mesh – connected synchronous motor is such that the induced e.m.f is 520 V. The impedance per phase is (0.5 + j 4) ohm. The friction and iron losses are constant at 1,000W. Calculate the line current.

(A) 303 A
(B) 239 A
(C) 335 A
(D) None

Q.3 A cylindrical rotor synchronous motor, with E_f = 1.5 pu, is connected to an infinites bus. The machine has a synchronous reactance of 1.2 pu and output power delivered to the load is 0.5 pu. With all losses ignored, the magnitude of reactive power delivered or absorbed, by the synchronous motor is

(A) 0.3125 pu
(B) 0.833 pu
(C) 0.4583 pu
(D) 0.5237 pu

Q.4 6600V, 3 phase star-connected synchronous motor draws a full load current of 80A at 0.8 pf leading. The armature resistance is 2.2Ω and reactance 22Ω per phase. If the straw loss of the machine are 3200W. Then output power and efficiency?

(A)692578W, 92.90%
(B)689378W, 93.79%
(C)731618W, 89.21%
(D)686178W, 93.79%

Q.5 A 9KVA, 208V, 1200 rpm, 3 phase 60 Hz , Y connected synchronous generator has the following parameters

The armature-winding impedance = 0.3+j5 Ω/phase

Field winding resistance = 4.5 Ω

Rotational loss = 500 W

The field winding current is 5A, when the generator operates at its full load and 0.8 pf lagging. What is the efficiency of the generator?

(A)99.30% (B)86% (C)92.7% (D)83.33%

Type 10: Cascading of Motors

When two machines are mechanically coupled then their speeds are same.

Sample Problem 10:
A 4 pole induction motor (main) and a 6 pole motor (auxiliary) are connected in cumulative cascade. Frequency in the secondary winding of the auxiliary motor is observed to be 1Hz . For a supply frequency of 50 Hz the speed of the cascade set is?

(A)1485 rpm (B)990 rpm (C)608rpm (D)588rpm

Solution: (D) is correct option

Given $P_1 = 4$; $P_2 = 6$; $f_2 = 1\text{Hz}$; $f = 50\text{Hz}$

$f_2 = S_2 f_1$; $f_1 = S_1 f$

$\therefore f_2 = S_1 S_2 f \Rightarrow S_1 S_2 = 0.02$

For cumulative cascade

$$\frac{120f}{P_1}(1-S_1) = \frac{120S_1 f}{P_2}(1-S_2)$$

$$\frac{1}{P_1} - \frac{S_1}{P_1} = \frac{S_1}{P_2} - \frac{S_1 S_2}{P_2}$$

$$S_1\left[\frac{1}{P_1} + \frac{1}{P_2}\right] = \frac{1}{P_1} + \frac{S_1 S_2}{P_2}$$

$$S_1\left[\frac{P_1 + P_2}{P_1 P_2}\right] = \frac{1}{P_1} + \frac{S_1 S_2}{P_2}$$

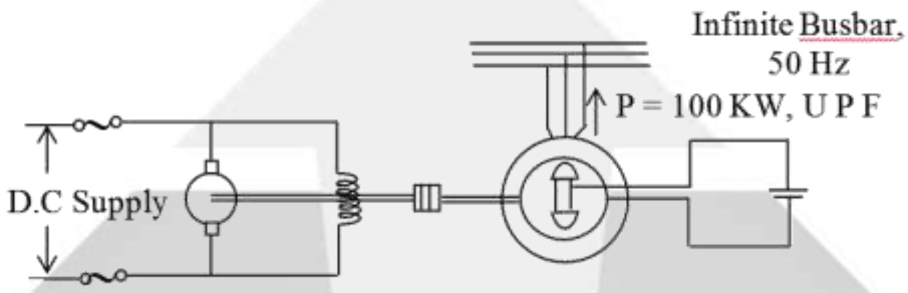
$$S_1\left[\frac{10}{24}\right] = \left[\frac{1}{4} + \frac{0.02}{6}\right]$$

$$S_1 = 0.608$$

Speed of cascade set $= \frac{120f}{P_1}(1-S_1) = \frac{120 \times 50}{4}(1-0.608) = 588 \text{ rpm}$

Unsolved Problems:

Q.1 A d.c. motor is coupled to a 3 - ϕ, 4 – pole, 50Hz synchronous generator operating on the bus bar, feeding a power of 100 KW at UPF to the bus bar as shown in figure. The Speed of the D.C. motor is 1500 rpm.



If the fuse of the d.c. motor blows, then

(A) d. c machine acts as generator, synchronous machine acts as motor, at lead P.F and the set rotate at 1500 rpm.
(B) d.c machine acts as generator, synchronous machine acts as motor, at lag P.F and the set rotate at 1500 rpm.
(C)d.c machine acts as generator, synchronous machine acts as a generator at lag P.F, the set rotate at less than 1500 rpm.
(D) the d.c machine acts as generator, synchronous machine acts as motor at UPF and the set rotate at 1500 rpm.

Q.2 A 50k.w synchronous motor is tested by driving it by another motor. When the excitation is not switched on the driving motor takes 800w. When the armature is short circuited and the rated armature current of 10A is passed through it, the driving motor requires 2500w. On open circuiting the armature with rated excitation, the driving motor takes 1800w. Calculate the efficiency at 50% of the load.

(A) 89.28% (B) 92.08% (C) 87.71% (C) 91.82%

Q.3 A 4 pole, 3 phase, 50 Hz synchronous machine has its rotor directly coupled to that of a 3 phase slip-ring induction motor. Stators of both machines are connected to the same 3 phase, 50 Hz supply. It is desired to use such an arrangement to generate 150 Hz across the rotor terminals of the induction motor. Determine the number of poles for which the induction machine should be wound

(A)12 or 24 (B)2 or 4 (C)10 or 20 (D)8 or 16

Q.4 The rotor of a 50 Hz, 4 pole, 3 phase synchronous motor is directly coupled to the rotor of a 50 Hz, 6 pole, 3 phase IM. If the stators of both the machines are given balanced 3 phase 50c/s supplies of rated voltage values. The possible induced frequencies in the rotor of induction motor are 25 Hz and ________Hz.

(A)50 (B)75 (C)125 (D)150

Answer Key

	1	2	3	4	5
Type 1	A	C	A	B	
Type 2	B	C	C	A	
Type 3	A	C	B		
Type 4	A	B	C	C	A
Type 5	B	C	A	D	
Type 6	B	B	B	A	
Type 7	A	D	B	C	
Type 8	C	B	D		
Type 9	C	A	A	D	B
Type 10	A	D	D	C	

Induction Machines

Type 1: Rotating Magnetic Fields

For Induction Motor, refer to Electrical Machine K-Notes, Induction Machines

Common Mistake:
Please read the question carefully as to whose speed is asked with respect to what like speed may be asked with respect to Stator Magnetic Field and we may calculate with respect to Stator.

Sample Problem 1:
A 3-phase, 4-pole slip ring induction motor is connected to 3-phase, 50 Hz supply from the rotor side through slip rings and the stator terminals are shorted. The machine is found to be running at 1440 rpm. Determine:
(i) The frequency of stator current
(ii) The speed of rotor magnetic field w.r.t. rotor
(iii) The speed of stator magnetic field w.r.t. rotor and its direction w.r.t. direction of rotation of rotor.
(iv)The speed of stator magnetic field w.r.t. rotor magnetic field.

Solution:
When 3-phase voltage is applied to rotor

- A rotor (rotating) magnetic field is setup which rotates at speed

$$n = \frac{120 * 50}{4} = 1500\text{rpm}$$

- This cuts stator conductors and induces an emf in stator which in turn produces current as stator is short-circuited.
- Now, induced current opposes cause of induction so stator will try to reduce relative speed between stator & rotating magnetic field which can only be done by slowing down rotor magnetic field as stator cannot rotate.
- This can only be done by rotating rotor in direction opposite to that of magnetic field.

(i) Net speed of rotor magnetic field = 1500 – 1440 =60rpm

$$60\text{rpm} = \frac{120 * fs}{4}$$

$$Fs = 2Hz$$

(ii) Speed of rotor magnetic field wrt rotor = 1500rpm
Speed of rotor magnetic field wrt stator = 60rpm
Direction of magnetic field is opposite to that of rotor.

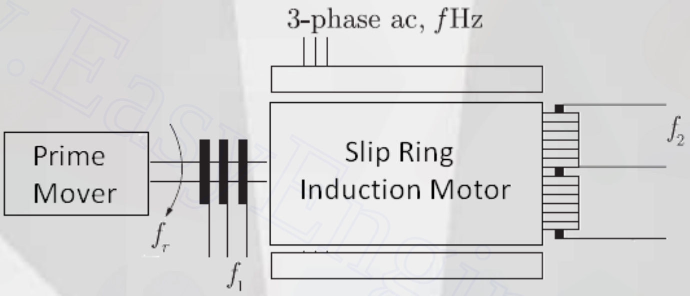
(iii) Speed of stator magnetic field = $\frac{120 * fs}{P} = \frac{120 * 2}{4} = 60rpm$ .Direction of magnetic field is opposite to the direction of the rotor.

(iv) Speed of stator magnetic field wrt rotor magnetic field =60 – 1500 = - 1440 rpm
Negative sign indicates it is opposite in direction to rotor magnetic field & in same direction as rotor.

Unsolved Problems:

Q.1 A 4-pole induction motor, supplied by a slightly unbalanced three-phase 50 Hz source, is rotating at 1440 rpm. The electrical frequency in Hz of the induced negative sequence current in the rotor is
(A) 100 (B) 98 (C) 52 (D) 48

Q.2 A three phase slip-ring induction motor, provided with a commutator winding, is shown in the figure. The motor rotates in clockwise direction when the rotor windings are closed.



If the rotor winding is open circuited and the system is made to run at rotational speed f_r with the help of prime-mover in anti-clockwise direction, then the frequency of voltage across slip rings is f_1 and frequency of voltage across commutator brushes is f_2. The values of f_1 and f_2 respectively are
(A) $f + f_r$ and f (B) $f - f_r$ and f
(C) $f - f_r$ and $f + f_r$ (D) $f + f_r$ and $f - f_r$

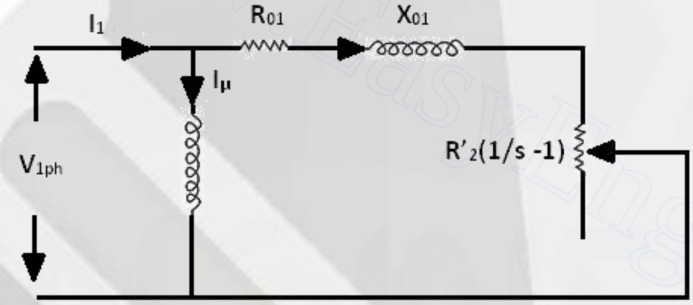
Q.3 A 3-phase, 440 V, 50 Hz, 4-pole slip ring induction motor is feed from the rotor side through an auto-transformer and the stator is connected to a variable resistance. The variable resistance is adjusted such the motor runs at 1410 rpm. The speed of rotation of stator magnetic field with respect to rotor structure will be
(A) 90 rpm in the direction of rotation
(B) 90 rpm in the opposite direction of rotation
(C) 1500 rpm in the direction of rotation
(D) 1500 rpm in the opposite direction of rotation

Type 2: Torque-Slip Characteristics

For Concept, refer to Electrical Machines K-Notes, Induction Machines

Common Mistake:
Remember the approximations to the Torque expression at low slip and high slip and usually at full-load we consider low slip and consider torque as directly proportional to slip.

Sample Problem 2:
A 3-phase, 4-pole, 400 V 50 Hz, star connected induction motor has following circuit parameters $r_1 = 1.0\ \Omega$, $r'_2 = 0.5\ \Omega$, $X_1 = X'_2 = 1.2\ \Omega$, $X_m = 35\ \Omega$
The starting torque when the motor is started direct-on-line is (use approximate equivalent circuit model)
(A) 63.6 Nm (B) 74.3 Nm (C) 190.8 Nm (D) 222.9 Nm
Solution: (A) is correct option
The approximate equivalent circuit model of the Induction motor is



$X_{01} = X_1 + X_2^1 \qquad , R_{01} = R_1 + R_2^1$

$R_2^1 + R_2^1(\frac{1}{s} - 1) = \frac{R_2^1}{s}$

During starting slip s=1

$$I_r^1 = \frac{V_{1ph}}{\sqrt{\left(R_1 + \frac{R_2^1}{s}\right)^2 + \left(X_1 + X_2^1\right)^2}} = \frac{\frac{400}{\sqrt{3}}}{\sqrt{\left(1 + \frac{0.5}{1}\right)^2 + (1.2 + 1.2)^2}} = 81.6\text{ A}$$

Starting Torque

$$T_{st} = \frac{60}{2\pi N_s} \times 3(I_r^1)^2 \times \frac{R_2^1}{s} = \frac{60}{2\pi \times 1500} \times 3 \times (81.6)^2 \times \frac{0.5}{1} \qquad [\because N_s = 1500\text{ rpm}]$$

$T_{st} = 63.6$ N-m

Sample Problem 3:

A three-phase squirrel cage induction motor has a starting torque of 150% and a maximum torque of 300% with respect to rated torque at rated voltage and rated frequency. Neglect the stator resistance and rotational losses. The value of slip for maximum torque is

(A) 13.48% (B) 16.42% (C) 18.92% (D) 26.79%

Solution: (D) is correct option

Given a 3-ϕ squirrel cage induction motor starting torque is 150% and maximum torque 300%

So $T_{Start} = 1.5T_{FL}$

$T_{max} = 3T_{FL}$

$$\frac{T_{Start}}{T_{max}} = \frac{1}{2}$$

Then

$$\frac{T_{Start}}{T_{max}} = \frac{2S_{max}}{S_{max}^2 + 1^2} = \frac{1}{2}$$

$$S_{max}^2 - 4S_{max} + 1 = 0$$

$$\text{So}, S_{max} = 26.786\%$$

Unsolved Problems:

Q.1 A 3-phase, squirrel cage I.M. has a short-circuit current equal to 4-times the full-load current. The full-load torque is 150 N-m, the slip being 3%. If started by inserting a resistance in the stator circuit that limits the starting current to twice the full current, the starting torque is

(A) 75 N-m (B) 37.5 N-m (C) 18 N-m (D) None

Q.2 A 3-ϕ, 50Hz, 12 pole induction motor has star connected rotor and the resistance measured across any two slip rings is 0.04Ω. Its full load slip is 0.02. The torque required by the load varies as the speed squared. The torque-slip curve to be a straight line in the normal operating region. The resistance to be inserted in the rotor circuit to reduce the full load speed to 350 RPM is

(A) 0.342 Ω (B) 0.568 Ω (C) 0.632 Ω (D) 0.753 Ω

Q.3. For a 3-ϕ IM, maximum torque is twice the full load torque and starting torque is twice the full load torque. Neglect stator impedance. In order to get a full load slip of 5%, the percentage reduction in rotor circuit resistance is

(A) 53.82 % (B) 43.75% (C) 62.68% (D) 47.65%

Q.4 A 400 V, 50 Hz, 4 pole 3–phase star – connected induction motor has the following data Stator leakage impedance 0.5 + j 1.2Ω, Standstill rotor leakage impedance per phase referred to stator 0.3+j1.0Ω, Full load slip 0.05. No load current is assumed negligible. If an external resistance of 1.2Ω per phase and referred to stator is inserted on the rotor circuit, the magnitude of dynamic torque is?

(A) 268.35 Nm (B) 292.56 Nm (C) 337.45 Nm (D) 386.84 Nm

Q.5 A 10KW, 6 pole, 50Hz, 3 phase induction motor has linear torque-slip characteristic between zero torque and maximum torque. The slip at which maximum torque of 520 N-m occurs is 0.2. For mechanical losses of 600W, find the speed at which the motor would run when delivering rated shaft power.

(A)921.7 rpm (B)959.5 rpm (C)987.1 rpm (D)943.6 rpm

Q.6 A 400V, 1450rpm, 50Hz wound rotor induction motor has the following circuit model parameters $R_1 = 0.3\Omega$, $R_2^1 = 0.25\Omega$, $X_1 = X_2^1 = 0.6\Omega$, $X_M = 35\Omega$; Starting torque produced by I.M. and the maximum torque produced by I.M. is ?

(A) 142.4 N-m, 161 N-m (B) 136.3 N-m, 148 N-m

(C) 142.4 N-m, 159 N-m (D) 152.4 N-m, 159 N-m

Q.7 A wound rotor induction motor runs with a slip of 0.03 when developing full load torque. Its rotor resistance is 0.25 ohm per phase. If an external resistance of 0.50 ohm per phase is connected across the sup rings, what is the slip for full torque?

(A) 0.03 (B) 0.06 (C) 0.09 (D) 0.1

Q.8 An 8 pole, 50Hz, 3 - ϕ induction motor is running at 4% slip when delivering full load torque. It has stand still rotor resistance of 0.1 Ω and reactance of 0.6Ωper phase. If additional resistance of 0.5Ω/phase is inserted in the rotor circuit, The speed of induction motor if the full load torque remains constant is

(A) 570rpm (B) 700rpm (C) 520rpm (D) 620rpm

Q.9 A Squirrel case induction motor has a slip of 4% at full load. Its starting current is five times the full load current. The stator impedance and magnetizing current may be neglected. The rotor resistance is assumed constant. Slip at maximum torque is

(A) 10% (B) 20% (C) 30% (D) 40%

Type 3: Efficiency

For Concept, refer Electrical Machines K-Notes, Induction Machines

Common Mistake:
We cannot use rated power of a machine while calculating efficiency unless the motor is being run at Full Load.

Sample Problem 4:
The power input to a 415V, 50 Hz, 6 pole , 3phase induction motor running at 975 rpm is 40KW and friction and windage losses total 2 KW. The efficiency of the motor is?

(A)92.5% (B)90% (C)91% (D)88%

Solution: (B) is correct option
Power input =40 KW

$$\text{slip} = \frac{N_s - N}{N_s} = \frac{1000-975}{1000} = 0.025$$

Stator output =40KW – 1KW = 39KW
$\therefore$ Rotor input =39KW
Gross mechanical output =rotor input *(1-s)
=39K(1-0.025)
=38025 W
Net mechanical output =Gross mech. o/p – windage loss
=38025-2000
=36025 W

$$\therefore \eta = \frac{o/p}{i/p} = \frac{36025}{40000} \times 100 = 90.0\%$$

Unsolved Problems

Q.1 An induction motor has an efficiency of 0.9 when the load is 50 HP. At this load, the stator copper losses and rotor copper losses each equal to the iron loss. The mechanical losses are on third of the no load losses. The total mechanical power developed is

(A) 27134 W (B) 28342 W (C) 38681 W (D) 42178 W

Q.2 The power input to the rotor of a 440-V, 50 Hz, 3-phase induction motor is 50 KW. The rotor e.m.f. makes 120 complete cycles per minute. The rotor resistance per phase is……………ohm, if the rotor current is 50 A.

(A) 0.134 (B) 0.267 (C) 0.2 (D) 0.12

Q.3 A 3-ϕ, 4-pole, 60kW, 50Hz I.M connected to rated supply voltage and running without load consumes 3KW when prevented from rotating it draws rated current at 30% rated supply and takes a power input of 4KW. Assuming that under rated load conditions, the stator and rotor copper losses are equal and that the mechanical losses are 30% of the no load losses. Compute the slip at rated load.

(A) 0.023 (B) 0.0318 (C) 0.0432 (D) 0.045

Q.4 A 3-phase 10 –pole, 50 Hz wound rotor induction motor is driven by an adjustable speed D.C motor. The output power taken from rotor slip rings is 48 KW at 0.8 pf lagging at a frequency of 120 Hz. Neglect the all machine losses, leakage impedance drops and exciting currents are neglected. The KVA rating of the induction motor stator is

(A) 60 KVA (B) 10 KVA (C) 40 KVA (D) 25 KVA

Q.5 A 3 phase induction motor has its stator copper loss equal to the sum of the mechanical and iron losses is equal to one-third of stator copper loss. If its efficiency is 79%. Calculate the slip. Take mechanical loss equal to iron loss.

(A)0.0398 (B)0.0347 (C)0.0313 (D)0.0366

Type 4: Tests on an Induction Motor

For Concept, refer to Electrical Machines K-Notes, Induction Machines

Common Mistake:
Sometimes the blocked rotor test may not be given at rated current so to calculated Full-Load Copper Losses we need to change it to rated current.

Sample Problem 5:
A 3-phase, 10 kW, 400 V, 4-pole, 50Hz, star connected induction motor draws 20A on full load. Its no load and blocked rotor test data are given below.
No Load Test : 400 V 6 A 1002 W
Blocked Rotor Test : 90 V 15 A 762 W
Neglecting copper loss in no load test and core loss in blocked rotor test, estimate motor's full load efficiency
(A) 76% (B) 81% (C) 82.4% (D) 85%
Solution: (B) is correct option
Given that 3-ϕ induction motor star connected
P = 10 kW, V = 400 V, Poles = 4, f = 50 Hz
Y connected induction motor,
Rated full load current =20A
From no load Test constant losses =1002 W
From Blocked rotor test Cu losses =762 W
In Blocked rotor test the current circulated is 15A , but full load current is 20A

Cu loss $\propto I^2$

$$\frac{W_{cu_2}}{W_{cu_1}} = \left(\frac{20}{15}\right)^2$$

$$W_{cu_2} = \left(\frac{20}{15}\right)^2 \times 762$$

Full load Cu loss $W_{cu_2} = 1353.67\,W$

$$\%\eta_{\text{Full load}} = \frac{\text{output}}{\text{output} + \text{losses}} \times 100$$

$$= \frac{10 \times 10^3}{10 \times 10^3 + 1002 + 1354.67} \times 100 = 80.927\% \approx 81\%$$

Unsolved Problems:

Q.1 On short circuit test, a 12 pole, 3-phase, 50 Hz Induction motor, with an equivalent rotor resistance equal to the stator resistance, took 250 A and 100 kW. The starting torque developed by the motor is

(A) 980 N-m (B) 950 N-m (C) 850 N-m (D) 880 N-m

Q.2 A 400V , 50Hz 3 phase star-connected squirrel-cage induction motor gives the following test results :

No load or open circuit test (line values): 400V, 9A, 560W

Blocked rotor or short circuit test (line values): 210V, 36A , 4820W

The effective stator resistance is 0.72Ω per phase. Calculate stator magnetizing reactance and per phase rotor resistance respectively?

(A)24 Ω ,0.578 Ω (B)27 Ω ,0.582 (C)25 Ω ,0.587 Ω (D)29 Ω,0.590 Ω

Q.3 Blocked rotor test on a 3 phase, 40KW, 400V, 50Hz, 6 pole star connected induction motor gave the following data: 200V, 110A , pf=0.4

Determine the starting torque for a 3 phase voltage of 380V at 45 Hz. Neglect magnetizing current and assume stator and rotor ohmic losses equal.

(A)306.65 N-m (B)354.12 N-m (C)316.96 N-m (D)312.594 N-m

Q.4 A 10 pole, 3 phase, 50 Hz, delta connected induction motor takes 120KW during blocked-rotor test at rated voltage and frequency. Stator ohmic loss is assumed equal to rotor ohmic loss during blocked rotor test. What would be the starting torque if phase winding are connected in star and DOL starting is used?

(A)315.46 N-m (B)326.56 N-m (C)318.31 N-m (D)312.59 N-m

Type 5: Speed Control of Induction Motor

For Concept, refer to Electrical Machines K-Notes, Induction Machines

Common Mistake:

While Calculating new rotor speed make sure that synchronous speed is according to new frequency and not use the original synchronous speed.

Sample Problem 6:
The speed of a 4-pole induction motor is controlled by varying the supply frequency while maintaining the ratio of supply voltage to supply frequency (V/f) constant. At rated frequency of 50 Hz and rated voltage of 400 V its speed is 1440 rpm. Find the speed at 30 Hz, if the load torque is constant
(A) 882 rpm (B) 864 rpm (C) 840 rpm (D) 828 rpm

Solution: (C) is correct option
Given speed of a 4-pole induction motor is controlled by varying the supply frequency when the ratio of supply voltage and frequency is constant.
f = 50 Hz, V = 400 V, N = 1440 rpm

So, $V \propto f$

$$\frac{V_1}{V_2}=\frac{f_1}{f_2} \quad \Rightarrow V_2 = 400\times\frac{30}{50}=240$$

$$T \propto \left(\frac{V^2}{f}\right)\times S$$

$$\frac{S_2}{S_1}=\left(\frac{V_1}{V_2}\right)^2\times\frac{f_2}{f_1}\times\frac{T_2}{T_1} \qquad \text{Given } T_1 = T_2$$

Then $$S_2 = 0.04\times\left(\frac{400}{240}\right)^2\times\frac{30}{50}$$

$$S_2 = 0.066$$

$$N_r = N_s(1-S)$$

$$\because \; N_r = \frac{120f}{P}$$

$$\text{So } N_r = \frac{120\times 30}{4}(1-0.066)$$

$$N_r = 840.6 \text{ rpm}$$

Unsolved Problems:

Q.1 A230V, 20H.P, 60Hz, 6-pole, 3-phase induction motor driving a constant torque load at rated frequency, rated voltage and rated horse-power has a speed of 1175 R.P.M and an efficiency of 92.1% what will be the speed of the motor, if there is a 10% drop in voltage and 6% drop in frequency. Assume that friction, windage and stray power losses remain constant
(A) 1112 rpm (B) 1120 rpm (C) 1101 rpm (D) 1110 rpm

Q.2 An ac induction motor is used for a speed control application. It is driven from an inverter with a constant V/f control. The motor name-plate details are as follows:

V : 415 V, 3-ϕ, 50 Hz, N : 2850 rpm.

The motor is run with the inverter output frequency set at 40 Hz and with half the rated slip. The running speed of the motor is

(A) 2400 rpm (B) 2280 rpm (C) 2790 rpm (D) 2340 rpm

Q.3 A 10KW , 50Hz , 4 pole, 3 phase induction motor has leakage impedance of (0.2+j1.5) Ω per phase at stand still. When delivering full-load torque, the motor runs at 1440 rpm. Stand still rotor emf per phase is 60V. Determine the magnitude of emf injected at the rotor terminals for a speed of 1800 rpm, for a constant-torque load

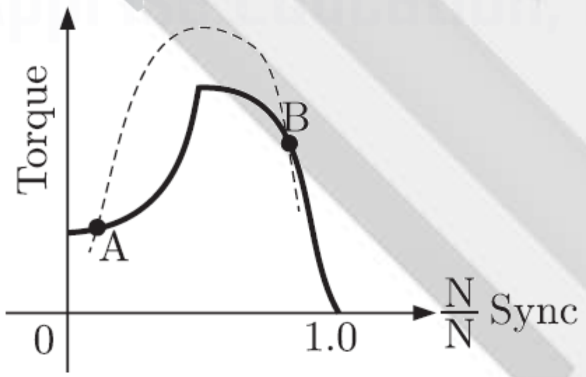
(A)22.13V (B)19.14V (C)16.87V (D)18.03V

Type 6: Induction Motor Stability

For Concept, refer to Electrical Machines K-Notes, Induction Machines

Common Mistake:
If we are using the derivative condition for Stability as mentioned in Sample Problem below then we need to make sure that the curve is Torque-Speed as sometimes the curve may be Speed-Torque.

Sample Problem 7:
A 3-phase squirrel cage induction motor supplied from a balanced 3-phase source drives a mechanical load. The torque-speed characteristics of the motor (solid curve) and of the load (dotted curve) are shown. Of the two equilibrium points A and B, which of the following options correctly describes the stability of A and B?



(A) A is stable, B is unstable
(B) A is unstable, B is stable
(C) Both are stable
(D) Both are unstable

Solution: (A) is correct option

- At point A if speed increases (operating point shifts towards the right) then Load Torque becomes more than Motor Torque and thus net toque becomes negative and motor decelerates and speed decreases and it tries to go back to initial speed.
- At point A if speed decreases (operating point shifts towards the left) then Load Torque becomes less than Motor Torque and thus net toque becomes positive and motor accelerates and speed increases and it tries to go back to initial speed.

So A is stable.

- At point B if speed increases (operating point shifts towards the right) then Load Torque becomes less than Motor Torque and thus net toque becomes positive and motor accelerates and speed increases and operating point moves away from B.
- At point B if speed decreases (operating point shifts towards the left) then Load Torque becomes more than Motor Torque and thus net toque becomes negative and motor decelerates and speed decreases and operating point moves away from B.

So B is un-stable.

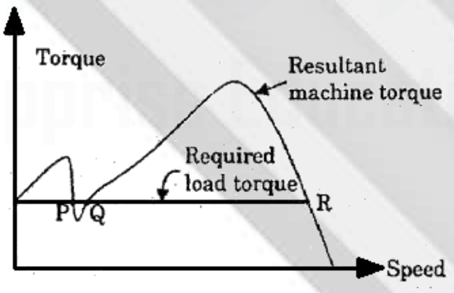
Alternate Method:

An operating point is stable if $\frac{dT_M}{dn} < \frac{dT_L}{dn}$

Where T_M is the motor torque and T_L is the load torque and "n" is the motor speed.

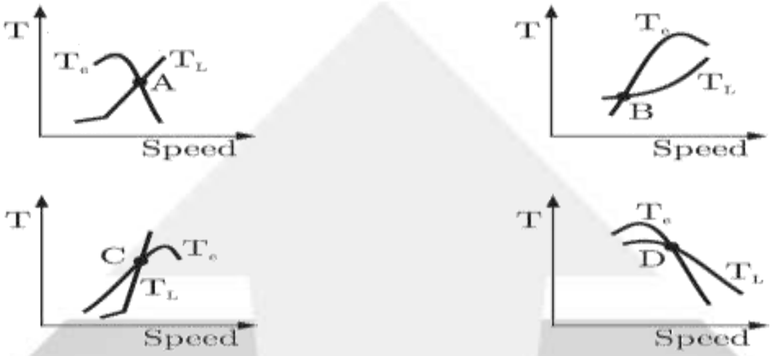
By this method A is stable and B is unstable.

Q.1 The required load torque line intersects the resultant torque- speed characteristic of a 3-phase squirrel cage induction motor at points P, Q and R as shown in the figure above. Which is/are the stable opening point(s)?



(A) P and Q
(B)Q and R
(C) P and R
(D)Only R

Q.2 The electromagnetic torque T_e of a drive and its connected load torque T_L are as Shown below. Out of the operating points A, B, C and D, the stable ones are



(A) A, C, D   (B) B, C   (C) A, D   (D) B, C, D

Type 7: Starting of Induction Motor

For Concept, refer to Electrical Machines K-Notes, Induction Machines.

Common Mistake:

If the starting torque is given in pu that means we are given the ration of Starting Torque to Full Load Torque and same is the case with Starting Current.

Sample Problem 8:

A three phase squirrel cage induction motor has a starting current of seven times the full load current and full load slip of 5%. If a star-delta starter is used to start this induction motor, the per unit starting torque will be

(A) 0.607   (B) 0.816   (C) 1.225   (D) 1.616

Solution: (B) is correct option

$$\frac{T_{st}}{T_{FL}} = \left(\frac{I_{st}}{I_{FL}}\right)^2 S_{FL} = \left(\frac{\frac{I_{sc}}{\sqrt{3}}}{I_{FL}}\right)^2 S_{FL} \qquad \left[\because I_{sc} = 7I_{FL}\right]$$

$$\frac{T_{st}}{T_{FL}} = \left(\frac{7I_{FL}}{\sqrt{3}I_{FL}}\right)^2 \times 0.05 = 0.816$$

Unsolved Problems:

Q.1 With direct on line starter, a 3 – phase delta connected induction motor takes starting line current of 30A and develops a starting torque of 173.2 Nm. When started by star- delta starter, the starting line current and starting torque are respectively equal to

(A) 10A, 100 Nm   (B) 17.32A, 100 Nm
(C) 10A, 57.73 Nm   (D) 17.32A, 57.73 Nm

Q.2 A 2.3 KV, 3 phase, 50 Hz squirrel cage induction motor has starting current of 600A and starting torque of 640 Nm. The output/input voltage ratio of an auto–transformer to reduce the starting current to 150A is 0.5. The new starting torque is

(A) 120 Nm (B) 140 Nm (C) 160 Nm (D) 172 Nm

Q.3 A 3-ϕ delta connected squirrel cage I-M has a starting current of I_Δ and as starting torque of T_Δ at rated voltage. If the starting current and starting torque while the motor is started through star-delta starter and auto transformer (with 60% voltage) starter alternatively are I_y and T_y and I_{auto} end T_{auto} respectively, then $\frac{I_y}{I_\Delta} : \frac{I_{auto}}{I_\Delta} : \frac{T_y}{T_\Delta} : \frac{T_{auto}}{T_\Delta}$ is equal to…………, I_y and I_Δ are line currents taken by the motor at the starting .

(A) $1/\sqrt{3}$: 0.6 : $1/\sqrt{3}$: 0.6
(B) 1/3 : 0.36 : $1/\sqrt{3}$: 0.6
(C) $1/\sqrt{3}$: 0.36 : 1/3 : 0.36
(D) 1/3 : 0.36 : 1/3 : 0.36

Q.4 A 2.3KV, 3 phase 50 Hz SCIM has starting current of 600 N-m. The per unit tapping of auto-transformer to reduce the starting current from mains to 150A and the corresponding starting torque would respectively be?

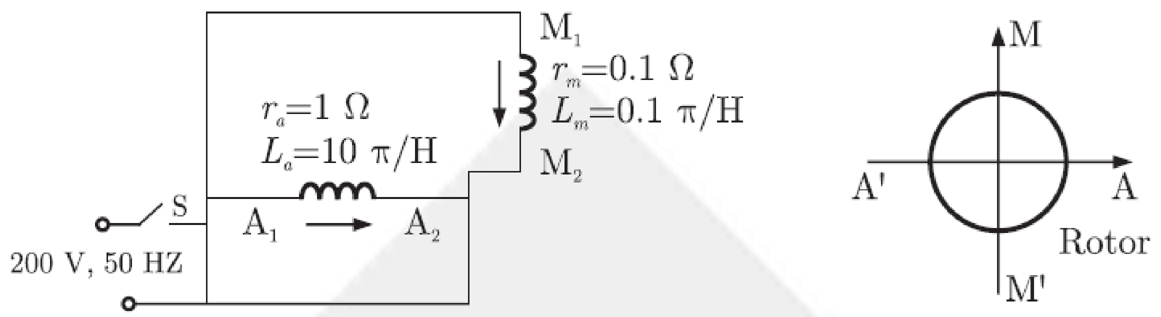
(A)0.5, 160N-m
(B)0.25, 40 N-m
(C)0.6, 230.4 N-m
(D)0.4, 102.4 N-m

Type 8: Single Phase Induction Motor

For Concept, refer to Electrical Machines K-Notes, Single Phase Induction Motor.

Common Mistake:
When we place a capacitor in the auxiliary winding to create 90^0 phase difference in current of Main and Auxiliary Winding then if we take ($X_L – X_C$) while calculating the angle of auxiliary winding then difference of phase angles of main and auxiliary winding should be 90^0 else if we take ($X_C – X_L$) then we equate sum of angles to 90^0.

Sample Problem 9:
A 200 V, 50 Hz, single-phase induction motor has the following connection diagram and winding orientations as shown. MM' is the axis of the main stator winding (M_1M_2) and AA' is that of the auxiliary winding (A_1A_2). Directions of the winding axis indicate direction of flux when currents in the windings are in the directions shown. Parameters of each winding are indicated. When switch S is closed the motor



(A) rotates clockwise
(B) rotates anti-clockwise
(C) does not rotate
(D) rotates momentarily and comes to a halt

Solution: (C) is correct option

$X_m = 2\pi f L_m = 10\Omega$, $R_m = 0.1\Omega$, R_a=1Ω , X_a=$2\pi f L_a = 1000\Omega$

$\phi_m = \tan^{-1}\left(\frac{X_m}{R_m}\right) = 89.427^0$, $\phi_a = \tan^{-1}\left(\frac{X_a}{R_a}\right) = 89.9427^0$

$\alpha = \phi_a - \phi_m = 0.5157^0 \cong 0^0$

But starting torque $T_{st} \propto I_m I_a \sin\alpha$

As α=0

Though very small amount of torque is produced. But because of inertia of rotor the produced torque is not sufficient to drive the rotor hence the rotor will not rotate.

But if the torque were higher the motor would rotate in the same direction as rotating magnetic field.

Unsolved Problems:

Q.1 A 1 – ϕ induction motor has stator windings in space quadrature and is supplied with a 1 - ϕ voltage of 200V at 50Hz. The stand still impedance of the main winding is (5.2+j10.1)Ω and that of auxiliary winding is (19.7 + j14.2)Ω. The value of capacitance to be inserted in the auxiliary winding for max. Starting torque is

(A) 124 μF (B) 131 μF (C) 128 μF (D) 136 μF

Q.2 A 250 W, 230 V, 50-Hz capacitor start motor has the following impedances. Main winding Z_m = (7 + j 5) ohm Auxiliary winding Z_a = (11.5 + j 5) ohm. The value of the capacitor to cause 90° displacement between the main and auxiliary winding currents is ?

(A) 156 μF (B) 165 μF (C) 140 μF (D) 148 μF

Q.3 A resistance split-phase motor is rated at 0.5HP,1600 rev/min, 120V, 50Hz. When the rotor is locked, a test at reduced voltage on the main and auxiliary winding yields the following results:

	Main winding	Auxilary winding
Applied Voltage	E= 24V	E =24V
Current	I_n=5A	I_a=2A
Active Power	P_m= 60W	P_a= 24W

The phase angle (in degrees) between I_a and I_m is?

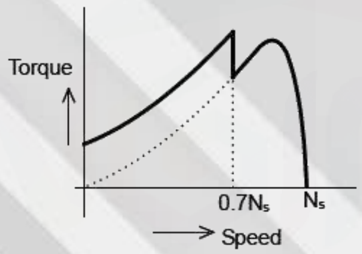
(A)30^0 (B)50^0 (C)0^0 (D)90^0

Q.4 A 50 Hz split phase induction motor has a resistance of 5Ω and an inductive reactance of 20Ω each in both main and auxiliary winding. The value of resistance to be added in series with auxiliary winding such that the main and auxiliary winding current becomes equal in magnitude is?

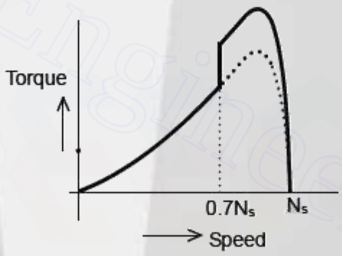
(A)15Ω (B)20Ω (C)16.2Ω (D)25Ω

Q.5 A single phase induction motor is provided with capacitor and centrifugal switch in series with auxiliary winding. The switch is expected to operate at a speed of 0.7 Ns, but due to malfunctioning the switch fails to operate. The torque-speed characteristic of the motor is represented by

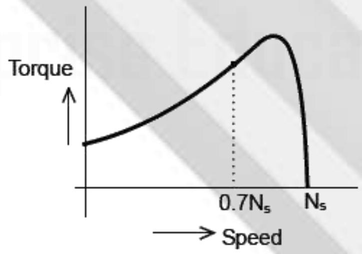
(A)



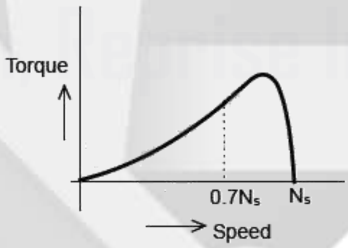
(B)



(C)



(D)



Answer Key

	1	2	3	4	5	6	7	8	9
Type 1	B	A	C						
Type 2	C	B	C	D	B	C	C	A	B
Type 3	C	B	B	D	B				
Type 4	B	A	D	C					
Type 5	C	D	B						
Type 6	C	C							
Type 7	C	C	D	B					
Type 8	B	A	C	A	C				

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