ENGINEERING TRIPOS PART IIA

Monday 29 April 2013 2 to 3.30

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.*

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

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

Final version

1 (a) A 42 V (nominal) electrical system has been proposed for future cars. An outline circuit of a step-down converter for reducing the 42 V (nominal) DC to 12 V for components designed for that voltage is shown in Fig. 1.

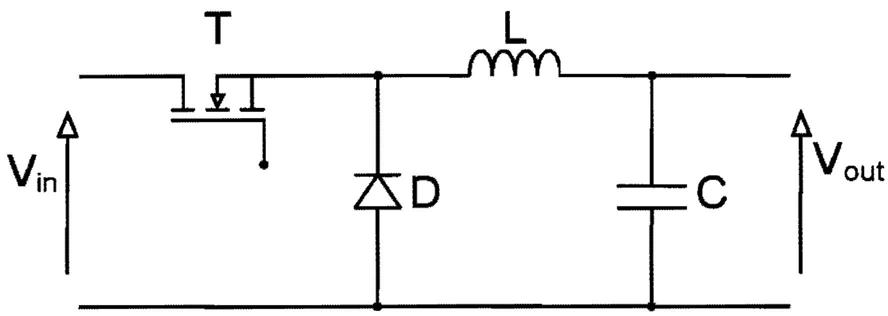

Fig. 1

(i) Find the range of duty cycles required to achieve a constant 12 V output if the input voltage can vary between 39 V and 53 V, assuming ideal components. [10%]

(ii) Show that the ripple current, ΔI, at the boundary between continuous or discontinuous current is

$$\Delta \mathrm{I} = \frac{1}{L} V_{IN}(l - \rho)\rho T$$

Where T is the switching period. [20%]

(iii) Find the minimum value of inductance to ensure continuous current operation if the switching frequency is 100 kHz and the load current varies between 1 A and 10 A. [20%]

(b) In an alternative configuration, the 12 V battery is retained so a step up converter is needed to generate the 42 V line.

(i) Sketch an outline of a step-up converter. [10%]

(ii) Sketch wave form of inductor current and voltage across the transistor switch, showing carefully their time relationship. [20%]

(iii) Determine the minimum voltage rating for the transistor switch. [10%]

(iv) Can the circuit be made to work satisfactorily in the discontinuous current mode? [10%]

2 (a) The IGBT is the preferred device for new HVDC equipment based on multiple inverter cells, one of which is shown schematically in Fig. 2(a). Give three reasons for the choice of IGBTs.

(i) Explain why a relatively low switching frequency is used whilst retaining fast switching. [25%]

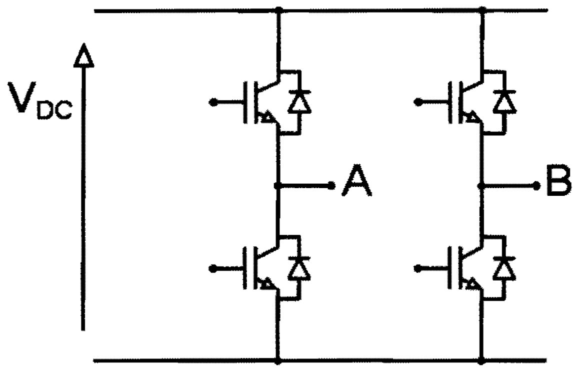

Fig. 2 (a)

(ii) In Fig. 2 (a) diodes are shown in anti-parallel to the IGBTs. Explain the purpose of these diodes and show how the inverter of Fig. 2 (a) can be operated in both step up and step down modes, stating any essential additional components. [25%]

(b) (i) What advantages does Space Vector Modulation (SVM) offer compared to Sine Wave Pulse Width Modulation (SVPWM)? [10%]

(ii) For the IGBT inverter shown in Fig. 2(b) identify the eight switch states. Make a table showing which switches are on and which are off and state the outputs of each half bridge. [10%]

(iii) On a vector diagram indicate the use of the zero states. [10%]

(iv) What is the maximum fundamental line output voltage with SVM? [10%]

(v) Briefly describe the implementation of SVM in a microcontroller array. [10%]

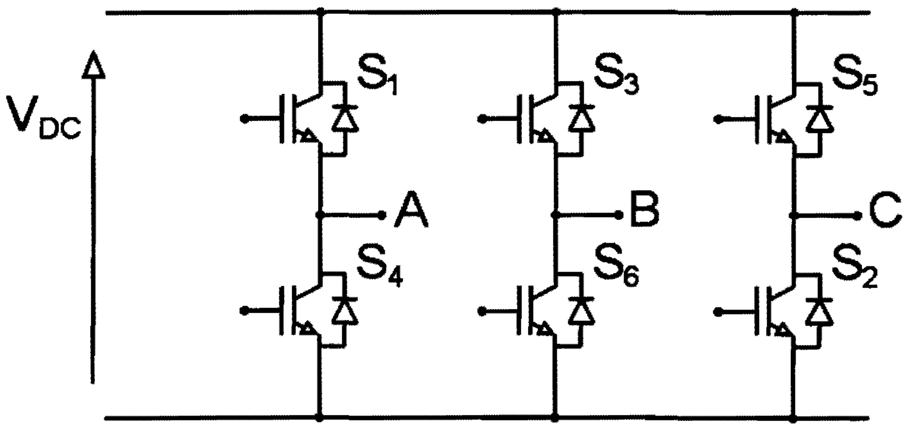

Fig. 2(b)

3 (a) (i) A portable welder requires a 300 V, 10 A (nominal) supply, which is to be obtained using the single-phase bridge rectifier shown in Fig. 3 (a). The output voltage must not fall below 275 V. Choose a value for the smoothing capacitor, noting any assumptions made. [25%]

(ii) Based on your value, estimate the conduction angle of the diodes and explain why such circuits are not preferred for new equipment. [15%]

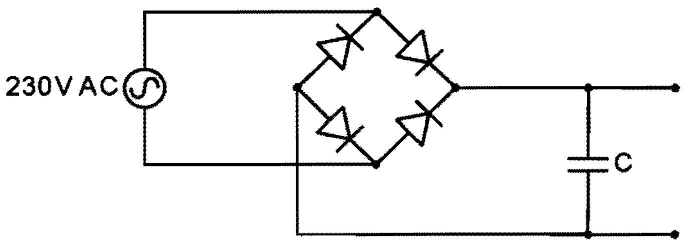

Fig. 3 (a)

(b) (i) A power factor correcting circuit is shown in Fig. 3 (b). For the load of Part (a), the controller chip manufacturer recommends continuous conduction in L1, with a sinusoidal 50 Hz current waveform and low current ripple. Give two reasons why operating at the boundary of continuous conduction in L1 is attractive and state two drawbacks. [20%]

(ii) What type of diodes are required for the diodes in the circuit Fig. 3 (b)? [10%]

(iii) Describe how this circuit could be operated to correct the power factor and deliver a fixed output voltage. Include in your answer descriptions of the switching strategy used forT1 and T2. [20%]

(iv) Under what conditions could the circuit cease to function correctly? [10%]

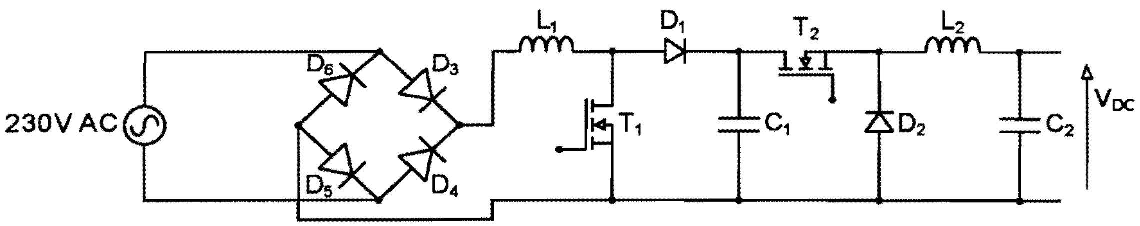

Fig. 3 (b)

4 (a) A 50 A MOSFET is used for an application with an inductive load taking a sensibly constant 25 A.

(i) Sketch the turn on wave forms showing the time relationship of the gate voltage, the drain current and the drain-source voltage. Indicate the gate plateau region. [30%]

(ii) For a nominal duty cycle of 50 % and a switching frequency of 450 kHz, estimate the on-state losses and the switching losses. You may assume the turn-off and turn-on losses are equal. The gate drive voltage is 15 V, and the gate resistor is 5 Ω. The gate voltage of the MOSFET is 5 V at a current of 25 A and the on-resistance is 20 mΩ. The supply voltage is 200 V and the reverse transfer capacitance is 100 pF. [30%]

(b) The excitation coil of a device for detecting foreign particles in meat pies can be represented by an inductance of 50 μH and resistance of 5 Ω. The coil is supplied by a full bridge inverter operating from a 200 V DC link.

(i) Calculate the fundamental current and that of the first harmonic if the bridge is switched at 450 kHz. [10%]

(ii) A capacitor is added in series to give a series resonant circuit. What value should be used to resonate at 450 kHz? [10%]

(iii) What is the new value of the fundamental component of the current? [10%]

(iv) How can the switching of the bridge be modified to regulate the current? [10%]

END OF PAPER