Version RAM/2

EGT2
ENGINEERING TRIPOS PART IIA

Monday 27 April 2015 9.30 to 11

Module 3B3

SWITCH-MODE ELECTRONICS

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

10 minutes reading time is allowed for this paper.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 (a) (i) A 2 kW induction cooker design needs a dc supply from the 50 Hz, 230 V mains. A full bridge rectifier is suggested. Stating your assumptions, estimate the smoothing capacitor needed for 20% ripple. [25%]

(ii) Sketch the ac current waveform and estimate the peak diode current and the conduction angle. [35%]

(b) An alternative design for the dc supply uses two *boost* converter stages to draw sinusoidal current from the ac supply as shown in Fig. 1. Assuming the inductors smooth the current to the required sinusoidal shape, find the peak diode current and the new value of the smoothing capacitor. [40%]

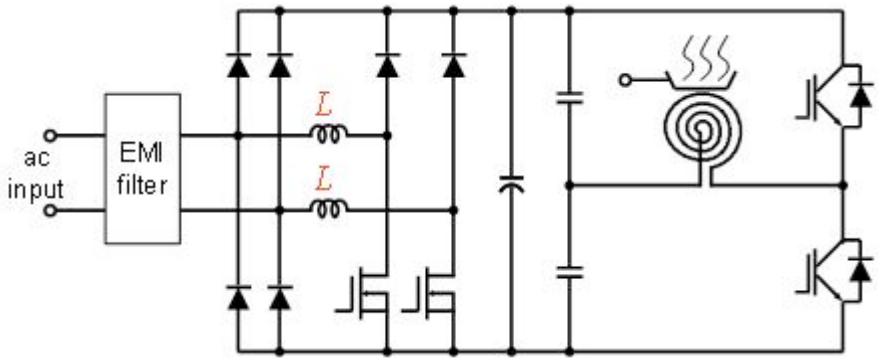

Fig. 1

2 (a) State why switch mode power conversion is widely used. [5%]

(b) Suggest a suitable power conversion circuit for the following applications, assuming that the supply is rectified mains, giving reasons for your choice

(i) Outdoor LED Christmas lights requiring 14 V DC with a total load of 20 W [10%]

(ii) The tube of a compact fluorescent lamp rated at 20 W to be excited at 45 kHz [10%]

(c) A basic step-up converter uses a MOSFET, diode, inductor and capacitor.

(i) Show how these components are arranged to configure this converter and briefly explain the function of each component [20%]

(ii) Show that ratio of output to input voltage be related by

$$V_{out} = V_{in} \frac{1}{1-\rho}$$

State the conditions under which this expression is valid? [20%]

(iii) Find the maximum value of inductor that can be used if the circuit is to remain in continuous conduction mode when employed to supply a 400 V DC link from a battery voltage of 200 V. The maximum current to be supplied to the DC link is 20 A and the switching frequency is 20 kHz. [20%]

(iv) What are the minimum breakdown voltage ratings of the diode and transistor for the circuit of part (iii)? [10%]

(v) State how the converter can be controlled if it is to operate in both the continuous and discontinuous modes. [5%]

3 (a) (i) Give two reasons why devices with MOS gates are popular with circuit designers. [5%]

(ii) Describe two ways of driving the high-side gate in a *half-bridge* circuit comprising two MOSFETs [15%]

(b) A MOSFET operates with a clamped highly inductive load. Find the drain current *turn-on* time when the *drain* current is 50 A from a 28 V supply, assuming the drive circuit has a negligible rise time. The gate circuit supply voltage is 5 V and the series gate resistance is 2.2 Ω.

The MOSFET's *transfer characteristic* above the threshold voltage is

$$I_D = 30(V_{GS} - 2.8)^2$$

The input and reverse transfer capacitances are 4.5 nF and 18 pF respectively.

Comment on the characteristics of the turn-on time.. [40%]

(c) A *full bridge inverter* is to be designed for driving the ground coil of a contactless charging system for electric vehicles. The coil and the load can be represented as a series resonant circuit comprising an inductor of 380 μH and a capacitor of 33 nF, in series with a resistance of 22.8 Ω, of which 1.7 Ω accounts for losses in the coil.

(i) Assuming that the bridge delivers a square wave output at the resonant frequency, find the minimum DC link voltage if the fundamental power transferred is 3 kW. [25%]

(ii) What voltage rating is required for the 33 nF capacitor and what type of capacitor would be suitable? [10%]

(iii) How could the system be modified to ensure rated power delivery even if the inductance falls as a result of imperfect alignment of the vehicle and ground coil? [5%]

4 (a) Suggest suitable devices and switching frequencies, giving reasons for your choices, for three-phase bridges to be used for the following motor drive applications

(i) A central heating pump with a maximum power of 100 W [10%]

(ii) A drive for a baggage handling system rated at 5 kW [10%]

(iii) A cement kiln drive rated at 10 MW [10%]

(b) A *three-phase full bridge inverter* intended for Pulse Width Modulation (PWM) operation is shown in Fig. 2.

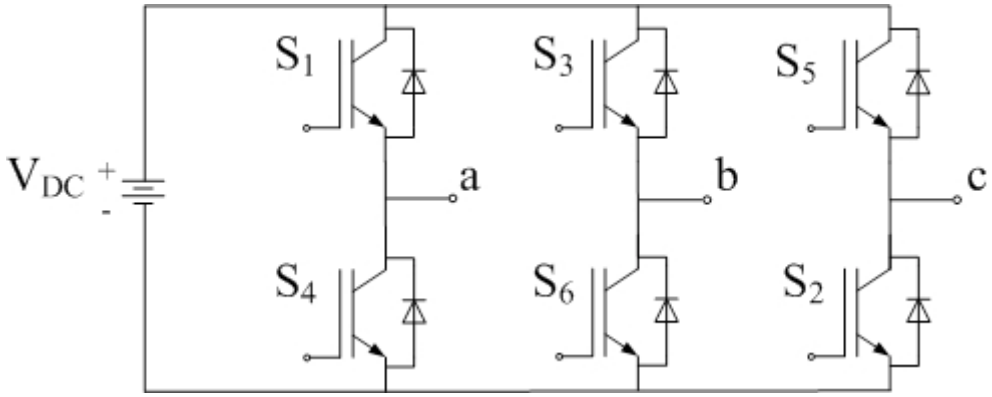

Fig. 2

(i) With reference to the line voltages generated by this inverter, explain how the devices are switched in the unipolar and bipolar switching modes. [15%]

(ii) What advantages are gained from operating in the unipolar mode? [5%]

(iii) Is the absence of a neutral connection an issue? [5%]

(c) (i) Make a table to identify the eight switch states of the inverter in Fig. 2 and give corresponding outputs of each of the half-bridges. [20%]

(ii) What is meant by a zero state and how are they used in *Space Vector Modulation* (SVM) [10%]

(iii) Using a vector diagram, explain how SVM can give a larger fundamental output voltage for a given DC link voltage than sine wave (or naturally sampled PWM). What is the increase? [15%]

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Numerical answers 3B3

Q1 (a) (i) 1.05 mF

(ii) 64.7 A, 37°

(b) 11.4 A, 600 μF

Q2 ((b) (iii) 62.5 μH

(iv) Both 400 V

Q3 (b) 18.1 ns

(c) (i) 302 V

(ii) 1807 V