NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2017-2018

EE3010 – ELECTRICAL DEVICES AND MACHINES

November / December 2017 Time Allowed: 2 hours

INSTRUCTIONS

1. This paper contains 4 questions and comprises 5 pages.
2. Answer ALL questions.
3. All questions carry equal marks.
4. This is a closed book examination.
5. Unless specifically stated, all symbols have their usual meanings.

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1. (a) For the magnetic circuit of Figure 1, a 500-turn coil is wound on the left limb and there is an air gap $l_g = 2$ mm long in the center limb. The mean lengths of the various magnetic sections are $l_1 = l_2 = 58$ cm and $l_3 = l_4 = 7.99$ cm. Each limb has a cross-sectional area of 4 cm². The relative permeability μ_r of the core is 2000 and the permeability of free space μ_o is $4\pi \times 10^{-7}$ H/m. Neglect leakage and fringing in your calculations.

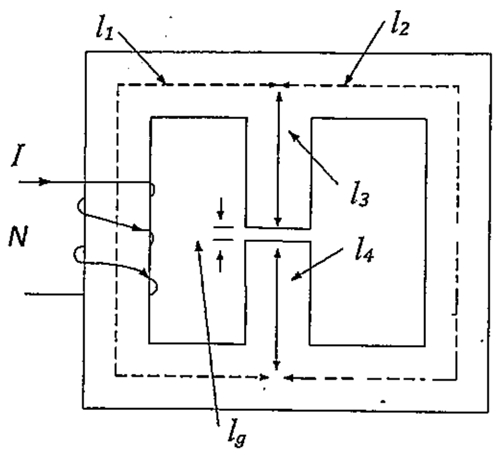

Figure 1

Note: Question No. 1 continues on page 2.

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(i) Let the fluxes in the left, right and center limbs be ϕ_1, ϕ_2 and ϕ_3, respectively. Determine the mmf and the current required to produce a flux of 2.5 mWb in the left limb. Also, calculate the fluxes in the right and the center limbs.

(12 Marks)

(ii) Determine the energy stored in the core and in the air gap. Also, find the inductance of the coil.

(5 Marks)

(b) A ring of magnetic material is wound with a coil of 400 turns. The reluctance of the ring is 1×10^5 At/Wb. Determine the amplitudes of the flux and exciting current in the steady-state when the coil is excited with a voltage of $240\cos(100\pi t)$. Assume the coil to be ideal with no resistance.

(4 Marks)

(c) Two coils, Coil 1 and Coil 2, are placed close to each other. A current of 5 mA in Coil 1 produces a flux in Coil 1 and of this total flux, 5 μWb are linked with Coil 2 of 75 turns. If the current in Coil 1 is changed from 0.4 A to 0 A in 0.02 s, determine the change in flux linking Coil 2, and the induced emf in Coil 2 during this period.

(4 Marks)

2. A 100-kVA, 2300/230-V, 50-Hz single-phase transformer has the following parameters:

$R_1 = 0.01\ \Omega$, $X_1 = 0.25\ \Omega$, $R_2 = 0.005\ \Omega$, $X_2 = 0.0075\ \Omega$,

$R_c = 15000\ \Omega$, $X_m = 1600\ \Omega$

Using the approximate equivalent circuit of the transformer referred to the primary side, determine:

(a) The primary input voltage when the transformer is delivering full-load at

(i) 0.852 power factor leading.

(ii) 0.852 power factor lagging.

The secondary terminal voltage is kept at 230 V. You may take $\vec{V}_2 = 230\angle 0^o$ V.

(16 Marks)

Note: Question No. 2 continues on page 3.

(b) The voltage regulation of the transformer when operating at full-load at

(i) 0.852 power factor leading.

(ii) 0.852 power factor lagging.

Comment on the performance of the transformer in each case.

(4 Marks)

(c) The input current drawn from the supply when the transformer is delivering full-load at 0.852 power factor lagging. Hence, calculate the input power and the efficiency of the transformer.

(5 Marks)

3. (a) Consider a 3-phase, 50-Hz, 6-pole induction motor.

(i) Determine the speed of the motor if the frequency of the rotor emf is 4 Hz.

(ii) If the motor is running at a slip of 0.04 and the torque developed is 160 Nm, determine the power developed, the rotor copper loss and the efficiency of the motor at this operating condition. Assume that the stator copper loss and rotational losses are 800 W and 1200 W, respectively.

(8 Marks)

(b) A 3-phase, 4160-V, 60-Hz, 4-pole, wye-connected induction motor has the following per phase parameters referred to the stator:

$$R_1 = 0.521\ \Omega,\ R_2 = 1.958\ \Omega,\ X_1 = 4.98\ \Omega,\ X_2 = 5.32\ \Omega,\ X_M = 136\ \Omega$$

The induction motor is connected to a 3-phase, 4160-V, 60-Hz supply. If the rotational losses of the motor are 3500 W and the motor is running at a speed of 1725 rpm, determine the following:

(i) Input power factor.

(ii) Input power.

(iii) Output power.

(10 Marks)

Note: Question No. 3 continues on page 4.

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(c) A 3-phase, 50-Hz, 6-pole, wye-connected induction motor has a rotor resistance of 0.25 Ω per phase referred to the stator. It develops a maximum torque of 100 Nm at a speed of 875 rpm. Assume that the stator winding resistance and stator leakage reactance can be neglected.
(Hint : Use the Thevenin equivalent circuit and find X_2.)

(i) Determine the line voltage applied to the motor.

(ii) Determine the torque developed at a slip of 5 %.

(7 Marks)

4. (a) The magnetization curve of a dc machine obtained at a speed of 1800 rpm is shown in Figure 2 on page 5. The machine is operated as a separately excited dc generator. The armature and field resistances of the machine are 0.28 Ω and 138 Ω, respectively. The constant rotational losses of the machine are 500 W. The field winding is connected in series with a variable resistor R_{ext} and the field circuit is fed by a constant 138 V dc supply. Neglect the effects of armature reaction and consider the following cases:

(i) The dc generator is driven at 1800 rpm. If R_{ext} is changed from 0 Ω to 92 Ω, determine the minimum and maximum values of the no-load terminal voltages.

(ii) The dc generator is driven at 1800 rpm. If the generator delivers an armature current of 100 A, determine the efficiency of the generator when $R_{ext} = 0\ \Omega$.

(iii) If the dc generator is driven at 1500 rpm and the generator delivers an output power of 12.2 kW with an armature current of 100 A, what is the required value of R_{ext} ?

(15 Marks)

(b) The armature and field resistances of a 600-V dc shunt motor are 0.18 Ω and 108 Ω, respectively. The motor drives a load at a speed of 880 rpm. The output power of the motor is 63 kW and the efficiency of the motor at this load is 88 %.

(i) Determine the constant rotational losses.

(ii) Determine the armature current for a developed torque of 608 Nm.

(10 Marks)

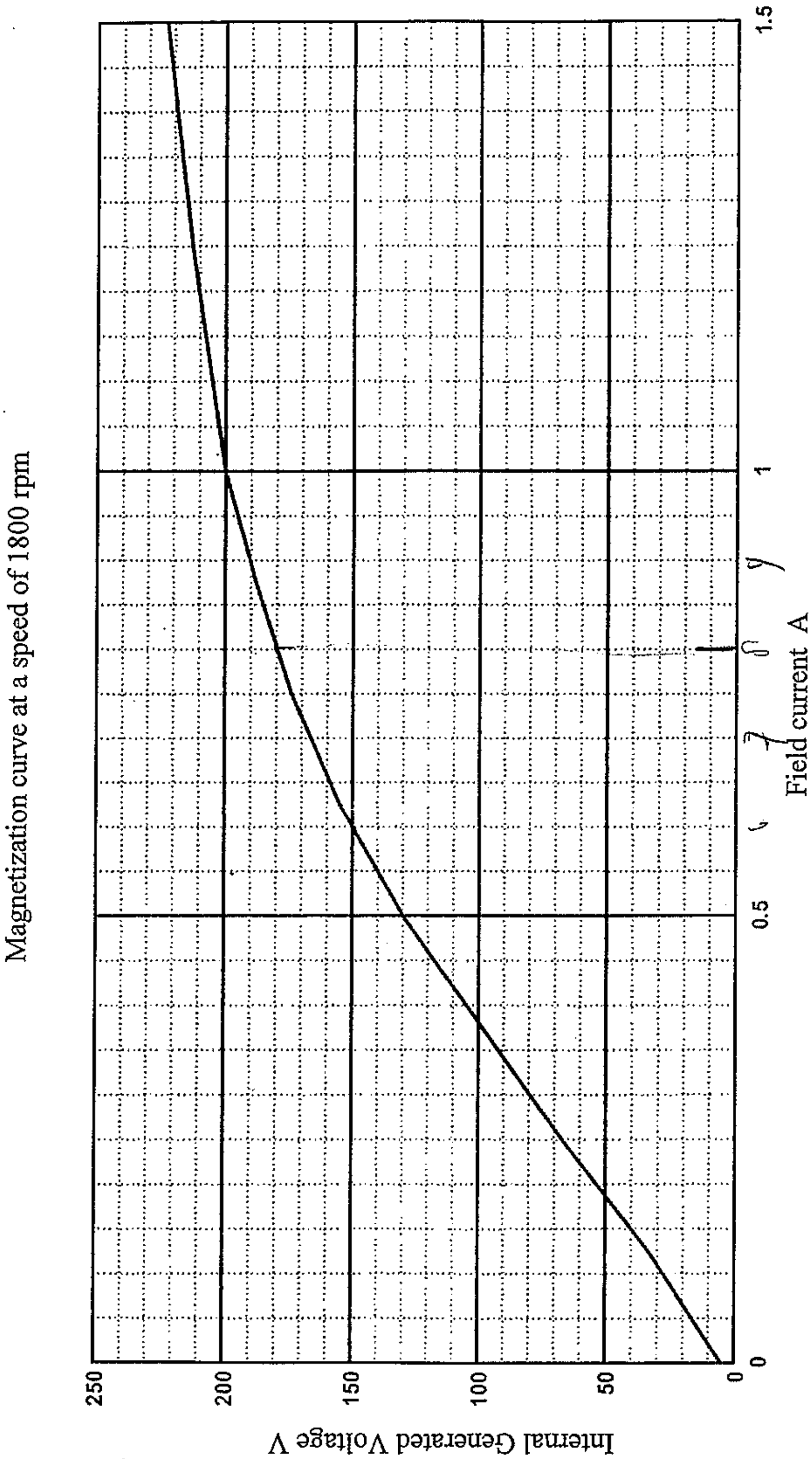

Figure 2

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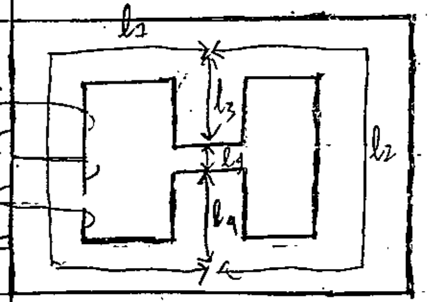
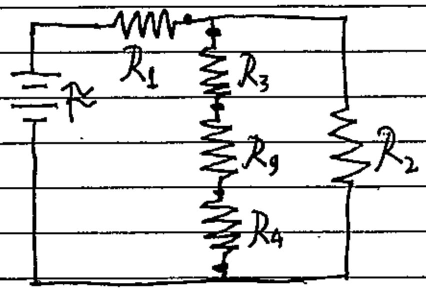
1a)



$N(turn) = 500t$
$l_1 = l_2 = 0.58m$
$l_g = 2\times10^{-3} m$
$l_3 = l_4 = 7.99\times10^{-2} m$
$A = 4\times10^{-4} m^2$
$\mu_0 = 4\pi\times10^{-7} H/m$
$\mu_r = 2000$

Equivalent Magnetic Circuit



i) $\Phi_1 = \Phi_2 + \Phi_3 = 2.5\, mWb$

- since $l_1 = l_2$:

$$R_1 = R_2 = \frac{l_2}{\mu_0\mu_r A} = \frac{0.58\,m}{2000\times4\pi\times10^{-7}\,Hm^{-1}\times4\times10^{-4}\,m^2} = \frac{1812500}{\pi}H^{-1} \simeq 576936.6687\,H^{-1}$$

- Since $l_3 = l_4$:

$$R_3 = R_4 = \frac{l_4}{\mu_0\mu_r A} = \frac{7.99\times10^{-2}\,m}{2000\times4\pi\times10^{-7}\,Hm^{-1}\times4\times10^{-4}\,m^2} = \frac{499375}{2\pi}H^{-1} \simeq 79477.99972\,H^{-1}$$

$$R_g = \frac{l_g}{\mu_0 A} = \frac{2\times10^{-3}\,m}{4\pi\times10^{-7}\,Hm^{-1}\times4\times10^{-4}\,m^2} = \frac{1.25\times10^{7}}{\pi}H^{-1} \simeq 3978873.577\,H^{-1}$$

Fluxes at the limbs

$\Phi_1 = 2.5\times10^{-3}\,Wb$

$$\Phi_2 = \frac{R_3+R_4+R_g}{R_2+R_3+R_4+R_g}\times\Phi_1 = \frac{2R_3+R_g}{R_2+2R_3+R_g}\times\Phi_1 =$$

$$= \frac{\left(2\times\frac{499375}{2\pi}H^{-1}\right)+\frac{1.25\times10^{7}}{\pi}H^{-1}}{\frac{1812500}{\pi}H^{-1}+\left(2\times\frac{499375}{2\pi}H^{-1}\right)+\frac{1.25\times10^{7}}{\pi}H^{-1}}\times 2.5\times10^{-3}\,Wb = 2.19408\times10^{-3}\,Wb$$

$$\Phi_3 = \Phi_1 - \Phi_2 = (2.5-2.19408)\times10^{-3}\,Wb = 0.30592\times10^{-3}\,Wb$$

1a) $\mathcal{R}_{total} = \mathcal{R}_1 + [\mathcal{R}_2 \| (\mathcal{R}_3 + \mathcal{R}_g + \mathcal{R}_4)] = \frac{10^6}{\pi}\{1.8125 + [\frac{1.8125 \times (0.499375 + 12.5)}{12.5 + 0.499375 + 1.8125}]\}\ H^{-1}$

$= 1083274.732\ H^{-1}$

mmf and current

$\mathcal{F} = \mathcal{R}_{total} * \Phi_1 = 1083274.732\ H^{-1} * 2.5 \times 10^{-3}\ Wb = 2708.186831\ At$

$\text{Current} = \frac{\mathcal{F}}{N} = \frac{2708.186831\ At}{500t} = 5.41637\ A$

ii) $\text{Total energy stored} = \frac{1}{2}\Phi_1^2 \mathcal{R}_{total} = \frac{1}{2}(2.5 \times 10^{-3}\ Wb)^2 * 1083274.732\ H^{-1}$

$= 3.385234\ J$

Energy in air gap and in core

$\text{Energy in air gap} = \frac{1}{2}\Phi_2^2 \mathcal{R}_g = \frac{1}{2}(0.30592 \times 10^{-3}\ Wb)^2 * \frac{1.25 \times 10^7}{\pi}\ H^{-1}$

$= 0.186186\ J$

Energy in core = Total energy stored − Energy in air gap

$= 3.385234\ J - 0.186186\ J = 3.199048\ J$

Inductance of the core

$L = \frac{N^2}{\mathcal{R}_{total}} = \frac{500^2}{1083274.732\ H^{-1}} = 230.7817\ mH$

b) $N = 400$

$\mathcal{R}_{RING} = 10^5\ At\ Wb^{-1}$

Amplitude of the flux

$\frac{d\Phi(t)}{dt} = \frac{e(t)}{N}$

$\Phi(t) = \frac{1}{N}\int e(t)\,dt = \frac{1}{400}\int 240\cos(100\pi t)\,dt = \frac{3}{500\pi}\sin(100\pi t)\ Wb$

$|\Phi(t)| = \frac{3}{500\pi}\ Wb = 1.90986\ mWb$

1b) Exciting Current

$$L = \frac{N^2}{\mathcal{R}_{Ring}} = \frac{400^2}{10^5 H} = 1.6\,H$$

$$\frac{\partial i(t)}{\partial t} = \frac{e(t)}{L} = \frac{240}{1.6}\cos(100\pi t) = 150\cos(100\pi t)$$

$$i(t) = \frac{1}{L}\int e(t)\,dt = \frac{150}{100\pi}\sin(100\pi t)$$

$$|i(t)| = \frac{150}{100\pi}A = 0.477465\,A$$

1c) In two coils, current is always propotional to magnetic flux:

- $i_1 \sim \Phi_{12}$ (Flux at coil 1)
- $i_2 \sim \Phi_{21}$ (Flux at coil 2)
- $\frac{\partial \Phi_{12}(t)}{\partial t} \sim \frac{\partial \Phi_{21}(t)}{\partial t}$

Since change in current is constant:

$$\frac{\frac{\partial \Phi_{21}(t)}{\partial t}}{\frac{\partial i_2(t)}{\partial t}} = \frac{\partial \Phi_{21}(t)}{\partial i_2(t)} = \frac{\Phi_{21}}{i_2} = \frac{5\times 10^{-6}\,Wb}{5\times 10^{-3}\,A} = 10^{-3}\,Wb/A$$

Change in flux linking Coil 2 $[\Phi_{21}(t)]$

$$\frac{\partial \Phi_{21}(t)}{\partial t} = \frac{\partial \Phi_{21}(t)}{\partial i_2(t)} \times \frac{\partial i_2(t)}{\partial t} = 10^{-3}\,Wb/A \times \frac{[0A - 0.4A]}{0.02\,s} = 10^{-3}\,Wb/A \times -20\,A/s$$

$$= -2\times 10^{-2}\,Wb/s$$

Induced emf in Coil 2 (e_2)

$$e_2 = \left|N\frac{\partial \Phi_{21}(t)}{\partial t}\right| = 75t \times 2\times 10^{-2}\,Wb/s = 1.5V$$

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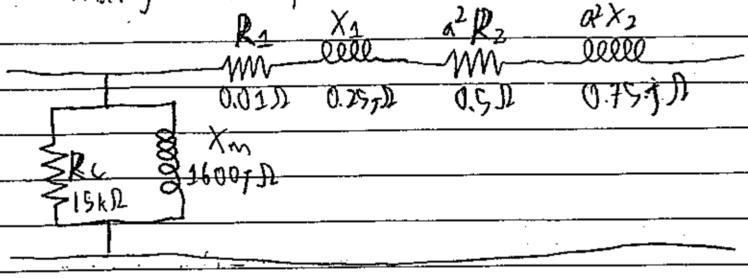
2) Primary side equivalent circuit :



$a = 10$

a) Primary Input Voltage at full load

i) 0.852 power factor leading

$$|I_{Lead}| = \frac{10000VA}{2300\ V} = \frac{1000}{23} A$$

$$I_{lead} = |I_{Lead}|\left[pf + \sin[\cos^{-1}(pf)]\right] = \frac{1000}{23}\left[0.852 + \sin[\cos^{-1}(0.852)]\right] A$$

$$= \left[\frac{852}{23} + 22.7627i\right] A$$

$$V_{1\,lead} = aV_2 + \left[R_1 + a^2R_2 + j(X_1 + a^2X_2)\right] I_{lead}$$

$$= 2300 + (0.51 + j)\left(\frac{852}{23} + 22.7627j\right)$$

$$= [2296.1295 + 48.6524j]\ V$$

$$= 2296.6449 \angle 1.21385^\circ\ V$$

$$|V_{1\,lead}| = 2296.6449\ V$$

ii) 0.852 power factor lagging

$$|I_{lag}| = |I_{lead}| = \frac{1000}{23} A$$

$$I_{lag} = |I_{lag}|\left[pf - \sin[\cos^{-1}(pf)]\right] = \frac{1000}{23}\left[0.852 - \sin[\cos^{-1}(0.852)]\right]$$

$$= \left[\frac{852}{23} - 22.7627i\right] A$$

$$V_{1\,lag} = aV_2 + \left[R_1 + a^2R_2 + j(X_1 + a^2X_2)\right] I_{lag} = 2300 + (0.51 + j)\left(\frac{852}{23} - 22.7627j\right)$$

$$= [2341.6549 + 25.4345j]\ V = 2341.79299 \angle 0.62231^\circ\ V$$

$$|V_{1\,lag}| = 2341.79299\ V$$

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2b) Voltage regulation

i) 0.852 power factor leading

$$VR_{lead} = \frac{|V_1 lead| - aV_2}{aV_2} = \frac{2296.6449 - 2300}{2300} \times 100\% = -0.145874\%$$

ii) 0.852 power factor lagging

$$VR_{lag} = \frac{|V_1 lag| - aV_2}{aV_2} = \frac{2341.7929 - 2300}{2300} \times 100\% = 1.81709\%$$

2c) Input Power and efficiency for Full load 0.852 pf lag

P_{out} lag $= VA \times pf = 100kVA \times 0.852 = 85200\,W$

$P_{cu-FL} = |I_{lag}|^2 (R_1 + a^2 R_2) = \left(\frac{1000}{23} A\right)^2 (0.51\Omega) = 964.0832W$

$P_{IRON} = \frac{|V_1 lag|^2}{R_C} = \frac{(2341.79299V)^2}{15000\Omega} = 365.5996\,W$

$P_{IN} = P_{out} + P_{cu-FL} + P_{IRON} = 85200W + 964.0832W + 365.5996W$
$= 86529.6828\,W$

$Eff = \frac{P_{out}}{P_{in}} = \frac{85200}{86529.6828} \times 100\% = 98.4633\%$

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3a) i) motor speed (n_m)

$f_{rotor} = s\, f_{sync}$

$s = \frac{f_{rotor}}{f_{sync}} = \frac{4Hz}{50Hz} \times 100\% = 8\%$

$n_{sync} = 120 \frac{f_{sync}}{pole} = 120 \times \frac{50}{6} = 1000\,rpm$

$n_m = (1-s)\, n_{sync} = (1-0.08) \times 1000\,rpm = 920\,rpm$

ii) P_{dev}, P_{RCL}, and effeciency

$T_{DEV} = 160\,N_m = \frac{P_{AG}}{\omega_{sync}} = \frac{P_{DEV}}{\omega_m}$

$P_{AG} = \omega_{sync} T_{dev} = 1000 \frac{2\pi}{60} rad/s * 160Nm = \frac{16000}{3}\pi W = 16755.16082 W$

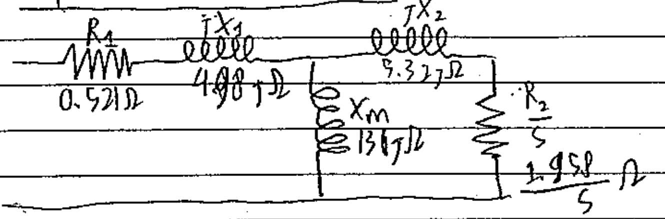
$P_{DEV} = (1-s) P_{AG} = (1-0.08)\, 16755.16082 W = 5120\pi W$
$= 16084.9544 W$

$P_{RCL} = P_{AG} - P_{DEV} = \frac{16000}{3}\pi W - 5120\pi W = \frac{640}{3}\pi W = 670.20643 W$

$P_{out} = P_{DEV} - P_{ROT} = 5120\pi W - 1200 W = 14884.3544 W$

$eff = \frac{P_{out}}{P_{in}} = \frac{14884.3544 W}{17555.1608 W} \times 100\% = 84.7862\%$

3b) Equivalent circuit:



$V_\phi = \frac{4160}{\sqrt{3}}$
$p = 4$ pole
$f = 60\,Hz$
$n_{sync} = 120 \times \frac{60}{4} = 1800\,rpm$
$n_m = 1725\,rpm$

$s = \frac{n_{sync} - n_m}{n_{sync}} = \frac{1800-1725}{1800} = \frac{1}{24}$

$\frac{R_2}{s} = \frac{1.958\Omega}{\frac{1}{24}} = 24 \times 1.958\,\Omega = 46.992\,\Omega$

$Z_{total} = R_1 + X_1 j + [X_m \,||\, (jX_2 + R_2/s)] = 0.521 + 4.98j + \left[\frac{(46.992 + 5.32j)\,136j}{46.992\Omega + 141.32j\Omega}\right]$

$= [39.7086 + 23.1305j]\,\Omega$

3 b) i) $\vec{I_1} = \frac{V_\phi}{Z_{total}} = \frac{\frac{4160}{\sqrt{3}} V}{[39.7086 + 23.1305j]\Omega} = [45.1613 - 26.3667j] A$

$= 52.2646 \angle -30.221° A$

Input Power Factor

Input power factor $= \cos(\angle \vec{I_1}) = \cos(-30.221°) = 0.8641$ lag

ii) Input Power

$V_\phi = \frac{V_{line}}{\sqrt{3}}$

$P_{IN} = 3 \cdot V_\phi \times |\vec{I_1}| \times pf = \sqrt{3} \cdot V_{line} |\vec{I_1}| pf$ (4)

$= \sqrt{3} \times 4160V \times 52.2646 A \times 0.8641 = 325406.0282 W$

iii) Output power

$P_{SCL} = |\vec{I_1}|^2 R_1 = 1423.1576 W$

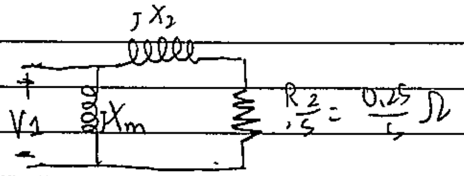
$P_{AG} = P_{IN} - P_{SCL} = 325406.0282 W - 1423.1576 W$
$= 323982.8706 W$

$P_{dev} = (1-s) = (1 - \frac{1}{24}) 323982.8706 W = 310483.5844 W$

$P_{out} = P_{Dev} - P_{ROT} = 310483.5844 W - 3500 W = 306983.5844 W$

c)
P = 6 pole
$f = 50 Hz$
$R_2 = 0.25 \Omega$
$\tau_{dev\,max} = 100 Nm$
$n_m = 875 rpm$

$R_1 = X_1 = 0 \Omega$
$n_{sync} = 120 \times \frac{50}{6} = 1000 rpm$



i) $S_{max} = \frac{n_{sync} - n_m}{n_{sync}} = \frac{1000 - 875}{1000} \times 100\% = 12.5\%$

For max. torque: $\left|\frac{R_2}{s}\right| = |X_2|$

Since $R_1 = 0$: Therefore
- $P_{SCL} = 0 W$
- $P_{IN} = P_{AG}$

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3c) i) $P_{AG} = |\vec{I_2}|^2 \frac{R_2}{s}$

$$|\vec{I_2}| = \sqrt{\frac{sP_{AG}}{R_2}} = \sqrt{\frac{0.125 \times \frac{10000}{3}\pi W}{0.25\Omega}} = \sqrt{\frac{5000}{3}\pi} A = 72.3601255 A$$

Since $R_1 = X_1 = 0$

$$\vec{Z_{TH}} = \frac{R_2}{s} + X_2 j = \frac{0.25}{0.125} + 2j = [2+2j]\Omega = 2\sqrt{2}\angle 45^\circ \Omega$$

Line Voltage $(\vec{V_1})$

$$|\vec{V_1}| = |\vec{Z_{TH}}||\vec{I_2}| = 72.3601255 \times 2\sqrt{2} = 204.6653416V$$

$$\vec{V_1} = 204.665416 \angle 0^\circ V$$

ii) $s' = 5\% = 0.05$

$$\vec{Z_{TH}}' = \frac{R_2}{s'} + X_2 j = \frac{0.25}{0.05} + 2j = 5+2j\,\Omega$$

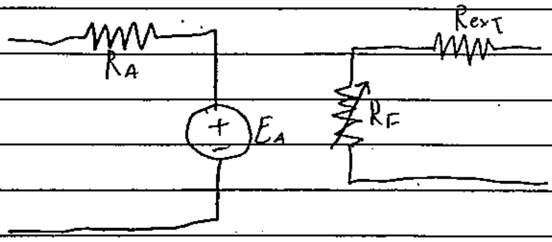
$$\vec{I_2}' = \frac{\vec{V_1}}{\vec{Z_{TH}}'} = \frac{204.665416V}{5+2j\,\Omega} = 38.005414\angle -21.80141^\circ$$

$$P_{AG}' = |I_2'|^2 \frac{R_2}{s'} = 38.005414^2 \times \frac{0.25}{0.05} = 7222.6573 W$$

Develop torque at $s' = 5\%$

$$\tau_{dev}' = \frac{P_{AG}'}{\omega_{sync}} = \frac{7222.6573W}{1000 \cdot \frac{2\pi}{60}} = 68.9156 Nm$$

4a) DC seperated Generator



$R_A = 0.28\,\Omega$
$R_F = 138\,\Omega$
$P_{ROT} = 500\,W$
$V_F = 138\,V$

i) $R_{ext\_min} = 0\,\Omega$

$R_{ext\_max} = 92\,\Omega$

$$I_{F\,MAX} = \frac{V_F}{R_F + R_{ext\_min}} = \frac{138\,V}{138\,\Omega + 0} = 1\,A$$

$$I_{F\,MIN} = \frac{V_F}{R_F + R_{ext\_max}} = \frac{138\,V}{138\,\Omega + 92\,\Omega} = 0.6\,A$$

Min and Max no-load terminal voltage at 1800 rpm

For no load $\rightarrow V_T = E_A$

$V_{T\,MAX} = E_A(I_{F\,MAX}) = 200\,V$

$V_{T\,MIN} = E_A(I_{F\,MIN}) = 150\,V$

ii) $I_A = 100\,A$

$R_{ext} = 0$

$$I_F = \frac{V_F}{R_F + R_{ext}} = \frac{138\,V}{138\,\Omega + 0\,\Omega} = 1\,A$$

$V_T = E_A(I_F) - I_A R_A = 200V - [100A * 0.28\,\Omega] = 172\,V$

$P_{IN} = P_{rot} + E_A(I_F) * I_A + V_F I_F = 500W + (200V * 100A) + (138V * 1A)$

$= 20638\,W$

$P_{out} = V_T I_A = 172\,V * 100A = 17200\,W$

$$\text{Effeciency} = \frac{P_{out}}{P_{IN}} = \frac{17200\,W}{20638\,W} = 83.34141\,\%$$

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a) iii) $P_{out} = 12200\,W$

$I_A = 100A$

$V_T = \frac{P_{out}}{I_A} = \frac{12200W}{100A} = 122V$

$E_A(1500\,rpm) = V_T + I_A R_A = 122V + (100A * 0.28\Omega) = 150V$

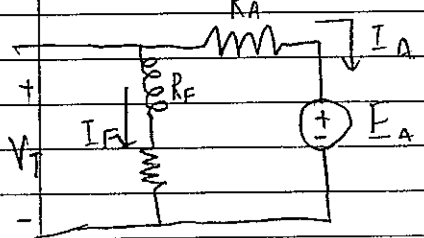
$E_A'(1800\,rpm) = \frac{n_m'}{n_m} \times E_A(1500\,rpm) = \frac{1800}{1500} \times 150V = 180V$

Rext' in the conditions

$I_F'(E_A') = 0.8A$

$R_{ext}' = \frac{V_F}{I_F'} - R_F = \frac{138}{0.8} - 138 = 34.5\Omega$

4b) DC shunt motor



$R_F = 108\Omega$

$R_A = 0.18\Omega$

$n_m = 880\,rpm$

$P_{OUT} = 63000\,W$

$eff = 88\%$

i) $P_{IN} = \frac{P_{out}}{eff} = \frac{63000\,W}{0.88} = 71590.9091$

$I_{IN} = \frac{P_{IN}}{V_{LINE}} = \frac{71590.9091\,W}{600\,V} = 119.3182\,A$

$I_A = I_{IN} - I_F = I_{IN} - \frac{V_{LINE}}{R_F} = 119.3182A - \frac{600V}{108\Omega} = 113.76263A$

$E_A(n_m) = V_T - I_A R_A = 600V - (113.76263A * 0.18\Omega)$

$= 579.5228V$

$P_{DEV} = E_A I_A = 579.5228V * 113.76263A = 65928.02743W$

Rotational losses

$P_{rot} = P_{DEV} - P_{OUT} = 65928.02743W - 63000W$

$= 2928.02743W$

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4b) ii) $\tau_{dev} = 608 Nm$

$P_{DEV} = \tau_{dev} * \omega_m = 608 Nm * 880 \frac{2\pi}{60} = \frac{53504}{3} \pi W$

(I) $\frac{53504}{3} \pi W = E_A I_A$

$$\underline{V_T = I_A R_A + E_A} \quad \times I_A$$

$$V_T I_A = I_A^2 R_A + E_A I_A$$

$$0 = I_A^2 R_A - V_T I_A + E_A I_A$$

$$0 = 0.18 I_A^2 - 600 I_A + \frac{53504}{3} \pi$$

$$I_A = \frac{600 \pm \sqrt{600^2 - 4 * \frac{53504}{3} \pi * 0.18}}{0.36}$$

$$I_A = \frac{600 + \sqrt{600^2 - 4 * \frac{53504}{3} \pi * 0.18}}{0.36}$$

$= 3237.177 A$

$\boxed{\text{to High} \\ \text{Not possible}}$

$$I_A = \frac{600 - \sqrt{600^2 - (4 * \frac{53504}{3} \pi * 0.18)}}{0.36}$$

$= 96.1568 A$ ✓