Master. ✓ E2.3B

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2008

EEE PART II: MEng, BEng and ACGI

POWER (B)

Tuesday, 17 June 2:00 pm

Time allowed: 1:30 hours

There are FOUR questions on this paper.

Q1 is compulsory.
Answer Q1 and any two of questions 2-4.
Q1 carries 40% of the marks. Questions 2 to 4 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, T.C. Green

Second Marker(s) : C.A. Hernandez-Aramburo, C.A. Hernandez-Arambu
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1.

(a) Explain why very high voltages are used for electricity transmission and lower voltages for distribution. [4]

(b) Explain why a frequency of 50 Hz (or 60 Hz) was chosen for electricity generation and supply. [4]

(c) A switch-mode power supply is more efficient than a linear regulator but still has some power losses. Explain why those power losses arise. [4]

(d) Figure Q1 shows the output voltage of a buck switch-mode power supply as a function of output current when operated in open-loop with a set duty-cycle. Explain its shape. [4]

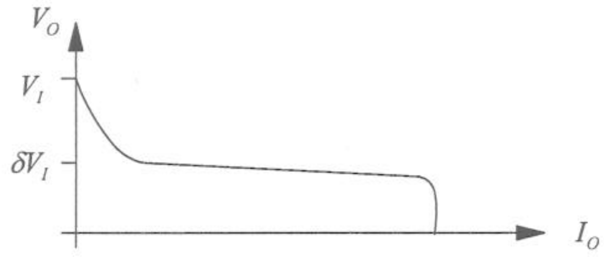

Figure Q1

(e) Explain, in outline, how a rotating magnetic field is created by a three-phase winding in the stator of an induction machine. (You may assume the machine has one pole-pair.) [4]

(f) Sketch the torque against speed graph of an induction machine, marking the point at which torque is zero and explain why torque is zero there. [4]

(g) Sketch the instantaneous power of a resistor and an inductor when a sinusoidal current flows through them both and comment on the real power consumed by each. [4]

(h) Explain the three-phase system so widely adopted in power systems. [4]

(i) Describe the role of a governor in a power station generator. [4]

(j) The electricity industry in the UK has been "unbundled" into four distinct functions with separate ownership. Describe the four functions. [4]

2. A boost switch-mode power supply, SMPS, as shown in figure Q2, has the following design properties.

Input voltage	$V_I = 6.0$ V
Output voltage	$V_O = 18.0$ V
Maximum output current	$I_O^{max} = 0.5$ A
Switching frequency	f = 10 kHz
Inductor	$L = 500$ μH
Capacitor	$C = 1{,}000$ μF
MOSFET on resistance	$R_{DS(on)} = 0.25\ \Omega$
MOSFET turn-on loss	$E_{on} = 13$ μJ when switched on at 1.5 A
MOSFET turn-off loss	$E_{off} = 7$ μJ when switched off at 1.5 A

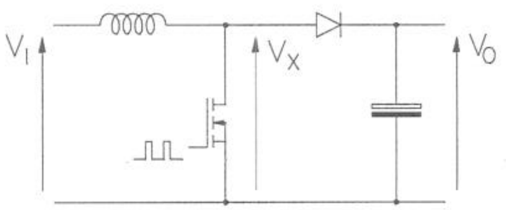

Figure Q2

(i) Calculate the duty-cycle at which the circuit should be operated assuming the circuit is in continuous conduction mode. [3]

(ii) Calculate 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]

(iii) Sketch the waveforms of the currents through the diode, capacitor and inductor for the conditions when the circuit operates at maximum output current. [5]

(iv) Calculate the voltage ripple across the capacitor. There is no need to consider the series resistance of the capacitor. [4]

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

(vi) Calculate the value of inductor current at which the SMPS enters discontinuous conduction mode and the value of output current to which this corresponds. [3]

(vii) Calculate the power losses in the MOSFET. [4]

(viii) It has been suggested that the switching frequency of this SMPS is too low. Discuss the advantages and disadvantages of raising the switching frequency. [4]

3. A 2-pole-pair, 3-phase induction machine is connected in star to a 480 V (line), 50 Hz supply. The equivalent circuit parameters, referred to the stator, are:

Stator resistance	0.06 Ω
Referred rotor resistance	0.08 Ω
Stator leakage reactance	0.30 Ω
Referred rotor leakage reactance	0.30 Ω
Magnetising reactance	20.0 Ω
Magnetising resistance	200 Ω

(a) For operation at 1,450 r.p.m. calculate the following:

(i) the slip; [3]

(ii) the stator current; [12]

(iii) the power losses; [5]

(iv) the mechanical power. [5]

(b) Without performing detailed calculations, comment on how the power losses, mechanical power and efficiency would change if the speed changed to 1,475 r.p.m., that is, if the slip is halved. [5]

4. A transformer has been designed as a step-down transformer for use in a 50 Hz distribution system. The design equations indicate that the following parameters will apply to the approximate equivalent circuit shown in figure Q4.

Combined winding resistance referred to primary	$R_W = 0.55\ \Omega$
Combined leakage reactance referred to primary	$X_W = 1.50\ \Omega$
Magnetising resistance	$R_M = 5\ \text{k}\Omega$
Magnetising reactance	$X_M = 800\ \Omega$
Primary to secondary turns-ratio	$N_P{:}N_S = 11{:}1$

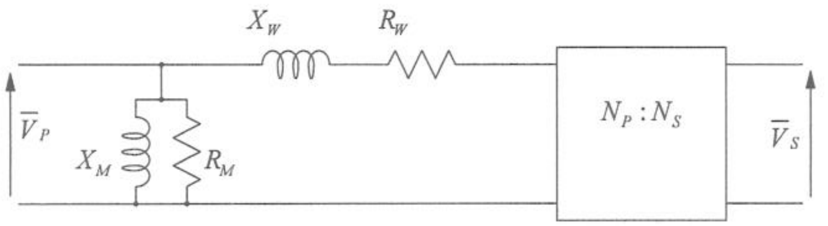

Figure Q4

(a) For the equivalent circuit in figure Q4:

(i) describe the physical effects in the real transformer that give rise to each component of the equivalent circuit; [5]

(ii) identify which components need to be considered when calculating the power losses in the transformer; [2]

(iii) discuss any approximations in this equivalent circuit. [3]

(b) The primary of the transformer is to be supplied at 33.0 kV and the secondary connected to a load of $0.40 + j0.25\ \Omega$.

(i) Calculate the secondary voltage and the voltage regulation that this represents. [5]

(ii) Calculate the real and reactive powers at the primary input and secondary output. [5]

(c) When built, the transformer is tested to establish if the parameters of the equivalent circuit are close to the design values. Using the following test data, calculate the actual parameters. With 33.0 kV applied to the primary and the secondary open-circuit, the primary current was 41.0 A and the input power 210 kW. With 1,000 V applied to the primary and the secondary short-circuit, the primary current was 635 A and the power 212 kW. [10]