IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2015

EEE PART II: MEng, BEng and ACGI

Corrected Copy

POWER ENGINEERING

Wednesday, 10 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

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

$$P_{3\Phi}=3V_PI_P\cos(\phi)$$

Power

$$=\sqrt{3}\,V_LI_L\cos(\phi)$$

Induction Machines

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

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)

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

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

Voltage Drop (approximate form)

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

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

a) The electricity supply industry in European countries has been separated (or unbundled) into four functions: generation, transmission, distribution and supply. Describe what each of the functions is, stating clearly the key differences, and why the four functions have different market and regulatory arrangements. [6]

b) Electricity supply systems are based on alternating current, AC.

i) Explain why all countries of the world have settled on either 50 or 60 Hz rather than higher or lower frequencies. [4]

ii) There are some cases where DC is preferred to AC for transmission of electrical power. Explain what these cases are. [4]

c) An overhead line has a series impedance $3 + j\,8\ \Omega$ and is used to supply a single-phase load. The source voltage is 20 kV and the load is 10 MW at a power factor of 0.90 lagging. Calculate the change of voltage magnitude between sending and receiving ends of the line. You may assume that the power drawn from the source is almost the same as the power delivered to the load (i.e. the line losses are small). [6]

d) Consider a typical photovoltaic panel.

i) Sketch the shape of the power versus voltage curve of a typical photovoltaic panel. [3]

ii) Add to the sketch two additional curves for an increase in illumination and for an increase in temperature. [4]

iii) Explain why a perturb-and-observe maximum power point tracking algorithm is used with photovoltaic panels. [3]

e) Consider a DC to AC converter for single-phase use.

i) Sketch a diagram of the DC to AC converter (either the 2-switch or 4-switch circuit). [3]

ii) Describe its operation. [5]

iii) Why might the basic circuit sometimes be supplemented by an *LC* filter? [2]

2.
A **buck** switch-mode power supply, SMPS, has been designed to provide a 5 V output voltage from an input voltage than is nominally 9 V but can vary by ±1.5 V. The output current will be in the range 0.1 A to 2.0 A. A 220 μF capacitor (with an ESR of 200 mΩ) and a 100 μH inductor have been used. The switching frequency is 250 kHz.

a) Calculate the range of duty-cycle required. [3]

2:55 b) For operation at the nominal input voltage, estimate the output voltage. Ripple. [8]

c) Determine whether the SMPS remains in continuous conduction across the full operating range. [7]

d. e) Consider now that the semiconductor devices used in the Buck SMPS are not perfect. The diode has a forward voltage drop during conduction, $V_{AK(on)}$ of 0.7 V. The switch used is a MOSFET with an on-state resistance, $R_{DS(on)}$ of 200 mΩ. Estimate the power loss in the SMPS at maximum output current and nominal input voltage. [6]

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what it says. otherwise ideal switches

f) By noting that the change of inductor current in the on-time plus that in the off-time sum to zero in steady state, derive an expression for the output voltage as a function of input voltage and duty cycle that accounts for the semiconductor voltage drops. You may assume continuous inductor current conduction. [6]

3. This questions addresses several aspects of 3-phase systems and induction machines.

a) A typical generator used in a power station has the following features. In each case explain why these features are chosen.

i) The stator and rotor are formed of laminated sheets of steel with a small air-gap between stator and rotor [3]

ii) A large number of coils are arranged around the inside circumference of the stator and connected into three phase windings [4]

b) A 3-phase supply has a line voltage of 400 V. It is connected to load composed of three impedances in star connection, each with a value of $25 + j\,10\ \Omega$.

i) Calculate line current that flows and the real and reactive power consumed by the load. [4]

ii) The load impedances are subject to some manufacturing tolerance. For the case of one impedance being 10% below its nominal value and another being 10% above, calculate the magnitude of the current that would flow in the neutral connection. [4]

c) A 3-phase, 2 pole-pair, induction machine is star-connected and provided with a supply with a line voltage of 400 V, 50 Hz.

A series of measurements were made while the machine was driving a particular mechanical load:

rotational speed	1,450 r.p.m.
stator current (magnitude)	135.1 A
power factor	0.82 lagging
referred rotor current (magnitude)	117.7 A

The winding parameters of the equivalent circuit of the machine, referred to the stator, are:

stator resistance	0.04 Ω,
stator leakage reactance	0.4 Ω,
referred rotor resistance	0.055 Ω,
referred rotor leakage reactance	0.4 Ω.
magnetising resistance	20 Ω.
magnetising reactance	8 Ω.

For the particular mechanical load under investigation, calculate the following:

i) the slip [2]

ii) the mechanical output power and electro-magnetic torque [5]

iii) the efficiency [3]

iv) the iron loss [5]