E&T2520 Electrical Machines 1
Miscellaneous Exercises

TRANSFORMER

Q1 A 20-kVA, 2000/200V, 50Hz single-phase transformer gives the following test results :

Open Circuit Test (HV side open)	200 V	4 A	125 W
Short Circuit Test (LV side short circuited)	60 V	10 A	280 W

i) Derive and draw the approximate equivalent circuit referring to the LV side.

ii) Determine the efficiency of the transformer at full load, 0.8 p.f. lagging.

Q2 A 1.1 kVA, 220/440V, 50Hz, single-phase transformer has the following test results:

	Voltage	Current	Power	Measure at
Open Circuit Test (high volt side open)	220V	1.0A	100W	low volt side
Short Circuit Test (low volt side shorted)	60V	3A	162W	high volt side

(a) Find the transformer parameters, $R_{eq(low)}$, $X_{eq(low)}$, R_c and X_m referred to the low volt side.

(b) Find the input voltage in phasor at low voltage side when the output voltage is kept at 400V, full load 0.8 power factor lagging.

(c) Find the total losses of the transformer when it is operated at full load 0.8 power factor lagging.

(d) Find the full load efficiency of the transformer when it is operated at full load 0.8 power factor lagging.

(e) Find maximum efficiency of the transformer operated at 0.8 power factor.

Q3 A single phase, 25 kVA, 220/440 V, 60 Hz transformer gave the following test results.

Open circuit test (440 V side open):	220 V	9.5 A	650 W
Short-circuit test (220 V side shorted):	37.5 V	55 A	950 W

(a) Derive the approximate equivalent circuit in per-unit values.

(b) Determine the voltage regulation at full load, 0.8 PF lagging and draw the phasor diagram.

Q4. A 10kVA, 200/400V 50Hz, single-phase transformer has the following equivalent circuit parameters.

Equivalent Resistance for core loss refer to 200V side	$R_{c1}=320\Omega$	
Magnetizing Reactance refer to 200V side	$X_{m1}=165\Omega$	
Primary winding (200V side) resistance and reactance	$R_1=0.03\Omega$,	$X_1=0.15\Omega$
Secondary winding (400V side) resistance and reactance	$R_2=0.12\Omega$,	$X_2=0.25\Omega$

Calculate the equivalent circuit parameters refer to 400V side. Find the percentage voltage regulation and efficiency when supplying full load at rated voltage 400V and 0.8 p.f. leading.

DC MACHINES

Q5 A 100kW, shunt excited dc generator has a field resistance of 200Ω. When the generator is delivering a rated output power, the terminal voltage is 500V and the generated emf is 525V. Find

(i) The armature resistance

Calculate, when the terminal voltage is set to 520V,

(ii) The generated emf if the output is reduced to 60% of rated output

Q6 A 100V DC supply is connected to a DC shunt motor (Ra = 0.1Ω with a rated current of 120A). At no load, the armature takes 6 amperes and runs at 1000rpm. Find:

i) the no-load loss,

ii) the full load speed if armature reaction is negligible,

iii) the corresponding torque for (ii),

iv) the full load speed if the armature reaction reduces 5% of the shunt field flux, and

v) the corresponding torque for (iv).

Q7 The magnetization characteristic of a separately excited DC generator at 1200rpm is found to be $E_a = 5 + 110\ I_f$, where E_a = armature voltage (V) and I_f = field current (A).

I_f is adjusted to 1A and a 2Ω load is connected to the armature. Given the armature resistance (Ra) = 0.2Ω and the armature reaction effect can be ignored, find:

i) the quantity of $K_a\phi$,

ii) the armature current,

iii) the torque, and

iv) the power taken by the load.

Q8B A dc machine is connected across a 240-volt line. It rotates at 1200 rpm and is generating 230 volts. The armature current is 40A.

(a) Is the machine functioning as a generator or as a motor?

(b) Determine the resistance of the armature circuit.

(c) Determine power loss in the armature circuit resistance and the electromagnetic power.

(d) Determine the electromagnetic torque in newton-meters.

(e) If the load is thrown off, what will the generated voltage and the rpm of the machine be, assuming (i) No armature reaction. (ii) 10% reduction of flux due to armature reaction at 40 amps armature current.

Q8D. A dc shunt machine (23 kW, 230V, 1500 rpm) has $R_a = 0.1\ \Omega$.

(i). The dc machine is connected to a 230 V supply. It runs at 1500 rpm at no-load and 1480 rpm at full-load armature current.

(a) Determine the generated voltage at full load.

(b) Determine the percentage reduction of flux in the machine due to armature reaction at full-load condition.

(ii). The dc machine now operates as a separately excited generator and the field current is kept the same as in part 1. It delivers full load at rated voltage.

(a) Determine the generated voltage at full load.

(b) Determine the speed at which the machine is driven.

(c) Determine the terminal voltage if the load is thrown off.

INDUCTION MACHINES

Q9 A 3-phase, 11.19kW, 380V, four-pole, 50Hz, 1440rpm induction motor delivers full output power to a load connected to its shaft. The windage friction loss of the motor is 700W.

(i) Determine the mechanical power.
(ii) Determine the air-gap power.
(iii) Determine the rotor copper loss.

The frequency of the emf induced in the rotor of a 3-phase, 6-pole, induction motor is found to have 180 cycles/min. The motor is connected to a 50Hz, 440V supply, calculate:

(i) The speed of the motor
(ii) The percentage slip of the motor

Q10 A 100kW, 3-phase, 380V, 50Hz, 4-pole, star-connected induction motor has the following test results:

	Voltage	Current	Power	Frequency
No Load Test	380V	40A	2000W	50 Hz
Lock Rotor Test	60V	120A	6000W	50 Hz

The stator resistance is 0.05Ω/phase.

The motor is delivering full load output and connected up to a 380V supply. Use the approximate equivalent circuit.

(i) Find the R_c and X_m of the magnetising branch elements.
(ii) Find the R_2' and X_{eq} of the equivalent circuit of the motor.
(iii) Find the full load current if the full load power factor and efficiency of the motor are both 0.8.
(iv) Find the full load slip if the mechanical loss is negligible.

Q11. The power supplied to a three-phase induction motor is 40 kW and the corresponding stator losses are 1.5 kW. Calculate (i) the total mechanical power developed and rotor I^2 R loss when the slip is 0.04 per unit (ii) the output kW of the motor and (iii) the efficiency of the motor, if the friction and windage losses are 0.8 kW. Neglect rotor iron and copper losses.

Q12 Assuming that the mechanical loss of the motor is negligible, and the DC resistance between any two stator terminals is 0.1Ω, the testing results on a 3-phase, 75kW, 380V, 50Hz, 4-pole, star-connected squirrel cage induction motor is summarized as follows.

No Load Test	380V	2067W	29A
Lock Rotor Test	188V	3240W	104A

i) Derive an approximate equivalent circuit per phase for the induction motor.

ii) Determine the input current and gross torque at 1455rpm.

SYNCHRONOUS MACHINES

Q13 c) A star connected 3-phase, 1000kVA, 10kV, 1500rpm synchronous generator has a resistance of 1.5Ω and a synchronous reactance of j15Ω per phase. The field current is adjusted to give the rated terminal voltage at open circuit. If the field current is kept unchanged, find the stator current when the machine terminals are short circuited.

d) The synchronous machine in (c) is now connected to an infinite bus. The generator is adjusted to give rated current at 0.8 power factor lagging, find :

i) the excitation voltage, E_f, and

ii) the percentage increase in the field current relative to the previous field current.

Q14 A 3-phase star-connected synchronous motor has the following name-plate data:

Speed	1500r.p.m.	PF	1
Voltage	6.6kV	Current	920A
Frequency	50Hz	Rating	10MW
Excitation:			
Voltage	100V	Current	5.5A

If the machine is operated at rated (full load) condition, find:

i) the number of poles,

ii) the output torque,

iii) the efficiency,

iv) the rotational loss (assume no winding resistance loss), and

v) the power loss in field circuit.

Q15. (a) When a 50 kVA, 3-phase,440-V, 60 Hz, star connected synchronous generator is driven at its rated speed, it is found that the open-circuit terminal voltage is 440 V line-to-line with a field current of 7 A. When the stator terminals are short circuited, rated current is produced by a field current of 5.5 A. Determine the synchronous reactance per phase.

(b) If the synchronous in (a) is used to supply an independent load of 40 kW with 0.85 lagging power factor at a potential of 440 V,

(i) Determine the field current required; and

(ii) if the load is reduced to 20 kW at 0.75 lagging power factor, to what value will the field current have to be reduced to maintain rated load potential?

Q16. The 3 phase synchronous motor of 10 MVA, 14kV, star-connected, R_s=0.07ohm/phase and X_s=16.5 ohm.phase is connected to a 3 phase, 14 kV, 60 Hz infinite bus and draws 5 MW at 0.85 leading power factor. Determine the values of the stator current (I_a), the excitation voltage (E_f), and the field current (I_f). Draw the phasor diagram. (Ans. Q6 I_a=242.6A, E_f=10.73kV, I_f=265A)

TRANSFORMERS (SOLUTIONS)

Q1

Open Circuit Test

LV side input voltage, V = 200V, LV side input current, I = 4A, LV side input power, P_{oc} = 125W

$P_{oc} = \frac{V^2}{R_{c2}} \Rightarrow R_{c2} = 320$ (LV Side) $I_m = \sqrt{I^2 - (\frac{V}{R_{c2}})^2} \Rightarrow X_{m2} = \frac{V}{I_m} = 50.6$ (LV side)

Short Circuit Test

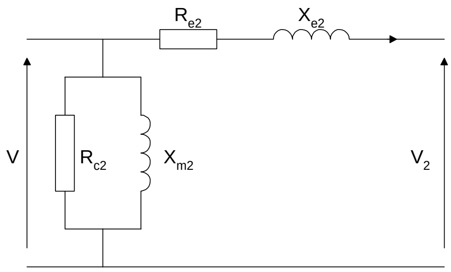
HV side input voltage = 60V,

HV side input current = 10A,

HV side input power = P_{oc} =280W

$P_{sc} = I^2 R_e \Rightarrow R_e = 2.8\Omega$ (HV side) $X_e = \sqrt{(\frac{V}{I})^2 - R_e^2} \Rightarrow X_e = 5.3\Omega$ (HV side)

$$R_{e2} = R_e(\frac{V_2}{V_1})^2 = 0.028\Omega, X_{e2} = X_e(\frac{V_2}{V_1})^2 = 0.053\Omega$$



Full load output power = 20kVA $\times$ 0.8 = 16kW, the full load efficiency is

$$\eta = \frac{\text{Output power}}{\text{Output power} + \text{Iron loss} + \text{Copper loss}} \times 100\%, \quad \eta = \frac{16k}{16k + 125 + 280} \times 100\% \quad = 97.53\%$$

Q4.

$$X_{M2} = X_{M1}\left(\frac{V_2}{V_1}\right)^2 = \underline{\underline{660\Omega}}, \qquad R_{C2} = R_{C1}\left(\frac{V_2}{V_1}\right)^2 = \underline{\underline{1280\Omega}}$$

$$X_{e2} = X_2 + X_1\left(\frac{V_2}{V_1}\right)^2 = \underline{\underline{0.85\Omega}} \quad R_{e2} = R_2 + R_1\left(\frac{V_2}{V_1}\right)^2 = \underline{\underline{0.24\Omega}}$$

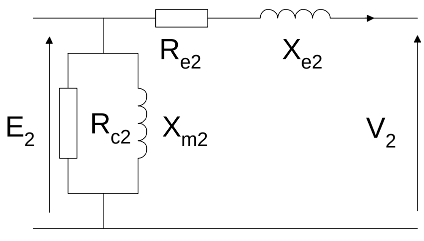
V_{BASE1}=200V V_{BASE2}= 400V I_{BASE1}= 50A I_{BASE2}=25A

S_{BASE1}=10kVA S_{BASE2}=10kVA

$Z_{BASE1}=(V_{BASE1})^2/S_{BASE1}=4\Omega$ $Z_{BASE2}=(V_{BASE2})^2/S_{BASE2}=16\Omega$

X_e (pu)= X_{e2}/Z_{BASE2}=0.053 R_e (pu)= R_{e2}/Z_{BASE2}=0.015

X_M (pu)= X_{M2}/Z_{BASE2}=41.25 R_C (pu)= R_{C2}/Z_{BASE2}=80



$$V_{NL} = V + I_2 Z_e = V\angle 0 + (R_{e2} + jX_{e2})xI\angle(\cos^{-1}(p.f.)) \Rightarrow |V_{NL}| = 0.98 \text{ (pu)}$$

$$VR = \frac{V_{NL} - V_2}{V_2} \times 100\% = \underline{\underline{-2\%}}$$

P_e=Core Loss = V_2^2/R_{C2}=125W, P_{cu}=Copper Loss=$I_2^2 R_{e2}$=150W

P_{out}=Output Power=$V_2 I_2 \cos\phi$=8000W, $Efficiency = \frac{P_{out}}{P_{out} + P_e + P_{cu}} \times 100 = \underline{\underline{96.6\%}}$

	TRANSFORMERS (SOLUTIONS)
Q2.	see below

B1. (a) O/C Test : $100 = 220(1) \times p.f.$ $\cos\phi = 0.4545$, $\sin\phi = 0.8907$

$$R_c = \frac{220}{1 \times 0.4545} = 484\Omega$$

$$X_m = \frac{220}{1 \times 0.8907} = 247\Omega$$

S/C Test $R_e = \frac{162}{3^2} = 18\Omega$ (refer to HV side)

$Z_e = \frac{60}{3} = 20\Omega$ (refer to HV side) $\therefore X_e = \sqrt{Z_e^2 - R_e^2}$

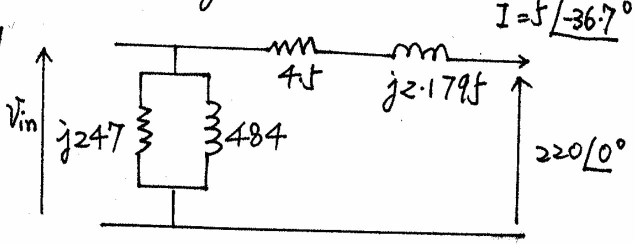
$\therefore X_e = j\,8.718$

Refer $R_e + jX_e$ (HV) to Low voltage side

$$(18 + j8.718) \times \left(\frac{2}{4}\right)^2 = 4.5 + 2.179j$$

(b). $V_{in} = 220\angle 0^\circ + 5\angle -36.87^\circ [4.5 + j2.1795]$

$= 244.58\angle -1.12^\circ$ V.



(c) Full load core loss $= 100W$ Full load current $= \frac{1100}{440} = 2.5A$ (HV)

Full load copper loss $= 5^2 \times 4.5 = 112.5W$ $\frac{1100}{220} = 5A$ (LV)

Total $= 100 + 112.5 = 212.5W$

(d) $$\eta_{FL} = \frac{1100 \times 0.8}{1100 \times 0.8 + 212.5} \times 100\% = 80.54\%$$

(e) η_{max} $100 = \lambda^2\, 112.5 \Rightarrow \lambda = 0.9428 = \frac{I}{I_{rated}}$

$$\eta_{max} = \frac{0.9428 \times 1100 \times 0.8}{0.9428 \times 1100 \times 0.8 + 200} \times 100\% = 80.576\%$$

TRANSFORMERS (SOLUTIONS)

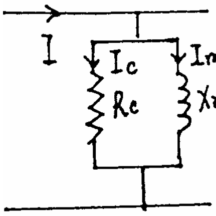
Q3

(10)

(2.5) O.C. Test. 220 V 9.5A 650W 440 side open

S.C. Test. 37.5V 55A 950W 220 side shorted

(a) From O.C. Test. $\frac{V^2}{R_c} = P \Rightarrow \frac{220^2}{R_c} = 650 \Rightarrow R_c = 74.46$.



$I_c = \frac{220}{74.46}$ $\quad I_m = \sqrt{I^2 - I_c^2} = \sqrt{9.5^2 - 2.95^2}$

$= 9.03$

$X_m = \frac{220}{9.03} = 24.36$ $\quad$ R_c, X_m refer to 220 side

From S.C. Test. $I^2 R_{eq} = P \Rightarrow R_{eq} = \frac{950}{55^2} = 0.314$

R_{eq}, X_{eq} refer to H.V. side $\quad X_{eq} = \sqrt{\left(\frac{37.5}{55}\right)^2 - 0.314^2} = 0.6032$

HV side

$V_{BASE} = 440$

$I_{BASE} = \frac{25000}{440} = 56.8$

$Z_{BASE} = \frac{440}{56.8} = 7.744$

LV side

$V_{BASE} = 220$

$I_{BASE} = \frac{25000}{220} = 113.64$

$Z_{BASE} = \frac{220}{113.64} = 1.936$

p.u.

p.u. $R_{eq} = \frac{0.314}{7.744} = 0.0405$ $\quad$ p.u. $R_c = \frac{74.46}{1.936} = 38.46$ p.u.

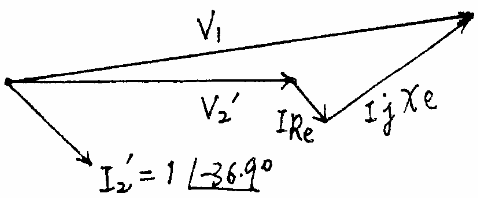
p.u. $X_{eq} = \frac{0.6032}{7.744} = 0.0779$ $\quad$ p.u. $X_m = \frac{24.36}{1.936} = 12.58$ p.u.

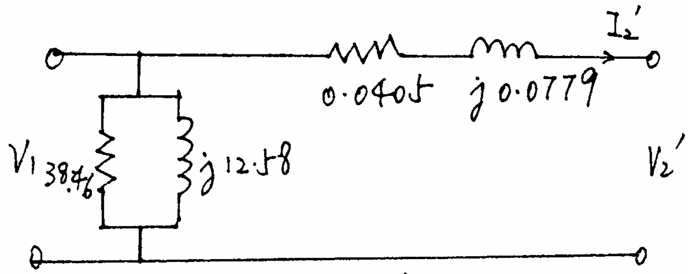
(b) $V_1 = V_2' + I_2'(R_{eq} + jX_{eq})$

$= 1\angle 0° + 1\angle -36.9 \,(0.0405 + j\,0.0779) = 1.08 \angle 2°$

$\therefore \quad VR = \frac{1.08 - 1}{1} \times 100\% = 8\%$

(c)





p.u. diagram.

DC MACHINES (SOLUTIONS)

Q5

(I)

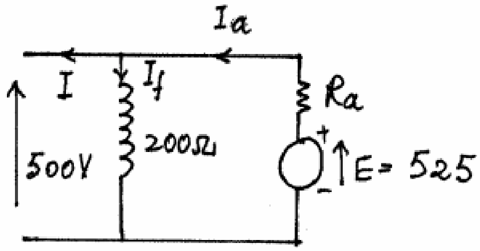
$P_{out} = 100kW$

$I = \frac{100kW}{500V} = 200A$

$I_f = \frac{500}{200} = 2.5A$

$\therefore I_a = 200 + 2.5 = 202.5A$

$525 = 500 + 202.5 R_a \Rightarrow R_a = 0.123\Omega$



(II)

$P_{out} = 60kW \quad V = 520V$

$R_a = 0.123$

$I = \frac{60kW}{520V} = 115.38A \quad I_f = \frac{520}{200} = 2.6A$

$I_a = I + I_f = 117.98A$

$E = 520 + 117.98(0.123) = 534.5V$

Q6.

$E_a = V_t - I_a R_a = 100 - 6 \times 0.1 = 99.4V$

No load loss = Ea x Ia = 99.4 x 6 = 596.4W

At full load,

Ea (fl) = V_t – IaRa = 100 – 120 x 0.1 = 88V

$\frac{E_a(fl)}{E_a(nl)} = \frac{K_a\phi_{fl}\omega_{fl}}{K_a\phi_{nl}\omega_{nl}} = \frac{\omega_{fl}}{\omega_{nl}}$ Therefore, $\frac{88}{99.4} = \frac{N_{fl}}{1000} \Rightarrow N_{fl} = 885.31$ rpm

$T = \frac{E_a I_a}{\omega} = \frac{88 \times 120}{2\pi \times \frac{885.31}{60}} = 113.9Nm$

$\frac{E_a(fl)}{E_a(nl)} = \frac{K_a\phi_{fl}\omega_{fl}}{K_a\phi_{nl}\omega_{nl}} = \frac{\phi_{fl}\omega_{fl}}{\phi_{nl}\omega_{nl}}$ Therefore, $\frac{88}{99.4} = \frac{0.95 \times N_{fl}}{1000} \Rightarrow N_{fl} = 931.9$ rpm

$T = \frac{E_a I_a}{\omega} = \frac{88 \times 120}{2\pi \times \frac{931.9}{60}} = 108.16Nm$

Q7

Ea= 5+110(1) = 115V

Wm = 1200 x 2π / 60 = 125.71 rad/s.

KaΦ = Ea/Wm = 115/125.71 = 0.915Vs/rad

Ia = Ea / (Ra+R_L) = 115/ (0.2 +2) = 52.27A

T = KaΦIa = 0.915 x 52.27 = 47.83Nm

$P = I_L^2 R_L = 52.27^2 \times 2 = 5464.3W$

Q8B	**DC MACHINES (SOLUTIONS)**
	(4.2 3) (8) a) $V_t = 240$ 1200 rpm 230 $I_a = 40$ $\because$ Terminal voltage $= 240 >$ generated voltage $= 230$ $\therefore$ The dc machine is operated as MOTOR. (b) $R_a = \frac{240-230}{40} = \frac{V_t - E_a}{I_a} = 0.25\Omega$ (c). Armature Resistance Loss $= I_a^2 R_a = 40^2 \times 0.25 = 400W$ Electro mechanical power $= E_a I_a = 230 \times 40 = 9200W$ (d). $\omega_m = \frac{1200}{60} 2\pi = 125.7$ rad s^{-1} $T = \frac{9200}{125.7} = 73.19$ Nm (e)(I). Load thrown off $I_a = 0 \Rightarrow T = 0$ $E_a = V_t = 240$ $240 = K\phi_{nL} n$ $\because$ Given $230 = K\phi_{FL} 1200$ Assume $\phi_{nL} = \phi_{FL}$ NO Armature reaction $\Rightarrow \frac{240}{230} = \frac{n}{1200} \Rightarrow n = 1252.2$ rpm. (II). If we assume $\phi_{nL}\, 0.9 = \phi_{FL}$ $\therefore \frac{240}{230} = \frac{n\, 0.9}{1200} \Rightarrow n = 1127$ rpm.

Q8D	(4.28) 23 kW. 230 V 1500 rpm $R_a = 0.1$ (10) $V_t = 230$ $n = 1500$ no-load $n = 1480$ full-load. <u>MOTOR</u> 1 (a) I_a full load $= \frac{23 \times 1000}{230} = 100$ A rated armature current $E_a = 230 - 100 \times 0.1 = 220$V 1 (b) $E_{a(NL)} = V_t = 230 = K\phi_{NL}\, 1500$ $E_{a(FL)} = 220 = K\phi_{FL}\, 1480. \Rightarrow \frac{\phi_{FL}}{\phi_{NL}} = \frac{1500}{1480} \times \frac{220}{230} = 0.97$ 3 % reduction <u>GEN</u> 2(a) $E_a = 230 + 100 \times 0.1 = 240$ $\because$ 2(b) I_f and I_a are same for both motoring & generating conditions, machine flux remains the same. $\frac{E_a\,(gen)\|_{FL}}{E_a\,(MOTOR)\|_{FL}} = \frac{240}{220} = \frac{K\,\phi_{FL}\, n}{K\,\phi_{FL}\, 1480} \Rightarrow n = 1614.6$ rpm. 2(c). $E_a\,(gen)\|_{NL} = K\phi_{NL}\, 1614.6 = V_t$ $E_a\,(motor)\|_{NL} = K\phi_{NL}\, 1500 = 230$ $\therefore \frac{V_t}{230} = \frac{1614.6}{1500} \Rightarrow V_t = 247.6$ V.

INDUCTION MACHINES (SOLUTIONS)

Q9

C1 (5) (d)

$P_m = 11190 + 700 = 11890$ = gross mechanical power

P_o = Airgap power = $\frac{P_m}{1-s} = \frac{11890}{1-0.04} = 12385\ W$

P_r = rotor copper Loss

$= 12385\ (0.04) = 495.4$

$= P_o \times s$

(e). $f_r = \frac{180}{60} = 3\ Hz$

slip $= \frac{f_r}{f} = \frac{3}{50} = 0.06$

$N_s = \frac{50 \times 60}{3} = \frac{f}{p} \times 60 = 1000$ rpm

$N_r = 1000(1-0.06) = 940$ rpm.

$= N_s(1-s)$

Q12

No Load Test

V=380⇒phase voltage = Vp=219.4V

I =Input current = 29A

Power Loss = P = 2067/3=689W (per phase)

$$P = \frac{V_p^{\ 2}}{R_c} \Rightarrow R_c = 69.86\Omega \quad I_m = \sqrt{I^2 - (\frac{V_p}{R_c})^2} \Rightarrow X_m = \frac{V_p}{I_m} = 7.6\Omega$$

$I_o = V/R_c + jV/(jX_m) = 3.14 - j28.7A$

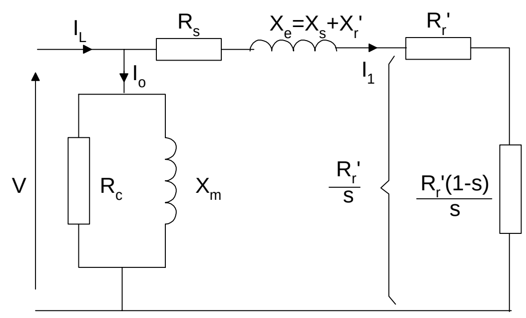
Lock rotor Test

Line Input voltage = 188V⇒V=108.5V(per phase)

Input current = 104A   Three phase power loss= 3240W ⇒P=1080W (per phase)

$P_{sc} = I^2 R_e \Rightarrow R_e = 0.1$, But $R_s = 0.1/2 = 0.05$

$\Rightarrow$ Rr = 0.05Ω $X_e = \sqrt{(\frac{V}{I})^2 - R_e^2} \Rightarrow X_e = 1.04\Omega$



Speed = 1455 ⇒ s =(1500-1455)/1500=0.03

$I_1 = V/Z = 219.4/(1.71+j1.04) = 109.6\angle(-31.25^o)A$

Rotor Power loss=$P_r = 3x109.6^2x0.05 = 1.8kW$

$Z = R_s + R_r/s + jXe = 1.71 + j1.04\Omega$

$I_L = I_1 + I_o = 96.8 - j85.7 = 129.3\ \angle(-\cos^{-1}(0.75))A$

Torque=$P_r/s/(2\pi 1500/60) = 382$ Nm

Q10 **INDUCTION MACHINES (SOLUTIONS)**

C2 (I) No-load Test $2400 = \sqrt{3}\ 380\ 40 \cos\phi$

$\cos\phi = \cos(85.67°)$

$I_0 = 50\ \angle -85.67°$

$\dfrac{2400}{\sqrt{3}} / I_0 \cos\phi = \quad R_c = 72.8\,\Omega$

$\dfrac{2400}{\sqrt{3}} / I_0 \sin\phi = X_m = 5.5$

(II) Lock Rotor Test: $6000 = 3(120)^2 R_e \Rightarrow R_e = 0.1389$

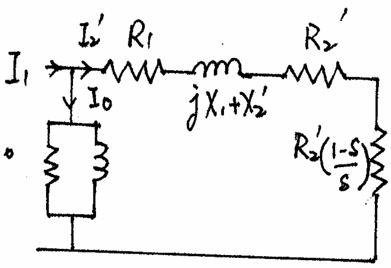
$R_2' = 0.1389 - 0.05$
$= 0.0889$

$\because Z_e = \dfrac{60/\sqrt{3}}{120} = 0.2886 \quad \therefore \quad X_e = \sqrt{0.2886^2 - 0.1389^2} = 0.253$

(III). $P_{out} = 100\text{kW} \quad \because P_{out}/P_{in} \times 100\,\% = \text{efficiency} = 80\%$

$\dfrac{100}{0.8} = P_{in} = \sqrt{3}\ 380\ I_1\ 0.8 \Rightarrow I_1 = 237.4$

I_1 = Input current to motor



$I_2' = I_1 - I_0 = 237.4\angle -36.87° - 50\angle -85.67°$

$= 208\angle -26°$

$P_{out} = P_{mech} = 100\text{kW}.$

$\therefore 100 \times 10^3 = 3 \times (I_2')^2 R_2' \left(\dfrac{1-s}{s}\right)$

$100 \times 10^3 = 3 \times (208)^2\ 0.0889 \times \left(\dfrac{1-s}{s}\right)$

$\Rightarrow s = 0.1034$ ✓.

Q11 Assume stator loss including stator copper and core loss

Airgap power = Input power – stator loss = 40 – 1.5 = 38.5 kW=3 $(I_2')^2$ R_2' / s

3 $(I_2')^2$ R_2' = Copper Loss = s 38.5 = 0.04 x 38.5 = 1.54 kW

Gross Mechanical Power Output = 3 $(I_2')^2$ R_2' (1-s) / s = 1.54 (1-s) / s = 1.54 x 0.96 / 0.04 =36.96kW

Actual Mechanical Power Output = Gross Mechanical Output-Rotational Loss=36.96-0.8=36.16kW

Efficiency = Output / Input x 100% = 36.16 / 40 x 100% = 90.4%

SYNCHRONOUS MACHINE (SOLUTION)

Q13 At no load, the generated emf

$E_f = \dfrac{10k}{\sqrt{3}} = 5.77kV$ Zs = 1.5 + j 15 = 15.06∠84.3° $I_a = \dfrac{E_f}{Z_s} = \dfrac{5770}{15.06}$ = 83.13A

Full load current, $I_a = \dfrac{1000k}{\sqrt{3}\times 10k}\angle -\cos^{-1} 0.8 = 57.735\angle\text{-}36.9°\text{A}$

$E_f = V_t + I_a Z_s \Rightarrow E_f = 5770\angle 0° + 57.735\angle -36.9° \times 15.06\angle 84.3° = 6392.4\angle 5.8°\text{V}$

E_f is proportional to I_f, hence % increase in I_f = (6392-5770)/5770 x 100% = 10.8%

Q14 **SYNCHRONOUS MACHINES (SOLUTIONS)**

1500= 2x50x60 / P , P = 4

T = 10000000 / (1500x2π/60) = 63,636.36 Nm,

Pin = 6600 x $3^{1/2}$ x920 x 1 = 10.517kW,

Pout = 10MW.

Efficiency = 10/10.517 x 100 % = 95%,

Rotational Loss = Pin – Pout = 517 kW

Power loss in field = 100 x 5.5 = 550W

Q15

$\because$ Field current $= 7A \Rightarrow$ open circuit voltage $= \frac{440}{\sqrt{3}}$

Field current $= 5.5A \Rightarrow$ short circuit current $= \frac{50\times10^3}{\sqrt{3}\,440}$

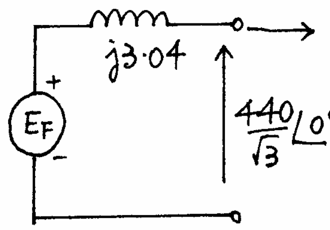
$\therefore$ Field current $= 7A \Rightarrow$ short circuit current $= \frac{7}{5.5}\times\frac{50\times10^3}{\sqrt{3}\,440} = 83.5\,A$

$\therefore$ Synchronous impedance $= \frac{440/\sqrt{3}}{83.5} = 3.04\,\Omega/\text{phase} = X_s \quad \because R_a \approx 0$

$\because$ Load power $= 40kW \quad 0.85$ p.f lagging

$\therefore$ Line current $= I \Rightarrow \sqrt{3}\,440\, I\, 0.85 = 40\times1000$

$I = 61.75A$



$61.75\,\angle -\cos^{-1}0.85$

$E_F = \frac{440}{\sqrt{3}}\angle 0° + 61.75\,\angle -\cos^{-1}0.85\; 3.04j$

$= \frac{440}{\sqrt{3}} + (52.5 - 32.7j)\,3.04j = 353.4 + j160$

$|E_F| = 388$ (per phase)

$\sqrt{3}\,388 = 671.9$ (line-to-line)

Assume field current $\propto E_F \quad \therefore \quad I_F = \frac{671.9}{440}\times 7 = 10.7A.$

Q16

$\theta = \cos^{-1}0.85 \qquad 0.85$ p.f leading

$P = 5\times10^6 = \sqrt{3}\;14\times10^3 \times |I| \times 0.85$

$I = 242.6\,\angle +31.8°$

$E_F = \frac{14\times10^3}{\sqrt{3}} - 242.6\,\angle +31.8°\;(0.07 + j16.5)$

$E_F = V - I Z_s$

$= 10.73\times10^3\,\angle -18.5°$

$I_F = \frac{10.73}{14/\sqrt{3}}$