Charles Darwin University

Final Examination

Family Name	
Given Name/s	
Student Number	
Teaching Period	Semester 2, 2017

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

INSTRUCTIONS TO CANDIDATES

EXAM CONDITIONS

<u>You may begin writing from the commencement of the examination session.</u> 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.

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QUESTION 1 (10 marks)

Answer the following questions in plain English, without using any equations or formulas. Answers should be brief and to-the-point. (2 marks each)

Q1.1 In the problems of magnetic circuits, an air gap is very often included. What is the practical significance of this air gap?

Q1.2 Why is a transformer more efficient than, for example, an induction motor?

Q1.3 Is the magnetic circuit (rotor and stator) of a dc machine not laminated?

Q1.4 What is the reason for most transmission system being AC?

Q1.5 We talk about friction and windage losses in machines. What is this windage loss and how do you measure it?

QUESTION 2 (10 marks)

A 20-kVA, 50-Hz, 2000/200-volt distribution transformer has leakage impedance of 0.42 + j 0.52 ohms in the high voltage winding and 0.004 + j 0.005 ohm in the low voltage winding. At rated voltage and frequency, the shunt branch admittance (note: not impedance) is 0.002 – j 0.015 siemens when seen from the low voltage side. Draw the equivalent circuit of the transformer referred to the high voltage side.

QUESTION 3 (10 marks)

A 1-MW, three-phase, star connected, 3.3-kV, 24-pole, 50-Hz synchronous motor has a synchronous reactance of 3.24 ohms per phase. The armature resistance may be ignored. This motor is energized from 3.3-kV infinite bus bars. The field excitation is adjusted until unity power factor at rated load is achieved. Compute the maximum power and torque that the motor can deliver with the excitation remaining unchanged.

QUESTION 4 (5 marks)

Draw the speed-torque characteristic of a shunt dc motor with torque in the horizontal axis and answer the following questions.

Q4.1 Does the characteristic indicate a constant-speed machine? Discuss.. (1 mark)

Q4.2 On the same graph, you wish to draw the characteristic of a differential compound dc motor with the same no-load speed as the separately excited motor. Does this characteristic go above or below the characteristic of the shunt motor? Explain.. (4 marks)

QUESTION 5 **(15 marks)**

The one-line diagram of a small three phase power system is shown in Figure 5 below. Load and equipment data are also given in the table following the figure. Determine the component impedances in per unit including the load. Take a common base of 100 MVA and 22 kV at the generator terminals.

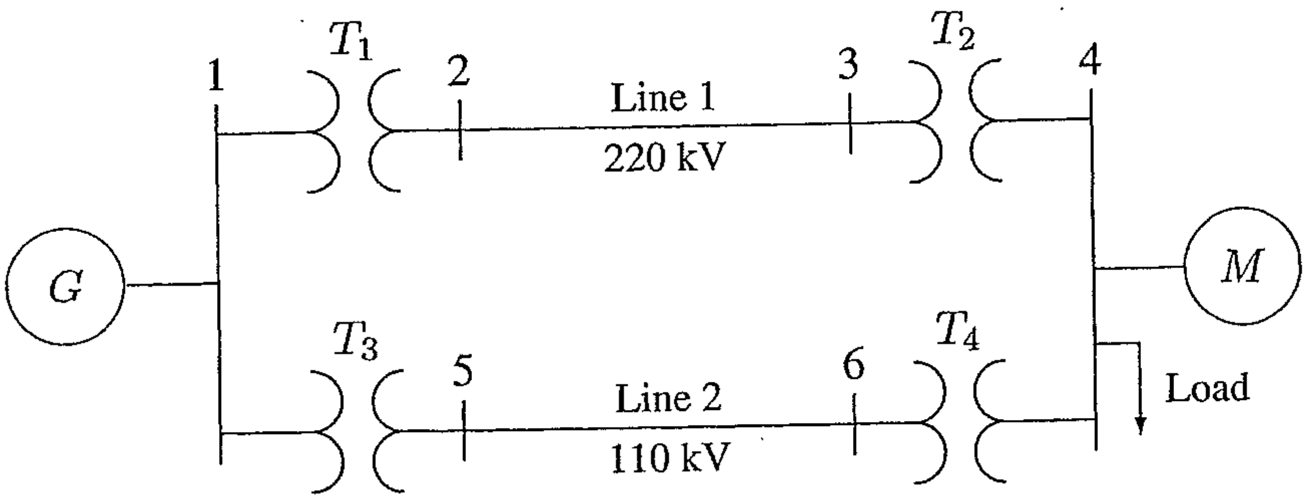

Figure 5 (Ref. Hadi Saadat, Power System Analysis, McGraw Hill,2002.)

System Component	Power rating (MVA)	Voltage rating (kV)	Reactance (%)
Generator, G	90	22	18
Transformer, T_1	50	22/220	10
Transformer, T_2	40	220/11	6
Transformer, T_3	40	22/110	6.4
Transformer, T_4	40	110/11	8
Motor, M	66.5	10.45	18.5
Line data			
Line 1			48.4 ohms
Line 2			65.43 ohms
Load data			
Load	57	10.45	0.6 pf lagging

End of questions.

FORMULAS

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

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

$\mu = \mu_r \mu_0$; $\Re = \lambda/\mu A$

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)

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

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

$P_{mech} = T_{mech}\, \omega_{mech} = (1-s)P_{air\_gap}$; 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: $E_f \propto I_f$ $\quad E_f = V_t + jI_a X_s$ $\quad E_f = V_t + I_a R_a + jI_d X_d + jI_q X_q$

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

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

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

PER UNIT SYSTEM: $Z_{pu} = \frac{Z_{ohm}}{Z_{base}}$; $Z_{base} = \frac{(kV_{base})^2}{MVA_{base}}$;

$S_{pu} = kV_{pu}\ kA_{pu}$ (no √**3**); $kA_{pu} = \frac{MVA_b}{\sqrt{3}\ kVA_b}$; $Z_{pu2} = Z_{pu1} \times \frac{S_{base2}}{S_{base1}} \times \frac{kV^2_{base1}}{kV^2_{base2}}$

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