UNIVERSITY OF ESWATINI

SUPPLEMENTARY EXAMINATION

2021

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

TITLE OF PAPER: POWER ELECTRONICS AND ELECTRIC DRIVES

COURSE CODE : EEE554

TIME ALLOWED: THREE HOURS

INSTRUCTIONS:

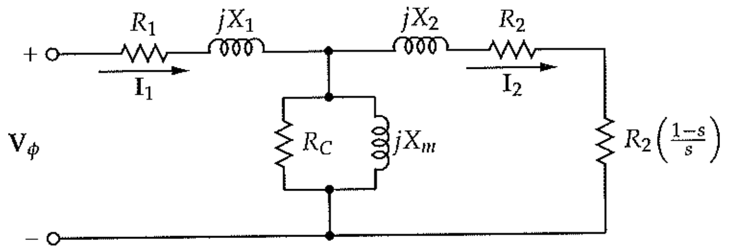
1. There are four questions in this paper. Answer ALL questions. Each question carries 25 marks.

2. If you think that not enough data has been given in any question you may assume any reasonable values.

THIS PAPER SHOULD NOT BE OPENED UNTIL PERMISSION HAS BEEN GIVEN BY THE INVIGILATOR

Question 1. [25]

(a) From the per phase equivalent circuit diagram for a three-phase induction machine shown below, explain what each of the following components in the equivalent circuit is modeling.



i. R_1 [2]

ii. X_1 [2]

iii. R_C [3]

iv. X_M [2]

v. X_2 [2]

vi. R_2 [2]

vii. $R_2\left(\frac{1-s}{s}\right)$ [3]

(b) What conditions are required in order to connect a synchronous machine to an infinite bus? [4]

(c) If we ignore the armature resistance of a synchronous machine, prove from a phasor diagram during generator operation, that the developed power of the synchronous machine can be given by the following equation: [5]

$$P_{\text{conv}} = \frac{3V_\phi E_A}{X_S}\sin\delta$$

Question 2. [25]

(a) With the supply voltage, V_ϕ, as reference, draw the typical phasor diagram for: (**N.B.**Show clearly the supply voltage, V_ϕ, the induced voltage, E_A, the line current, I_A, the voltage across the synchronous reactance, $jX_S I_A$, as well as the power angle, δ.)

i. a synchronous motor that is supplying reactive power to the supply. [3]

ii. a synchronous motor that is under excited. [3]

iii. a synchronous generator that is over excited. [3]

iv. a synchronous generator that is drawing reactive power from the supply. [3]

(b) This question concerns a 32 pole, 2.0 MVA, 3.3 kV wye connected three-phase 50 Hz synchronous motor with a synchronous reactance of 1.8 Ω/phase. For this question all losses can be ignored and hence also the armature resistance, R_A. Furthermore, we can assume that $E_A \propto I_F$.

i. Calculate the synchronous speed of the motor when it is connected to the 50 Hz supply. [3]

ii. The motor is synchronised to an infinite 3.3 kV, three-phase, 50 Hz bus. With the DC field current set at 125% of the value that it was when the synchronous motor was synchronised with the supply, the mechanical load on the motor is increased to 1.5 MW. Calculate the torque angle, δ, of the motor for this operating condition. [5]

iii. Calculate the magnitude of the supply line current for (ii.) above. [3]

iv. Calculate the power factor of the machine for (ii.) above and state whether it is leading or lagging. [2]

Question 3. [25]

The equivalent circuit parameters of a 37 kW, 400 V three-phase, wye-connected, 50 Hz, 1453 r/min squirrel-cage induction motor are shown in the Table below.

R_1	X_1	X_2	R_2	X_M
0.120 Ω	0.170 Ω	0.170 Ω	0.115 Ω	12.50 Ω

The core – and rotational losses of the induction motor together are equal to 875 W.

(a) From the name plate information, work out how many poles this induction motor has as well as what the synchronous speed of the induction motor would be when it is connected to a 50 Hz supply. [2]

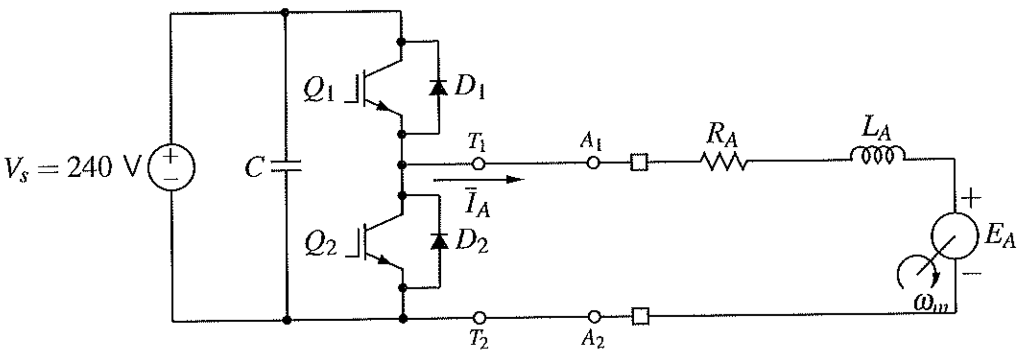
(b) Calculate the starting current (at standstill) that the induction motor would drawn from a 400 V, 50 Hz supply. [5]

(c) Calculate the pullout (or peak developed) torque of the induction motor when it is connected to a 400 V, 50 Hz supply. [9]

(d) The motor is now connected to a three-phase variable speed drive (VSD). The VSD is programmed to control this three-phase induction motor using the constant V/f ("volts-per-hertz") control principle. If the motor is driven at 400 V, 50 Hz by the VSD and the speed of the motor is 1460 r/min, calculate braking torque developed by the motor when the frequency output of the VSD is suddenly reduced to 45 Hz whilst the motor's speed remains constant at 1460 r/min. [9]

Question 4. [25]

A 240 V, 20 A permanent magnet DC servo motor has a motor constant, K_m=1.26, an armature resistance, R_A=2.56 Ω, an armature inductance, L_A=12 mH and is connected to a two-quadrant DC-DC converter as shown below.



(a) If the "switches" and diodes of the two-quadrant converter were considered to be ideal, calculate the duty cycle necessary so that the motor will be able to deliver torque of 25 Nm to a load at 750 r/min, if we were only to take into account the voltage drop across the two brushes of the motor. Assume that the voltage drop across each brush is equal to 1 V. [9]

(b) Calculate the duty cycle required for the same torque and speed values as in (a) above, if we were also to consider the 2.2 V "ON"-voltage of the IGBT "switches" of the two-quadrant converter as well as the 1.2 V "ON"-voltage of the diodes in anti-parallel with each IGBT. [4]

(c) Calculate and sketch the ripple armature current of the motor for the operating condition as in (b) above, if the IGBT's of the converter are switched at 25 kHz. [9]

(d) For the operating condition as in (b) above calculate the ripple torque component of the developed torque. [3]

Formulas

$$\sin(\alpha+\beta) = \sin\alpha\cos\beta + \cos\alpha\sin\beta$$
$$\sin(\alpha-\beta) = \sin\alpha\cos\beta - \cos\alpha\sin\beta$$
$$\cos(\alpha+\beta) = \cos\alpha\cos\beta - \sin\alpha\sin\beta$$
$$\cos(\alpha-\beta) = \cos\alpha\cos\beta + \sin\alpha\sin\beta$$
$$\oint_S \mathbf{B}\cdot d\mathbf{a} = 0$$
$$\int_S \mathbf{B}\cdot d\mathbf{a} = \phi$$
$$\oint_C \mathbf{H}\cdot d\mathbf{l} = Ni = \mathcal{F}$$
$$\mathbf{B} = \mu\mathbf{H}$$

$$\mathcal{F} = \phi\mathcal{R}$$
$$\mathcal{R} = \frac{\ell}{\mu A}$$

$$\mu = \mu_0\mu_r$$
$$\mu_0 = 4\pi\times 10^{-7}\ \mathrm{H/m}$$

$$\phi = \frac{2lrB_{peak}}{p}$$
$$\mu_R = \frac{B_r}{H_c'}$$
$$(Ni)_{equiv} = -H_c'd$$
$$\mathcal{R}_{equiv} = \frac{d}{\mu_R A_m}$$

$$L = \frac{N^2}{\mathcal{R}}$$

$$\lambda = N\phi$$

$$L = \frac{\lambda}{i}$$
$$e = \frac{d\lambda}{dt}$$

$$\begin{bmatrix}\lambda_1\\ \lambda_2\end{bmatrix} = \begin{bmatrix}L_{11} & L_{12}\\ L_{21} & L_{22}\end{bmatrix}\begin{bmatrix}i_1\\ i_2\end{bmatrix}$$

$$T = -\frac{\pi}{2}p^2\Phi_{sr}F_r sin\delta_r$$
$$\theta_{me} = p\theta_m$$
$$\omega_e = p\omega_m$$
$$\omega_m = \frac{2\pi}{60}n_m$$
$$p = \frac{\text{poles}}{2}$$
$$n_s = \frac{60f_e}{p}$$
$$s = \frac{n_s - n_m}{n_s}$$
$$P_m = \omega_m T_m$$

$$E_a = K_f i_F \omega_m$$
$$T_m = K_f i_F I_a$$
$$T_b = b_m\omega_m$$
$$T_J = J_m\frac{d\omega_m}{dt}$$

$$I_{base_{1\phi}} = \frac{S_{base_{3\phi}}}{3V_{base_{1\phi}}}$$
$$Z_{base} = \frac{V_{base_{1\phi}}}{I_{base_{1\phi}}}$$

Formulas

$$P_m = \frac{3V_\phi E_a}{X_s} sin\delta$$

$$I_a = \sqrt{\frac{i_d^2 + i_q^2}{2}}$$

$$T_{mech} = \frac{3pL_{af}i_F i_q}{2}$$

$$\lambda_{a(rms)} = \frac{V_a}{\omega_e} = \sqrt{\frac{\lambda_d^2 + \lambda_q^2}{2}}$$

$$\lambda_d = L_d i_d + L_{af} i_F$$

$$\lambda_q = L_q i_q$$

$$\sqrt{2}E_{af} = \omega_e L_{af} i_F$$

$$P_{gap} = 3\frac{R_2}{s} I_2^2$$

$$P_{rotor} = 3R_2 I_2^2$$

$$P_{mech} = P_{gap} - P_{rotor}$$

$$T_{mech} = 3\frac{poles}{2\omega_e} I_2^2 R_2 / s$$

$$P_{shaft} = P_{mech} - P_{rot}$$