Charles Darwin University

Final Examination

Family Name	
Given Name/s	
Student Number	
Teaching Period	Semester 1, 2019

ENG424 – Power Engineering	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.
3. Attempt all questions. 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.

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QUESTION 1 (15 MARKS)

Briefly answer the following questions.

Q1.1 What is flux linkage? What is its unit? Use plain English, not equations. **(1 mark)**

Q1.2 What is a power station? **(1 mark)**

Q1.3 Power factor is the ratio of two quantities. What are they? **(1 mark)**

Q1.4 How does a power transformer differ from a current or potential transformer? **(1 mark)**

Q1.5 Power utilities around the world generate ac voltage in sinusoidal form. Why? **(1 mark)**

Q1.6 Consider the numbers 1, 4, 13, 0, -3 and -7. Determine their root mean square value. **(1 mark)**

Q1.7 What is the difference between core type and shell type transformers? **(1 mark)**

Q1.8 What is eddy current loss in a transformer? Where does it occur? **(1 mark)**

Q1.9 Do you also have eddy current losses in other machines such as induction motors and dc motors?

(1 mark)

Q1.10 Consider a 5A ammeter is connected to the secondary side of a 100/5A current transformer (CT) in order to measure the current of the circuit. Safety considerations require that the CT has to be short circuited (or the primary circuit switched off) during a replacement of the ammeter. Explain why this is needed. **(1 marks)**

Q1.11 In a balanced three phase system, the magnitude of the line-to-line voltages roughly equal 1.732 times the magnitude of the phase voltages. Prove this statement by using a phasor diagram. **(2 marks)**

Q1.12 What is root mean square value of a sinusoidal voltage? Prove that this is roughly 70.7% of its maximum value. **(3 marks)**

GO TO THE NEXT PAGE FOR QUESTION 2

QUESTION 2 (15 MARKS)

A single-phase power system is shown in Figure 2 below. The power source feeds a 100-kVA, 14/2.4-kV transformer through a feeder impedance of 38.2 + j 140 ohms. The transformer equivalent series impedance referred to the low voltage side is 0.10 + j 0.40 as shown. The load on the transformer is 90 kW at a lagging power factor of 0.8 and at a voltage of 2400 volts.

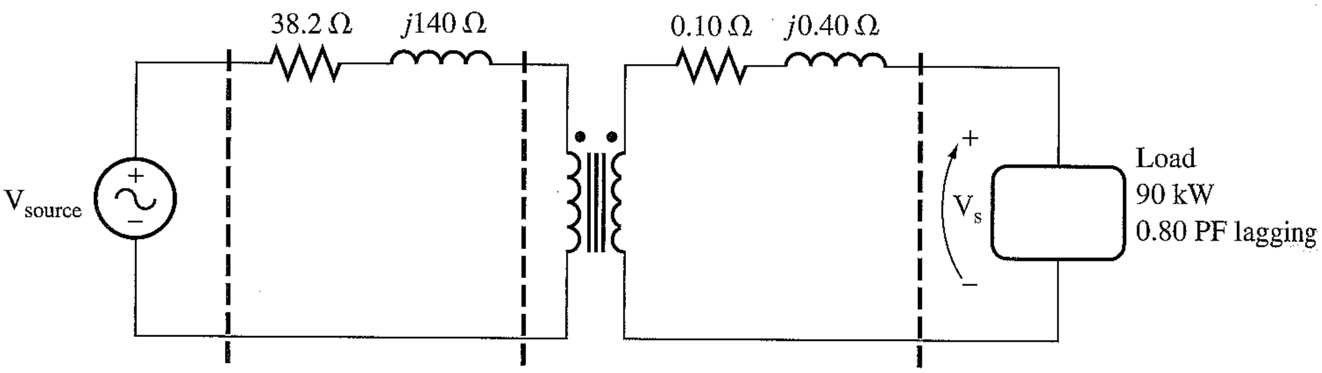

Figure 2: A simple power system for the Question 2.

Q2.1 What will be the voltage at the source. **(10 marks)**

Q2.2 What will be the voltage regulation of the transformer? **(3 marks)**

Q2.3 What is the efficiency of the power system? **(2 marks)**

QUESTION 3 (10 MARKS)

When a 50-kVA, 3-phase, 440-volt, 60 Hz synchronous generator is driven at its rated speed, it is found that the open circuit terminal voltage is 440 volts line-to-line with a field current of 7 amps. When the stator terminals are shorted together, rated current is produced by a field current of 5.5 amps.

Q3.1 Calculate the synchronous reactance of the machine. **(8 mark)**

Q3.2 Calculate the synchronous reactance in per unit based on machine ratings. **(2 mark)**

QUESTION 4 (10 MARKS)

Write short notes on the following machines. **(2 marks each)**

Q4.1 Universal motors

Q4.2 Brushless DC machines

Q4.3 Stepper motors

Q4.4 Capacitor start motors

Q4.5 Wound-rotor motors

FORMULAS

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

MAGNETIC CIRCUITS

$$L = \lambda/i = N^2/\Re = \mu N^2 A/d \,;$$

$$Ni = \sum H\lambda = \varphi\Re \,;\; B = \mu H = \mu Ni/\lambda \,;\; \mu = \mu_r \mu_0 \,;\quad \Re = \lambda/\mu A$$

TRANSFORMERS

$$\frac{V_P(t)}{V_S(t)} = \frac{I_S(t)}{I_P(t)} = \frac{N_P}{N_S} = a \;;\qquad Z_2' = a^2 Z_2 \,;\; R_c' = \frac{V_{oc}}{I_{oc}\cos\theta} \,;\; X_m = \frac{V_{oc}}{I_{oc}\sin\theta} \,;\; \cos\theta = \frac{P_{oc}}{V_{oc} I_{oc}} \,;$$

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{V_S I_S \cos(\theta_S)}{V_S I_S \cos(\theta_S) + P_{CORE} + P_{CU}} \times 100\%$$

$$\eta_{AD} = \frac{\text{Energy output over 24 hours}}{\text{Energy input over 24 hours}} \times 100\%$$

$$Voltage\,\mathrm{Re}\,gulation = \frac{|V_{S,NL}| - |V_{S,FL}|}{|V_{S,FL}|} \times 100\%$$

MACHINE FUNDAMENTALS

$\boldsymbol{\tau} = \boldsymbol{r} \times \boldsymbol{F};$ $\mathbf{F} = \mathbf{i}\,(\boldsymbol{\ell} \times \mathbf{B})$; $\mathbf{e}_{ind} = (\mathbf{v} \times \mathbf{B}).\boldsymbol{\ell}$; $\mathbf{E}_A = 4.44\, f\, N\, \varphi_{max}$

ALTERNATORS

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

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

$$P_{CONV} \;;\; P_{OUT} = \frac{3V_\phi E_A \sin(\delta)}{X_S} \;; \qquad \tau_{ind} = \frac{3V_\phi E_A \sin(\delta)}{\omega_m X_S}$$

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

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

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

INDUCTION MACHINES

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

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

$$slip,\ s @ \frac{n_{slip}}{n_{sync}} = \frac{n_{sync} - n_m}{n_{sync}} = 1 - \frac{n_m}{n_{sync}}$$

$$\boldsymbol{V}_{TH} = \boldsymbol{V}_\phi \frac{jX_M}{R_1 + j(X_1 + X_M)};\quad Z_{TH} = R_{TH} + jX_{TH} = \frac{jX_M(R_1 + jX_1)}{R_1 + j(X_1 + X_M)};\quad \tau_{ind} = \frac{3}{\omega_{sync}} I_2^2 \left(\frac{R_2}{s}\right);$$

$$\tau_{ind} = \frac{3V_{TH}^2}{\omega_{sync}} \frac{R_2/s}{\left(R_{TH} + R_2/s\right)^2 + \left(X_{TH} + X_2\right)^2} \quad s_{max} = \frac{R_2}{\sqrt{R_{TH}^2 + \left(X_{TH} + X_2\right)^2}}$$

$$\tau_{max} = \frac{3V_{TH}^2}{2\omega_{sync}\left[R_{TH} + \sqrt{R_{TH}^2 + \left(X_{TH} + X_2\right)^2}\right]}$$

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

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

$$s_{T max} = \frac{R_2'}{\sqrt{R_{th}^2 + (X_{th} + X_2')^2}};\quad T_{max} = \frac{1}{2\omega_s} \frac{V_{th}^2}{R_{th} + \sqrt{R_{th}^2 + (X_{th} + X_2')^2}}$$

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.

OTHERS

$S = \sqrt{3} V_L\, I_L$; $Z_{pu} = \frac{Z_{ohm}}{Z_{base}}$; $Z_b = \frac{(kV_b)^2}{MVA_b}$;

$S_{pu} = kV_{pu}\, kA_{pu}$ (no √**3**); $kA_{pu} = \frac{MVA_b}{\sqrt{3}\, kVA_b}$; $Z_{pu2} = Z_{pu1} \times \frac{S_{b2}}{S_{b1}} \times \frac{kV_{b1}^2}{kV_{b2}^2}$