Exam 1

1. Calculate the torque developed, in N-m, when a current of 25A flows through the conductors of the windings of a DC motor with the following particulars: 4 pole, lap winding, 320 conductors, pole-shoes 16 cm long subtending an angle of 62° at the centre, motor bore radius of 17 cm, air-gap flux density 0.75 Wb/m^2.

arc length of pole shoes $= \pi D \frac{62}{360}$

$= 0.184$

$\therefore$ pole shoe area $= 0.184 \times 0.16$

flux per pole $= 0.75 \times 0.184 \times 0.16$

$= 0.022$ wb

developed Torque

$= \frac{P \phi Z I_a}{2\pi a}$

$I_a \rightarrow 25 \times 4$ (as 25A is current in one coil)

$4 \rightarrow$ no of poles

$= \frac{4 \times 0.022 \times 320 \times 100}{2 \times \pi \times 4}$

$= 112.1$ N-m

2. A single-turn armature coil of a DC machine has an inductance of 4 mH in the commutating zone. Find what commutating field (in Wb) is required for the straight-line commutation of 50 A.

$$E = L\frac{di}{dt} \rightarrow \text{time to commutation}$$

$$di = 50 - (-50) = 100$$

$$E_r = 0.004 \times \frac{100}{\Delta t} \quad \text{--- (1)}$$

$E_r \rightarrow$ reactance emf.

for linear commutation, the reactance emf must be counter balanced by dynamically induced emf (E_d)

$$E_d = 2B_{av} l v \rightarrow \frac{\Delta x}{dt}$$

$$E_d = \frac{2 \times \{B_{av} \times l \times \Delta x\}}{\Delta t} \rightarrow \text{average flux in commutating zone}$$

$$E_d = \frac{2 \times \phi_c}{\Delta t} \quad \text{--- (2)}$$

$$E_r = E_d \Rightarrow \frac{0.4}{\cancel{\Delta t}} = \frac{2 \times \phi_c}{\cancel{\Delta t}}$$

$$\phi_c = 0.2 \text{ Wb}$$

All of you did it wrongly. Even copied with each other. However, incidently, answer matches.

3. A 500 V 4-pole separately excited generator has the following saturation characteristic (o.c.c.) at the rated speed –

Field Current, A	1	2	3	4	5	6	7	8
Generated e.m.f., V	140	280	375	445	500	540	574	600

The machine has 504 lap-connected armature conductors with brushes given an actual lead of 10°. The armature circuit resistance is 0.1 ohm. Determine the field excitations, in ampere, required for the rated terminal voltage and rated load of 150 A. Assume 10% of the cross-magnetising ampere turns as demagnetising effect. The shunt field has 1000 turns per pole.

→ Demagnetising ampere turns per pole AT_d

$$AT_d = \frac{\beta Z I_a}{360\, a} = \frac{10}{360} \cdot \frac{504 \cdot I}{4} = 3.5 I$$

$360 \to 2\pi$

AT_c = Cross magnetising ampere turns

$$= \left(\frac{1}{p} - \frac{\beta}{\pi}\right)\frac{Z I_a}{2a} = \left\{\frac{1}{4} - \frac{10}{180}\right\} \cdot \frac{504 I}{2 \times 4}$$

$$= 12.25 I$$

out of this 10% is demagnetising. So total demagnetising $AT_d = 3.5 I + 1.225 I$

Equivalent demagnetising field ampere

$$= \frac{4.725}{1000} I \quad I \to 150\text{ A}, \quad 1000 \to \text{shunt field}$$

$$= \frac{4.725 \times 150}{1000} = 0.708\text{ A}$$

From OCC I_f for 500 V → 5.4 A

$\therefore$ Total $I_f = 5.4 + 0.708$

$= 6.1$ A

4. Consider a generating station supplying power to the total load of 1000 kW. This station contains four DC generators in parallel, each rated at 250 kW, 250 V, and regulation of 4%. Determine the common terminal voltage, in Volts, of the station if the open-circuit voltage of one machine is raised by 5% and regulation of this machine also reduced by 10% of its pervious value.

For 3 m/cs whose open circuit voltage not changed, $V_{occ} = 1.04 \times 250 = 260\,V$

let terminal voltage is V, so –

$$V = 260 - \frac{10}{250} K_1 = 260 - 0.04 K_1$$

where K_1 is the kw load of each 3 m/cs.

Now for 4th m/c,

occ raised by 5%

$$V_{occ_4} = 250 \times 1.05 \times 1.036$$

regulation reduced by 10% of previous value

$$= 271.95\,V$$

& full load voltage –

$$V_{fl_4} = 250 \times 1.05 = 262.5\,V$$

$$V = 271.95 - \frac{(271.95 - 262.5)}{262.5} \times K_2$$

$$= 271.95 - 0.036 K_2$$

$K_2 \to (1000 - 3K_1)$ total load

$$= 235.95 + 0.108 K_1$$

Now $235.95 + 0.108 K_1 = 260 - 0.04 K_1$

$$\therefore K_1 = 162.5$$

$$K_2 = 512.5$$

$$V = 253.5\,V$$

5. In a 250 V, 4-pole series motor, three field winding sections are connected in series. The series motor is running at 500 rpm by taking a current of 40 A from mains supply. Determine the speed of the machine, in rpm, if all the field winding segments are now connected in parallel with one another. Neglect saturation and losses.

In DC series motor load torque is proportional to square of speed. So,

$$\left.\begin{aligned} T_1 &= k n_1^2 \\ T_2 &= k n_2^2 \end{aligned}\right\} \text{ T_1 \& T_2 are torques in first \& second cases.}$$

As the magnetic circuit is unsaturated

$$\phi_1 \propto I_{a_1} \ \& \ \phi_2 \propto I_{a_2}$$

$$\Rightarrow \phi_1 = k_1 I_{a_1} \quad \text{but} \quad \phi_2 = \frac{k_1}{3} I_{a_2}$$

→ as current in each coil is 1/3.

Also

$$T_1 = k_t \phi_1 I_{a_1} \ \& \ T_2 = k_t \phi_2 I_{a_2}$$

$$\therefore \frac{T_2}{T_1} = \frac{k_t \phi_2 I_{a_2}}{k_t \phi_1 I_{a_1}} = \frac{I_{a_2}^2}{3 I_{a_1}^2} = \frac{n_2^2}{n_1^2}$$

$$\therefore \frac{I_{a_2}}{I_{a_1}} = \sqrt{3}\,\frac{n_2}{n_1}$$

Also $V = k_v \phi_1 n_1$

$$= k_v k_1 I_{a_1} n_1$$

$\&$ $V = k_v \phi_2 n_2$

$$= \frac{k_v k_1 I_{a_2} n_2}{3}$$

So

$$I_{a_1} n_1 = \frac{1}{3} I_{a_2} n_2$$

$$\therefore \frac{I_{a_2}}{I_{a_1}} = 3\,\frac{n_1}{n_2}$$

$$\therefore \sqrt{3}\,\frac{n_2}{n_1} = 3\,\frac{n_1}{n_2}$$

$$\frac{n_2}{n_1} = (3)^{1/4}$$

$$\therefore n_2 = 1.316\, n_1 \xrightarrow{} 500$$

$$= 658 \text{ rpm}$$

6. A 200 V DC shunt motor takes 5 A at no-load and runs at 1000 rpm. The armature resistance is 0.6 ohm, and the field resistance is 100 ohm. Find the shaft torque, in N-m, when the motor input is 10 kW.

No load condition:

Field current $= \frac{200}{100} = 2A$

armature current $= 5 - 2 = 3A$

Back emf $E_1 = 200 - 3 \times 0.6 = 198.2$

Loaded condition:

Motor I/p $- 10,000\,W$

I/P current $= \frac{10,000}{200} = 50A$

armature current $= 50 - 2 = 48A$

Back emf $E_2 = 200 - 48 \times 0.6$
$= 171.2$

$\therefore \frac{E_2}{E_1} = \frac{\phi_2 n_2}{\phi_1 n_1} \rightarrow \phi_1 = \phi_2$ if I_f is constant

so $n_2 = \frac{E_2 \times n_1}{E_1} = 864$ rpm

Total no load power $= 200 \times 5 = 1000\,W$

no-load field + armature cu. loss $= 0.6 \times 3^2 + 100 \times \cancel{2}^2$
$= 405.4\,W$

$\therefore$ Constant loss $= 1000 - 405.4\,W$
$= 594.6\,W$

Armature cu loss under load $= (48)^2 \times 0.6$

Total loss under load $= 1382.4 + 594.6 + 100 \times 2^2$
$= 2377\,W$

Shaft power $= 10000 - 2377 = 7623\,W$

Shaft torque $= \frac{7623}{2 \times \pi \times \frac{864}{60}} = 84.3$ N-m

7. Consider a DC series motor with an unsaturated magnetic circuit and with negligible resistance. When motor is running at a certain speed on a given load, it takes 40 A at 450 V. If the load torque varies as the power of four of the speed, find the resistance, in ohm, necessary in series with the field winding to reduce speed by 30%.

Developed torque $T = K_t \phi I_a = K_t' I_a^2$ $\Big\}$ unsaturated magnetic circuit

Also T_L = Load torque $= K_1 n^4$

so $\left(\frac{I_{a2}}{I_{a1}}\right)^2 = \left(\frac{n_2}{n_1}\right)^4$

$I_{a1} = 40A$, $E_1 = 450V$

$n_2 = 0.7 n_1$

$\left(\frac{I_{a2}}{40}\right)^2 = (0.7)^4 \rightarrow I_{a2} = 19.6A$

$\frac{E_2}{E_1} = \frac{I_{a2} n_2}{I_{a1} n_1} \rightarrow E_2 = 154.35V$

Now $E_2 = V - I_{a2} R_2$

$154.35 = 450 - 19.6 R_2$

$R_2 = 15.1 \Omega$

8. A 50 h.p., 500 V DC shunt motor has a full-load efficiency of 90% and runs at 700 rpm. A series winding is added to raise the speed to 800 rpm. Find the efficiency (in %age) under the new condition. Given that, armature resistance = 0.3 ohm, series winding resistance = 0.1 ohm, shunt winding resistance = 250 ohm. Assume that the load torque and the constant losses remain constant.

hp to W

$$m/c\ I/p = \frac{50 \times 746}{0.9} = 41444.4\ W$$

$$\text{total loss} = 41444.4 - 37300 = 4144.4\ W$$

$$I/P\ \text{current}\ I_i = \frac{41444.4}{500} = 82.9\ A$$

$$\text{Shunt field current}\ I_{sh} = \frac{500}{250} = 2\ A$$

$$\text{armature current} = 82.9 - 2 = 80.9\ A$$

$$\text{Total Cu. loss} = \underbrace{(80.9)^2 \times 0.3}_{\text{armature cu loss}} + \underbrace{(2)^2 \times 250}_{\text{field cu loss}} = 2963.4\ W$$

$$\text{Constant losses} = 4144.4 - 2963.4 = 1181\ W$$

at $n_1 = 700$, $E_1 = 500 - 80.9 \times 0.3 = 475.73\ V$

at $n_1 = 800$, $E_2 = 500 - I_{a_2} \times 0.4$

Now ∵ motor torque is constant, so

$$T = K_t \phi I_a \rightarrow \phi \propto \frac{1}{I_a} \rightarrow \frac{\phi_2}{\phi_1} = \frac{I_{a_1}}{I_{a_2}}$$

$$\frac{E_2}{E_1} = \frac{\phi_2 n_2}{\phi_1 n_2} = \frac{I_{a_1} n_2}{I_{a_2} n_1} \Rightarrow I_{a_2} = 95.22\ A$$

$$I/P\ \text{current} = 95.22 + 2 = 97.22\ A$$

$$I/P\ \text{power} = 500 \times 97.22 = 48610\ W$$

$$\text{armature cu. loss} = (95.22)^2 \times 0.4 = 3626.7\ W$$

$$\text{Shunt field cu. loss} = 1000\ W$$

$$\text{Constant loss} = 1181\ W$$

$$\text{Total loss} = 5807.7\ W$$

$$O/P\ \text{power} = 48610 - 5807.7 = 42802.3$$

$$\text{Efficiency} = \frac{42802.3}{48610} \times 100 = 88.05\%$$

Exam Part 2

9. Calculate the efficiency, in %age, of a 5 kVA, 200/400 V single phase transformer when supplying full-load secondary current at unity power factor. The following are test results –
Open Circuit test with 200 V applied on the primary (l.v.) side – 1 A, 100 W.
Short Circuit test with 25 V applied on the secondary (h.v.) side – 10 A, 50 W.

Turns Ratio $a = 1/2$

$$R_o = \frac{V_1^2}{P_o} = \frac{(200)^2}{100} = 400 \text{ ohm}$$

$$X_o = \frac{V_1}{\sqrt{I_o^2 - \left(\frac{V_1}{R_o}\right)^2}} = 230.94 \text{ ohms}$$

$$R_e' = a^2 R_e = \frac{1}{4} \times \frac{P_{sc}}{I_{sc}^2} = 0.125$$

$$X_e' = a^2 \sqrt{\left(\frac{V_{sc}}{I_{sc}}\right)^2 - R_e^2}$$

$$= 0.6242 \text{ ohms}$$

At full load $I_2' = \frac{5 \times 10^3}{200} = 25A$

$$V_1 = V_2' + I_2'(R_e' + jX_e')$$

$$200 = V_2' + 3.125 + j\,15.605$$

$$(200)^2 = (V_2' + 3.125)^2 + (15.605)^2$$

$$V_2' = 196.265$$

Cu. loss $= (25)^2 \times 0.125 = 78.125W$

Iron loss $= 100$ W

$$\text{Efficiency} = \frac{196.265 \times 25}{196.265 \times 25 + 178.125} \times 100\%$$

$$= 96.5\%$$

10. A 5 kVA, 220/110 V transformer has the maximum efficiency of 96.97% at 0.8 power factor lagging. Its core loss is 50 W and full-load regulation at 0.8 p.f. lag is 5%. At what p.f. the full load regulation will be maximum for this transformer?

Let maximum efficiency occurs at x times the load.

So efficiency $= \dfrac{5 \times 0.8 \times x}{5 \times 0.8 \times x + 0.05 \times 2}$ ← core loss = cu. loss at max. efficiency

$$0.9697 = \frac{4x}{4x + 0.1}$$

$$x = 0.8$$

$\therefore$ cu. loss at full load $= \dfrac{50}{(0.8)^2} = 78.1\,W$

Regulation at full load 0.8 lag is 5%.

So,

$$0.05 = e_r \cos\theta + e_x \sin\theta$$

(e_r: pu, e_x: pu)

$$e_r \text{ in pu} = \frac{78.1}{5000} = \frac{P_{cu}}{\text{Full load VA}} = 0.0156$$

$$\therefore e_x = \frac{0.05 - 0.8 \times 0.0156}{0.6} = 0.0625$$

for max regulation $\dfrac{dr}{d\theta} = 0 = \dfrac{d}{d\theta}(\vec{r})$

where $r = e_r \cos\theta + e_x \sin\theta$

$$\frac{dr}{d\theta} = -e_r \sin\theta + e_x \cos\theta = 0$$

$$\tan\theta = \frac{e_x}{e_r} = 4 \Rightarrow \theta = 76^\circ \rightarrow \cos\theta = 0.242,\ \sin\theta = 0.97$$

So max $r = 0.0156 \times 0.242 + 0.0625 \times 0.97$

$$r = 0.0644$$

$$p.f. = 0.242$$

11. The maximum efficiency of a 3300/400 V single-phase transformer is 97% and occurs at ¾ of full load at unity power factor. if the impedance of the transformer is 9%, calculate regulation, in %age, at full load 0.8 pf lagging.

Let K = full load kVA

$$0.97 = \frac{3/4 K}{3/4 K + 2 \underbrace{P_{cu}}_{\text{copper loss at full load}} \left(\frac{3}{4}\right)^2}$$

$$P_{cu} = 0.02K$$

Now if I is full load current,

$$\frac{P_{cu}}{K} = \frac{I_2^2 R_e}{VI} = \frac{IR_e}{V} = e_r = 0.02$$

$$\because Z_e = 0.09$$

so $$x_e = \sqrt{(0.09)^2 - (0.02)^2} = 0.088$$

$$\text{regulation} = e_r \cos\theta + e_x \sin\theta$$

$$= 0.02 \times 0.8 + 0.088 \times 0.6$$

$$= 6.88\%$$

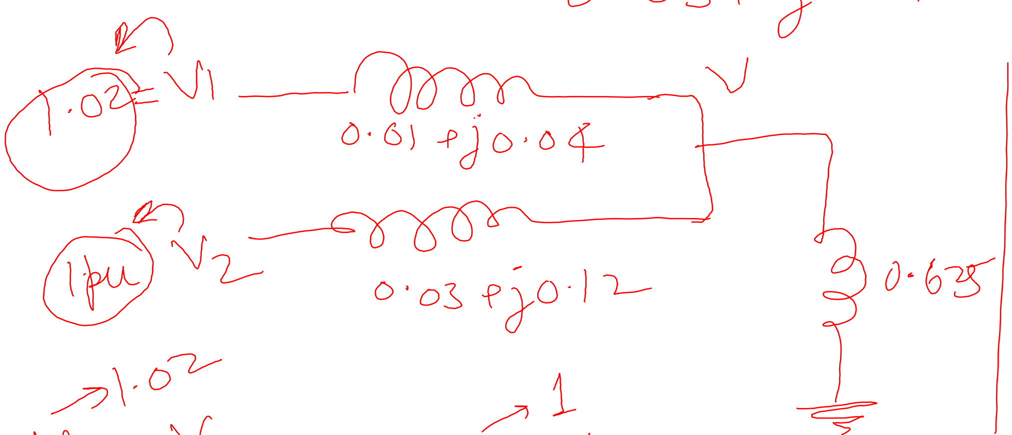
12. A 500 kVA 1-phase transformer with rated secondary voltage of 500 V and reactance drop of 4% and resistance drop of 1% is connected in parallel with the 250 kVA, 500 V transformer having reactance drop of 6% and resistance drop of 1.5%. Total load served by the parallel combination of transformers is 800 kW at unity pf. Calculate the terminal voltage, in V, across the load when open circuit secondary voltages of 500 kVA and 250 kVA transformers are 510 and 500, respectively.

Let Base kVA is 500 kVA & base voltage is 500 V

p.u impedance of 1st transformer $= 0.01 + j0.04$

pu impedance of 2nd transformer on 500 kVA base $= (0.015 + j0.06) \times \frac{500}{250}$

$= 0.03 + j0.12$



load impedance at 500 kVA base $= \frac{500}{800} = 0.625$

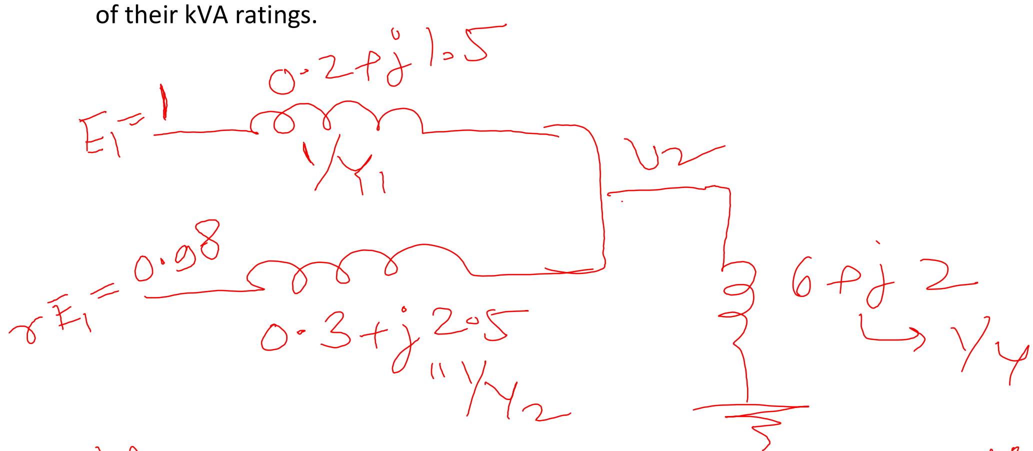
$$\frac{\overset{1.02}{V_1} - V}{0.01 + j0.04} + \frac{\overset{1}{V_2} - V}{0.03 + j0.12} = \frac{V}{0.625}$$

$$\frac{1.02 - V}{0.01 + j0.04} + \frac{1 - V}{0.03 + j0.12} = \frac{V}{0.625}$$

Solving, $|V|_{pu} = 1.001826$

$|V| = 500.91\ V$

13. A 200 kVA single phase transformer is working in parallel with a 100 kVA single phase transformer to supply a load of impedance 6+j2 ohm. The impedances of the transformers referred to the secondary side are respectively, 0.2 + j1.5 ohm and 0.3 + j2.5 ohm. The open circuit voltages of 200 kVA and 100 kVA transformers are in the ratio of 1:0.98. Calculate the inductive reactance, in ohm, to be connected in series with the secondary of the 100 kVA transformer so that the magnitude of currents delivered by the transformers are in proportion of their kVA ratings.



$$V_2 = \frac{E_1 Y_1 + r E_1 Y}{Y_1 + Y_2 + Y}$$

{ for simplicity using admittance values

$$I_1 = (E_1 - V_2) Y_1$$

$$I_2 = (r E_1 - V_2) Y_2$$

$$\therefore \frac{I_1}{I_2} = \frac{1-r}{Y} + \frac{1}{Y_2} \Big/ -\frac{1-r}{Y} + \frac{r}{Y_1}$$

$$= \frac{(1-r)Z + Z_2}{-(1-r)Z + rZ_1} = \frac{0.02(6+j2) + 0.3 + jX}{-0.02(6+j2) + 0.98(0.2+j1.5)}$$

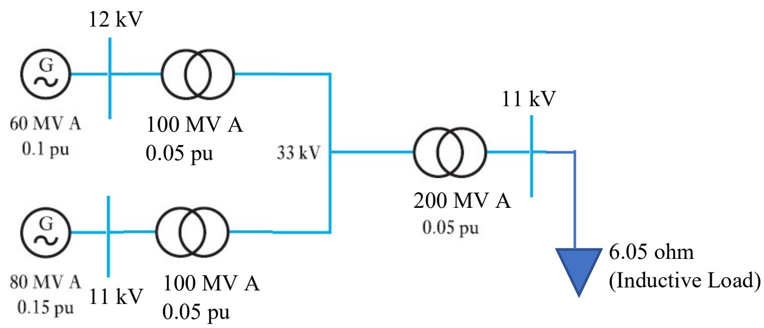
$$= \frac{0.42 + j(X + 0.04)}{0.076 + j1.43}$$

Now $\frac{I_1}{I_2} = 2 \rightarrow X = 2.79$ ohm

additional reactance $= 2.79 - 2.5$

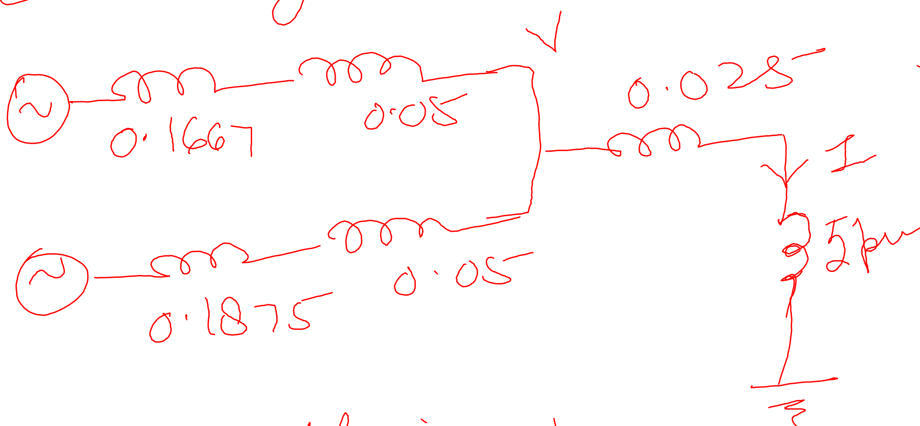
$= 0.29$ ohm

14. Consider the circuit shown in the figure below.



If the pu values mentioned in the figure are with respective to their own base, find the value of load current in kA.

Consider 33 kV, 100 MVA as base values.
converting circuit to modified base values –



Zbase at load
$= \frac{11 \times 11 \times 10^6}{100 \times 10^6}$
$= 1.21$ ohm
$\therefore$ 6.05 ohm = 5pu

Now, at V applying KCL,

$$\frac{1-V}{0.2167} + \frac{1-V}{0.2375} = \frac{V}{5.025}$$

$$V = 0.9782 \text{ pu}$$

$$I = 0.1947 \text{ pu}$$

$$I_{base} = \frac{100 \times 1000}{\sqrt{3} \times 11} = 5248.79 \text{ A}$$

$$\therefore I = 0.1947 \times 5248.79$$
$$= 1.02 \text{ kA}$$

Exam Part 3:

15. A 2-pole, 50 Hz three-phase star connected synchronous generator has the armature winding distributed in 60 slots with 4 conductors per slot. The armature coils have a span of five-sixth of the pole pitch. The rotor has 8 slots per pole. Each rotor slot contains 5000 ampere conductors and the rotor pole pitch is 14 degree. If the air gap flux per pole due to rotor m.m.f. is 0.5 Wb, determine the induced emf per phase, in V, in the armature of the generator.

$$Emf = 4.44 f \phi N K_b K_p$$

$$N = \text{No of turns / phase} = \frac{60 \times 4}{2 \times 3} = 40$$

K_b = breadth factor

$$= \frac{\sin n\alpha/2}{n \sin \alpha/2}$$

α → angle between adjacent slots

$$\alpha = \frac{360}{60} = 6^\circ$$

n = slots per pole per phase

$= 10$

$$= 0.955$$

$$K_p = \cos \frac{\rho}{2}$$

ρ → short pitch angle $= \frac{180}{6}$

($\frac{1}{6}$th short pitching)

$$K_p = 0.966$$

$$Emf = 4.44 \times 50 \times 0.5 \times 40 \times 0.955 \times 0.966$$

$$= 4096\ V$$

16. A 200 kVA, 11 kV, 3-phase, star connected alternator has a resistance of 0.3 ohm per phase and reactance pf 5 ohm per phase. It delivers full-load current at power factor 0.8 leading and normal rated voltage. Compute line voltage, in V, for the same excitation and load current at 0.8 pf lagging.

$$V_{ph} = \frac{11000}{\sqrt{3}} = 6351\ V$$

full load current $= \dfrac{200 \times 10^3}{\sqrt{3} \times 11 \times 10^3} = 105A$

leading pf case -

$$E_0 = V + I(R + jX_s)$$

$$= 6351 + 105(0.8 + j0.6)(0.3 + j5)$$

$$|E_0| = 6077.07$$

Now lagging case -

$$E_0 = V + 105(0.8 - j0.6)(0.3 + j5)$$

$$E_0 = V + 340.2 + j401.1$$

Now,

$$E_0^2 = (V + 340.2)^2 + (401.1)^2 = (6077.07)^2$$

$$\Rightarrow V = 5723.62\ V$$

$$V_{ll} = \sqrt{3} \times 5723.62\ V$$

$$= 9913\ V$$

17. Consider a 2500 kVA, 6600 V star connected alternator. With a field current of 30 A, full load current is obtained on short circuit curve and line voltage of 7160 is obtained on O.C.C. curve. The armature resistance per phase is 0.5 ohm. The leakage reactance per phase is 3.4 ohm. Determine the regulation, in per unit, for full-load and power factor 0.8 lagging.

Voltage per phase $= \frac{6600}{\sqrt{3}} = 3810\,V$

full load current $= \frac{2500 \times 10^3}{\sqrt{3} \times 6600} = 218.7\,A$

Synchronous impedance

$$Z_s = \frac{7160}{\sqrt{3} \times 218.7} = 18.9 \text{ ohm}$$

Syn. reactance $= \sqrt{(18.9)^2 - (0.5)^2}$

$= 18.89$

$$E_0 = V + I(\cos\theta - j\sin\theta)(R + jX_s)$$

$$= 3810 + 218.7(0.8 - j0.6)(0.5 + j18.89)$$

$$= 7154\angle 26.94^\circ$$

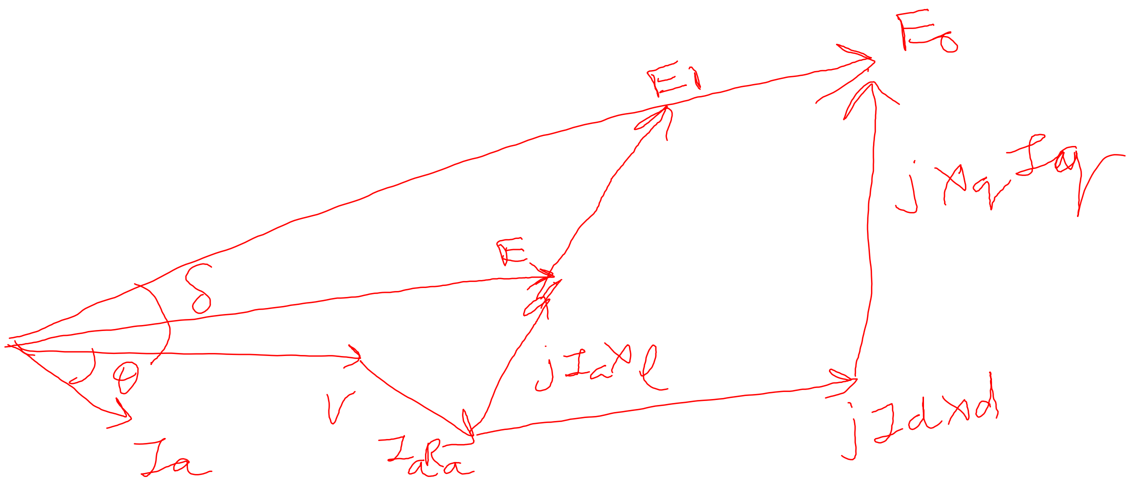
Regulation $= \frac{7154 - 3810}{3810} = 0.88$

18. A test on salient-pole synchronous generator gives X_d=100% and X_q=80%. The resistance is 1%. Determine the regulation, in per unit, on full load and 0.9 pf lagging. Neglect saturation.

$$E_1 = V + I(\cos\theta - j\sin\theta)(R + jX_q)$$

$$= 1 + (0.9 - j0.436)(0.01 + j0.8)$$

$$= 1.535\angle 27.8^\circ$$



From phasor diagram –

$$E_0 = E_1 + I_d(X_d - X_q) \qquad I_d = I\sin(\theta + \delta)$$

$$= 1\sin(27.8 + 25.84)$$

$$\therefore E_0 = 1.535 + 0.8(1 - 0.8) = 1.695$$

$$\text{Regulation} = \frac{1.695 - 1}{1} = 0.7$$

19. Two identical 3-phase star-connected generators supplying equal power while operating in parallel. Each generator has synchronous impedance of 1+j20 ohm per phase. They are supplying a total load of 800 kW at 4000 V and 0.8 pf lagging. The field of the first generator is so excited that its armature current is 80 A (lagging). Find the open circuit line emf, in Volts, of second generator.

terminal voltage/phase $= \frac{4000}{\sqrt{3}} = 2309.47V$

each supplies 400 kW

so, kVA of 1st Generator $= \sqrt{3} \times 4000 \times 80 \times 10^{-3} = 554.24$ kVA

$$\cos\theta_1 = \frac{400}{554.24} = 0.722$$

$$\sin\theta_1 = 0.692$$

$$\therefore I_1 = 80(0.722 - j0.692)$$

Now

$$I = \frac{800}{0.8 \times \sqrt{3} \times 4000}(0.8 - j0.6)$$

$$= 115.473 - j86.61$$

$$I_2 = I - I_1 = 57.713 - j31.25$$

so $E_2 = 2309.47 + (57.713 - j31.25)(1 + j20)$

$$\therefore |E_2| = 5535.4V$$

20. A 12 pole 50 Hz salient-pole synchronous generator is delivering power to a load operating at full load 0.8 pf lagging. The generator has negligible resistance, d-axis synchronous reactance as 1.1 pu, and q-axis synchronous reactance as 0.9 pu. Find the amount of power delivered by the generator to load in pu.

$$E_0 = V + I(\cos\theta - j\sin\theta)jX_q + I\sin(\theta+\delta)(X_d - X_q)$$

$$= \underbrace{1.54 + j0.72}_{\text{use for } \delta \text{ calculation}} + 1\times\sin(25.06 + 36.87)(1.1 - 0.9)$$

{See phasor of Q18}

$$|E_0| = 1.0765$$

$$P = \frac{EV}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta$$

$$= \frac{1.0765}{1.1}\sin(25.06) + \frac{1}{2}\left\{\frac{1}{0.9} - \frac{1}{1.1}\right\}\sin(2\times 25.06)$$

$$= 0.7224 + 0.08$$

$$= 0.8 \text{ pu}$$

Exam Part 4:

21. An induction motor has an efficiency of 0.85 when the load is 60 hp. At this load, the stator copper loss is equal to rotor copper loss and rotor copper loss is equal to the core-loss. The mechanical losses are one-fourth of the no-load loss. Calculate slip, in per unit, of the motor.

power o/p $= 60 \times 746 = 44760\,W$

power i/p $= \dfrac{44760}{0.85} = 52658.8\,W$

Total loss $= 55658.8 - 44760$

$= 7898.8\,W$

Let no load loss $= y$

core loss $= x$

at no load –

Mech loss + core loss = no load loss

$\dfrac{y}{4} + x = y \Rightarrow y = \dfrac{4}{3}x$

mech loss $y/4 = x/3$

so, $\overset{\text{stator cu loss}}{x} + \overset{\text{rotor cu loss}}{x} + \underset{\text{core loss}}{x} + \underset{\text{mech. loss}}{x/3} = 7898.8$

$x = 2369.6\,W$

air gap power $= 52658.8 - 2 \times 2369.6$

$= 47919.6\,W$

slip $s = \dfrac{\text{rotor cu loss}}{\text{airgap power}} = \dfrac{2369.6}{47919.6}$

$= 0.05$

22. The rotor resistance and total standstill reactance of a 3-phase induction motor are 0.02 ohm per phase and 0.08 ohm per phase, respectively. The full-load torque is developed in the motor at 0.04 slip and nominal voltage. Calculate the percentage reduction in stator voltage to develop full-load torque at 75% of full-load speed at nominal voltage.

at $S_1 = 0.04$

$$T_{fl} = \frac{mV_1^2}{\omega_S}\left\{\frac{0.02/0.04}{(0.02/0.04)^2 + (0.08)^2}\right\}$$

$$= 1.95\,\frac{mV_1^2}{\omega_S}$$

Second case, $n_2 = \frac{n_1}{100} \times 75 = 0.72 n_S$ ($n_1 \to 0.96 n_S$)

$$\therefore S_2 = \frac{n_S - 0.72 n_S}{n_S} = 0.28$$

$$T_{fl} = \frac{mV_2^2}{\omega_S}\left\{\frac{0.02/0.28}{\left(\frac{0.02}{0.28}\right)^2 + (0.08)^2}\right\}$$

$$= 6.2087\,\frac{m}{\omega_S}V_2^2$$

Now,

$$1.95\,\frac{mV_1^2}{\omega_S} = 6.2087\,\frac{m}{\omega_S}V_2^2$$

$$\Rightarrow V_2 = 0.5604\,V_1$$

% reduction in stator voltage =

$$\frac{V_1 - 0.5604V_1}{V} \times 100$$

$$= 44\%$$

23. From the short circuit test on 50 hp, 440 V, 50 Hz, 6-pole, star-connected, 3-phase induction motor, the following data were obtained –
V=200 V, I=125 A, pf=0.4 (line values). The motor drives a load having constant torque of 300 N-m. Estimate the maximum percentage reduction in the supply voltage possible before the motor stalls. Assume that the copper losses are equally divided between the stator and the rotor. Neglect magnetising current.

$$n_s = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

$$\omega_s = \frac{2\pi \times 1000}{60} = 104.72 \text{ rad/sec}$$

Short circuit voltage/phase $= \frac{200}{\sqrt{3}} = 115.5\,V$

" " current/phase $= 125\,A$

$$\therefore Z_{sc} = \frac{115.5}{125} = 0.924\,\Omega$$

$$\cos\phi_{sc} = 0.4$$

$$\therefore r_1 + r_2' = Z_{sc}\cos\phi_{sc} = 0.37 \text{ ohm}$$

$$x_1 + x_2' = Z_{sc}\sin\phi_{sc} = 0.847 \text{ ohm}$$

$$\therefore r_1 = r_2' = \frac{0.37}{2} = 0.185 \text{ ohm}$$

Let minimum voltage/phase possible is V_2

So torque, (min possible/to support load)

$$\frac{3V_2^2}{2 \times 104.72} \times \frac{1}{\sqrt{(0.185)^2 + (0.847)^2} + 0.185} = 300$$

$$V_2 = 148.44$$

$$\%\text{ change} = \frac{254 - 148.44}{254} = 41.6\%$$

24. A 3-phase, 50 Hz, 4-pole induction motor, having negligible stator resistance and mechanical loss, is running at 1425 rpm. At this speed, it provides the output of 8.95 kW. Now, if maximum torque in the motor is developed at 1350 rpm, calculate the starting torque, in N-m.

$$s = \frac{1500 - 1425}{1500} = 0.05$$

$$\text{airgap power} = \frac{8950}{1-0.05} = 9421\,W$$

$$T = \text{Developed torque} = \frac{9421}{2\pi \times \frac{1500}{60}} = 60\text{ N-m}$$

$$S_{mt} = S_{\text{at max torque}} = \frac{1500 - 1350}{1500} = 0.1$$

$$\frac{T}{T_{max}} = \frac{2}{\frac{S}{S_{mt}} + \frac{S_{mt}}{S}} = 0.8$$

$$T_{max} = 1.25\,T$$

$$T_{max} = 75\text{ N-m}$$

Now T_{st} = Starting torque

$$\frac{T_{st}}{T_{max}} = \frac{2}{\frac{1}{S_{mt}} + \frac{S_{mt}}{1}} = 0.198$$

$$T_{st} = 0.198 \times T_{max} = 14.85\text{ N-m}$$

25. A 3-phase induction motor, designed in India for voltage V1, is switched on to a voltage V2 in USA. Find the ratio V1/V2 to get equal starting torque and equal maximum torque from motor in India as well as in USA. Ignore stator impedance and assume rotor resistance is very less when compared with the rotor reactance.

at 50 Hz let x_2' is rotor reactance referred to primary

then at 60 Hz reactance $= 1.2\, x_2' = x_2''$

$$\frac{T_{m\,50}}{T_{m\,60}} = \frac{V_1^2}{2X_2'} \times \frac{2X_2''}{V_2^2} = 1$$

$$\left(\frac{V_1}{V_2}\right) = \left(\frac{1}{1.2}\right)^{1/2} = 0.9$$

26. The standstill impedances of the two cages of a double-cage induction motor, referred to stator, are (3.2 + j1.2) ohm and (0.5 + j6.5) ohm, respectively. If the full load slip is 0.05, find the ratio of starting torque to full load torque. Neglect magnetising current and stator impedance.

Impedance of two cages

$$Z_1 = 3.2 + j1.2, \quad Z_2 = 0.5 + j6.5$$

$$Z_{eq} = \frac{Z_1 Z_2}{Z_1 + Z_2} = 1.943 + j1.738$$

$$T_{st} = \frac{mV_1^2 \cdot 1.943}{(1.943)^2 + (1.738)^2} = 0.286 mV_1^2$$

at full load $s = 0.05$

$$Z_1' = \frac{3.2}{0.05} + j1.2 = 64 + j1.2$$

$$Z_2' = \frac{0.5}{0.05} + j6.5 = 10 + j6.5$$

$$Z_{eq} = 9.05 + j4.84$$

$$T_{fl} = \frac{mV_1^2 \, 9.05}{(9.05)^2 + (4.84)^2} = 0.086 mV_1^2$$

$$\therefore \frac{T_{st}}{T_{fl}} = 3.3$$