Charles Darwin University

Final Examination

Family Name	
Given Name/s	
Student Number	
Teaching Period	Semester 2, 2018

ENG224 – Electrical Machines and Power Systems	DURATION	
	Reading Time:	10 minutes
	Writing Time:	180 minutes

INSTRUCTIONS TO CANDIDATES

1. This examination is worth 50% of the total assessment for this unit.
2. Read the questions carefully before attempting. Attempt all questions.
3. Questions are not of equal value.
4. In order to explain your work, draw suitable (circuit) diagrams whenever possible.
5. Highlight the final answers.
6. Don't forget the units. Absence of a unit may cost you some credit.

EXAM CONDITIONS

You may begin writing from the commencement of the examination session. The reading time indicated above is provided as a guide only.

This is a CLOSED BOOK examination

Any non-programmable calculator is permitted

No handwritten notes are permitted

No dictionaries are permitted

ADDITIONAL AUTHORISED MATERIALS	EXAMINATION MATERIALS TO BE SUPPLIED
No additional printed material is permitted	1 x 20 Page Book 1 x Scrap Paper

THIS EXAMINATION IS PRINTED

DOUBLE-SIDED.

THIS PAGE HAS BEEN INTENTIONALLY

LEFT BLANK.

QUESTION 1 **(10 marks)**

Answer the following question briefly. Long discussion is discouraged. (1 mark for each question)

Q1.1 What is an auto transformer? Where is it used?
Q1.2 Why are steel cores of ac machines are always laminated?
Q1.3 Why is a transformer more efficient than an induction motor?
Q1.4 Why are not dc motors used as much as ac motors?
Q1.5 Can an induction motor have brushes like a dc motor?
Q1.6 Can two transformers be used to supply a three-phase load? Discuss briefly.
Q1.7 We know that electrical impedances are measured in ohms. But when a transformer name plate declares its impedance to be 10%. What does it actually mean?
Q1.8 Looking at the outside of a large power transformer, how can you identify the high and low voltage sides?
Q1.9 which side of a transformer (high or low voltage) would you expect the tap-changer to be installed and why?
Q1.10 The core with the windings of a transformer are immersed in a liquid. What is this liquid called and what is its important characteristic?

QUESTION 2 **(10 marks)**

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

Q2.1 Is the machine functioning as a generator or a motor? Explain. (1 mark)
Q2.2 Determine the armature resistance. (1 mark)
Q2.3 Determine the power loss in the armature circuit. (1 mark)
Q2.4 Determine the electromagnetic torque developed in the machine. (2 marks)
Q2.5 If the load connected to the machine is accidentally thrown off, what voltage will the machine generate? (1 mark)
Q2.6 Determine the speed at which the machine will rotate in order to develop the above voltage (see **Q2.5**). Assume that there is no armature reaction in the machine. (4 marks)

Go to next page for Question 3

QUESTION 3 (15 marks)

A three phase, 14 kilovolt, 10 MVA, 60 Hz, 2 pole, 0.85 power factor lagging, star connected, synchronous generator has a synchronous reactance of 20 ohms per phase and an armature resistance of 2 ohms per phase. The generator is connected to a 14 kV system.

Q3.1 Determine the excitation voltage at the rated condition of operation. (2 marks)

Q3.2 Draw a neat phasor diagram for this condition. (2 marks)

Q3.3 Determine the torque angle at this condition. (2 marks)

For the remaining parts of this question, assume armature resistance to be zero.

Q3.4 If the field current is kept constant, determine the maximum power that the generator can supply. (2 marks)

For the above condition of maximum power generation,

Q3.5 Determine the generator current. (2 marks)

Q3.6 Determine the generator power factor. (2 marks)

Q3.7 Draw a phasor diagram. (3 marks)

Go to next page for Question 4

QUESTION 4 (15 marks)

Q4.1 Draw the torque speed characteristic of a three-phase induction motor.
Label all the significant features. (1 mark)

Q4.2 How can the maximum torque point be moved along the speed axis? (1 mark)

Q4.3 Why would anybody like to do that (move the maximum torque to a different speed)? (1 mark)

Q4.4 Super impose the torque speed characteristic of a single-phase induction motor on the graph of **Q4.1**. (1 mark)

Q4.5 House hold ceiling fans often have a capacitor inside. Why? (1 mark)

Q4.6 Squirrel cage induction motors are said to be rugged. What does that mean? (1 mark)

Q4.7 A three phase, 280 volt, 60 Hz, 20 hp, 4 pole, induction motor has the following equivalent circuit parameters.

R_1 = 0.12 ohm; R_2' = 0.1 ohm;
$X_1 = X_2'$ = 0.25 ohm;
X_m = 10 ohms.
The rotational loss is 400 watts.

For a slip of 5%, determine the following.

Q4.7.1 The motor speed in rpm. (1 mark)
Q4.7.2 The motor current. (1 mark)
Q4.7.3 The stator copper loss. (1 mark)
Q4.7.4 The airgap power. (1 mark)
Q4.7.5 The rotor power loss (1 mark)
Q4.7.6 The shaft power. (1 mark)
Q4.7.7 The developed torque. (1 mark)
Q4.7.8 The efficiency. (1 mark)
Q4.7.9 Roughly, how much would be the maximum torque that this machine can develop? (1 marks)

<u>End of Questions</u>

FORMULAS

(Symbols have their usual meanings in the context of the particular formula)

MAGNETIC CIRCUITS: $L = \lambda/i = N^2/\Re = \mu N^2 A/d$; $Ni = \sum H\ell = \varphi\Re$; $B = \mu H = \mu Ni/\ell$; $\mu = \mu_r \mu_0$; $\Re = \ell/\mu A$

TRANSFORMERS: $\frac{V_1}{V_2} = \frac{I_2}{I_1} = \frac{N_1}{N_2}$; $Z_1 = \left(\frac{N_1}{N_2}\right)^2 Z_2$; $R_c' = \frac{V_{oc}}{I_{oc}\cos\theta}$; $X_m = \frac{V_{oc}}{I_{oc}\sin\theta}$; $\cos\theta = \frac{P_{oc}}{V_{oc} I_{oc}}$;

$$\eta = \frac{V_2' I_2' \cos\theta}{V_2' I_2' \cos\theta + P_c + R_{eq}'(I_2')^2} \times 100\% \quad \eta_{AD} = \frac{\text{Energy output over 24 hours}}{\text{Energy input over 24 hours}} \times 100\%$$

$$\text{Regulation} = \frac{\text{No load voltage} - \text{Full load voltage}}{\text{Full load voltage}} \times 100$$

INDUCTION MACHINES: (Torque and power are given on a per phase basis)

$n = 120\frac{f}{p}$; $s = \frac{(n_s - n)}{n_s}$; $f_2 = sf_1$; $E_{rms} = 4.44 f N_{ph} \varphi_p K_w$

$$V_{th} = \frac{X_m}{\sqrt{R_1^2 + (X_1 + X_m)^2}} V_1; \quad R_{th} \cong \left(\frac{X_m}{X_1 + X_m}\right)^2 R_1 \quad X_{th} \cong X_1$$

$P_{mech} = T_{mech}\,\omega_{mech} = (1-s)P_{air\_gap}$; Ideal Efficiency = 1-s;

$$T_{mech} = \frac{1}{\omega_s} I_2'^2 \frac{R_2'}{s} = \frac{1}{\omega_s} \frac{V_{th}^2}{(R_{th} + R_2'/s)^2 + (X_{th} + X_2')^2} \frac{R_2'}{s}; \quad P_{air\_gap} = I_2'^2 \frac{R_2'}{s}$$

$$s_{Tmax} = \frac{R_2'}{\sqrt{R_{th}^2 + (X_{th} + X_2')^2}}; \quad T_{max} = \frac{1}{2\omega_s} \frac{V_{th}^2}{R_{th} + \sqrt{R_{th}^2 + (X_{th} + X_2')^2}}$$

DC MACHINES: $K_a = \frac{Zp}{2\pi a}$; $E_a = K_a \varphi\omega$; $T = K_a \varphi I_a$; $P_{out} = E_a I_a = T\omega$; La=p wound.

ALTERNATORS: $E_f \propto I_f$ $\quad E_f = V_t + jI_a X_s \quad E_f = V_t + I_a R_a + jI_d X_d + jI_q X_q$

$$P = \frac{|V_t||E_f|}{|Z_s|}\cos(\theta_s - \delta) - \frac{|V_t|^2}{|Z_s|}\cos\theta_s \quad Q = \frac{|V_t||E_f|}{|Z_s|}\sin(\theta_s - \delta) - \frac{|V_t|^2}{|Z_s|}\cos\theta_s$$

$E_f = V_t\cos\delta \pm I_d X_d$, $I_a = |I_q| - j|I_d|$ and $V_t = |V_t|\angle{-\delta}$

$$P = \frac{|V_t||E_f|}{|X_d|}\sin\delta + \frac{|V_t|^2 (X_d - X_q)}{2X_d X_q}\sin 2\delta \quad Q = \frac{|V_t||E_f|}{|X_d|}\cos\delta + |V_t|^2 \left|\frac{\sin^2\delta}{X_q} + \frac{\cos^2\delta}{X_d}\right|$$

PER UNIT SYSTEM: $Z_{pu} = \frac{Z_{ohm}}{Z_{base}}$; $Z_{base} = \frac{(kV_{base})^2}{MVA_{base}}$; $Z_{pu2} = Z_{pu1} \times \frac{S_{base2}}{S_{base1}} \times \frac{kV_{base1}^2}{kV_{base2}^2}$

$S_{pu} = kV_{pu}\, kA_{pu}$ (no √**3**); $kA_{pu} = \frac{MVA_b}{\sqrt{3}\ kVA_b}$;

OTHERS: $S = \sqrt{3} V_L I_L$; 1 horse power = 746 watts.