IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2014

EEE PART II: MEng, BEng and ACGI

Corrected Copy

POWER ENGINEERING

15:05

Q. 3A iv

Wednesday, 11 June 2:00 pm

Time allowed: 2:00 hours

There are THREE questions on this paper.

Answer ALL questions.

Q1 carries 40% of the marks. Questions 2 and 3 carry equal marks (30% each).

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : T.C. Green
Second Marker(s) : B. Chaudhuri

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Information for Candidates

Switch-Mode Power Supplies

Voltage ratio equations for buck SMPS $\frac{V_o}{V_i} = \delta$ or $\frac{V_O}{V_I} = \frac{1}{1 + \frac{2fLI_O}{V_I \delta^2}}$

Voltage ratio equations for boost SMPS $\frac{V_o}{V_i} = \frac{1}{1-\delta}$ or $\frac{V_o}{V_i} = \frac{1}{1 - \frac{V_i \delta^2}{2fLI_i}}$

Three-Phase Systems

Line Voltages and Current

Star $V_L = \sqrt{3}\, V_P \quad I_L = I_P$ Delta $V_L = V_P \quad I_L = \sqrt{3}\, I_P$

Power
$$P_{3\Phi} = 3\, V_P I_P \cos(\phi)$$
$$= \sqrt{3}\, V_L I_L \cos(\phi)$$

Induction Machines

$$\omega_S = \frac{\omega_E}{P} \qquad s = \frac{\omega_S - \omega_R}{\omega_S} \qquad T_{em} = \frac{3\, I_R'^2\, R_R'}{\omega_R}\left(\frac{1-s}{s}\right)$$

Photovoltaic Systems

$$I_{PV} = I_{Ph} - I_{AK} - I_{Sh} \qquad I_{AK} = I_0\left[e^{\frac{V_{PV} + I_{PV} R_S}{K_I v_T}} - 1\right]$$

Power Flow in Lines and Cables

Cable Parameters

$$R'_{LF} = \frac{1}{\sigma_C \pi r_C^2} + \frac{1}{\sigma_C 2\pi r_O t_O} \quad L' = \frac{\mu_0}{2\pi}\ln\left(r_O / r_C\right) \quad C' = \frac{2\pi\varepsilon_0\varepsilon_{RI}}{\ln\left(r_O / r_C\right)} \quad G' = \frac{2\pi\sigma_I}{\ln\left(r_O / r_C\right)}$$

OHL Parameters (approximate form)

$$R'_{LF} = \frac{2}{\sigma_C \pi r_C^2} \quad L' = \frac{\mu_0}{\pi}\ln\left(d / r_C\right) \quad C' = \frac{\pi\varepsilon_0\varepsilon_{RI}}{\ln\left(d / r_C\right)} \quad G' = \frac{\pi\sigma_I}{\ln\left(d / r_C\right)}$$

Power Flow (full form)

$$P_S = \frac{V_S^2}{Z_{SR}}\cos(\theta) - \frac{V_S V_R}{Z_{SR}}\cos(\theta + \delta)$$

$$Q_S = \frac{V_S^2}{Z_{SR}}\sin(\theta) - \frac{V_S V_R}{Z_{SR}}\sin(\theta + \delta)$$

Voltage Drop (approximate form)

$$\Delta V = |V_S| - |V_R| \approx \frac{RP_S + XQ_S}{|V_S|}$$

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1. This question covers several topics and all parts should be attempted.

a) Describe the different roles undertaken by transmission networks and distribution networks. Describe some of the technical and configurational differences between these networks that follow from these different roles. [6]

b) Maintaining the proper rotational speed of generators is important in AC electricity systems.

i) Describe how it is that, once connected, a generator stays synchronised with the rest of the system. [4]

ii) Describe how the frequency of an AC network is maintained at its target value. [4]

c) A set of three impedances of 10+j2 Ω form a delta connected load. Calculate the line current magnitude and real and reactive powers that are drawn by this load from a three-phase supply of 400 V. [8]

d) Consider a Buck switch-mode power supply, SMPS.

i) Describe the operation of the SMPS. [5]

ii) Describe the difference between continuous and discontinuous current operation of an SMPS. [3]

iii) Derive an equation for the output voltage of a Buck SMPS in continuous operation, stating the basis for each step. [5]

e) What are the factors that lead to a PV panel not converting all of the incident sunlight energy into electrical energy for use? [5]

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2.

a) A distribution network operator wishes to establish a distribution connection with a 25 km route and operating at a phase voltage of 20 kV. Two options are being considered, a cable and an overhead line. The parameters of the cable are a resistance per unit length of $R'_{CAB} = 30$ mΩ/km and an inductive reactance of $X'_{CAB} = 90$ mΩ/km. For the overhead line the parameters are $R'_{OHL} = 50$ mΩ/km and an inductive reactance of $X'_{OHL} = 30$ mΩ/km. Estimate the voltage drop expected of each route option when the power consumed at the receiving end is 40 MW (per phase) at a power factor of 0.85 lagging. Neglect the shunt conductance effect in both cases. [10]

b) A 3-phase, 2 pole-pair, induction machine is star-connected and provided with a supply with a phase voltage of 500 V, 50 Hz. The winding parameters of the equivalent circuit of the machine, referred to the stator, are:

stator resistance	1.0 Ω,
stator leakage reactance	3.0 Ω,
referred rotor resistance	0.75 Ω,
referred rotor leakage reactance	2.0 Ω.

The magnetising reactance and resistance will be neglected.

When driving a particular mechanical load, the machine is observed to spin at 1,440 rpm.

i) Calculate the slip. [4]

ii) Calculate the stator current in complex form. [6]

iii) Calculate the electro-magnetic torque. [4]

iv) Calculate the efficiency (ignoring magnetising and friction losses). [6]

3.

A **boost** SMPS has the following design properties.

Input voltage	$V_I = 6.0$ V
Output voltage	$V_O = 24.0$ V
Maximum output current	$I_O^{max} = 1.0$ A
Switching frequency	$f = 50$ kHz
Inductor	$L = 1.5$ mH
Capacitor	to be determined

a) Consider the boost SMPS operating in continuous mode.

i) Calculate the duty-cycle at which the circuit should be operated to achieve an output voltage of $V_O = 24.0$ V. [3]

ii) Calculate the ripple component of the inductor current. [3]

iii) Find the average value of the current through the diode and the average current through the inductor when the load draws the maximum output current. [4]

iv) By assuming that the voltage ripple across the effective series resistance (ESR) of the capacitance is much larger than that across the capacitance, specify an ESR to achieve a voltage ripple at the output of less than 50 mV. [5]

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b) The SMPS is constructed with a MOSFET which has an on-state resistance of $R_{DS(on)}$ of 0.2 Ω and turn-on and turn-on and turn-off energy losses of 5 μJ and 7 μJ, respectively. The diode has a forward conduction voltage of $V_{AK(on)}$ of 0.8 V.

i) Calculate the power loss in the MOSFET when the SMPS operates at maximum output power. [4]

ii) Calculate the power loss in the diode when the SMPS operates at maximum output power. [3]

iii) Calculate the maximum thermal impedance that can be allowed between the MOSFET and ambient air (at 30°C) if the MOSFET junction temperature is not to exceed 100°C. [3]

c) A suggestion is made that the components of this SMPS could be made smaller if the switching frequency were increased. Comment on what you would expect to be achieved in the size of inductor, capacitor and heat sink for the redesigned power supply. [5]

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