ENGINEERING TRIPOS PART IIA

Monday 20 April 2009 2.30 to 4

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

1 (a) The power adapter for a set-top box provides the main 5 V , 1 A supply. The original design employs a mains transformer and a single phase bridge rectifier as shown in Fig. 1(a). Show that the ripple in the voltage at the output of the adapter is approximately proportional to the load current, stating your assumptions.

Obtain an expression for the average output voltage as a function of the load current, assuming that the transformer is ideal. [30%]

Carefully sketch the waveform of the ac supply current, when operating at 5 % ripple in the voltage, and estimate the value of the smoothing capacitor required for 5 % ripple at full load.

Estimate the efficiency of the adapter, assuming the transformer is ideal. [30%]

(b) The revised design for the power adapter of Part (a) is based on a high frequency converter to provide the required step down in voltage, as shown in Fig. 1(b). The switched mode converter draws high frequency pulses of current from the mains via the bridge rectifier, where the magnitude of each pulse is controlled so that they have a weighting which is sinusoidal at the mains frequency. Explain briefly why such a design is likely to have a low standby current and high efficiency when compared to that of Fig. 1(a).

The filter circuit at the secondary must absorb pulses of current. Neglecting the high switching frequency components of the current in the secondary, estimate the ripple in the output voltage when an average load current of 1 A is drawn. [30%]

Suggest two methods of improving the design such that the voltage ripple at the output is below 5% . [10%]

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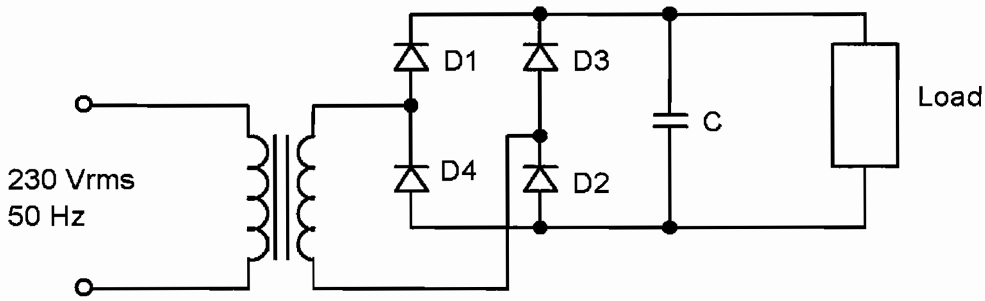

Fig. 1(a)

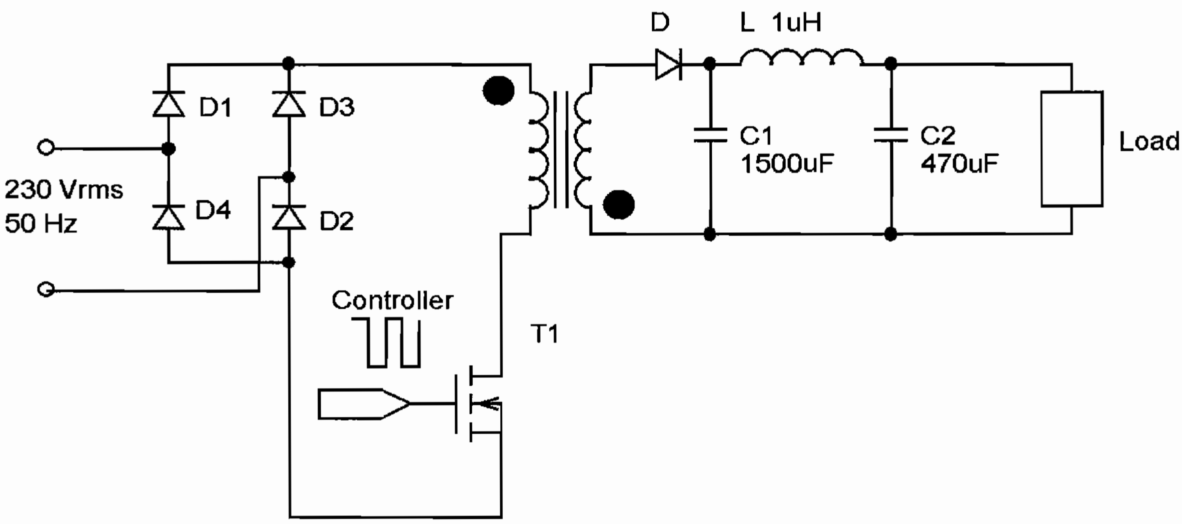

Fig. 1(b)

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2 (a) A train uses IGBTs for its main drive inverter rated at 1 MW as shown in Fig. 2. Explain briefly why the IGBT is a common choice and why the switching frequency is audible.

It is noted during a journey that the switching frequency appears to change slowly and then suddenly changes. Suggest why these effects occur. Outline briefly a simple scheme for generating the required IGBT switching times. [40%]

(b) Table 1 lists the allowable logic states of the switches for the IGBT inverter circuit shown in Fig. 2. Making reference to this table explain briefly how the circuit may function as an inverter and how the magnitudes of the voltages V_{ab}, V_{bc}, V_{ca} at the load may be reduced to a low value over one cycle.

Using the table of states, show that the careful choice of state sequences in *Space Vector Modulation* (SVM) allows for a lower switching frequency when considering harmonic voltages at the load. [35%]

(c) The inverter is to be operated according to the principle of SVM. When operating in the sector bounded by states V_1 and V_2, show that the duty cycle for the state V_2 is given by

$$m_s \sin \theta ,$$

where m_s is the modulation index for SVM and $m_s = 1$ is defined by the largest circle that can be drawn inside a hexagon.

Hence or otherwise calculate the value of the duty cycle for switch S_1 when the required space vector has $m_s = 0.25$ at 30^o with respect to V_1. The Direct-Inverse SVM strategy is applied. [25%]

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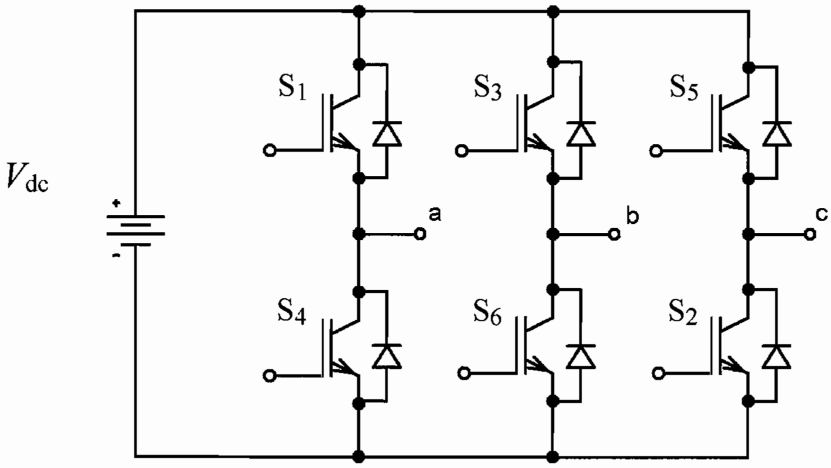

Fig. 2

Table 1

State	'ON' switches	$\frac{V_a}{V_{dc}}$	$\frac{V_b}{V_{dc}}$	$\frac{V_c}{V_{dc}}$
V_1	S_1 , S_6 , S_2	1	0	0
V_2	S_1 , S_3 , S_2	1	1	0
V_3	S_4 , S_3 , S_2	0	1	0
V_4	S_4 , S_3 , S_5	0	1	1
V_5	S_4 , S_6 , S_5	0	0	1
V_6	S_1 , S_6 , S_5	1	0	1
V_7	S_1 , S_3 , S_5	1	1	1
V_8	S_4 , S_6 , S_2	0	0	0

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3 (a) Give two reasons why a MOSFET may be preferred over a bipolar transistor for use as the main switching device in a 230 Vac to 5 V , 1 A dc power supply for a set-top box, shown in Fig. 3. Briefly justify your reasons with regard to the application. [20%]

(b) The flyback converter circuit shown in Fig. 3 forms the output stage of the dc power supply of Part (a). The converter is designed to be used at all times in the *Transition mode*, which is the boundary condition whereby the transformer magnetising current falls to zero immediately prior to the MOSFET turning back on. Show that the output voltage is given by

$$V_{dc} \frac{N_2}{N_1} \frac{\rho}{1-\rho} \quad ,$$

where V_{dc} is the rectified and smoothed mains voltage and ρ is the duty cycle of the MOSFET. [25%]

The magnetising inductance of the transformer is 1.5 mH on the primary side, which has 240 turns in its winding. The secondary side has 5 turns. For European use, an 800V MOSFET is chosen for the switching device. Sketch the MOSFET drain-source voltage and current for a switching cycle, and find the peak value of the drain-source voltage, when the controller (not shown in Fig. 3) maintains the output voltage at 5 V , with V_{dc} at 340 V. [25%]

The minimum value of V_{dc} is expected to be 240 V . For this condition, under full load, find the duty ratio and switching frequency of the converter.

By consideration of the behaviour at an input voltage V_{dc} of 300 V or otherwise, comment on the choice of operating in the Transition mode. [30%]

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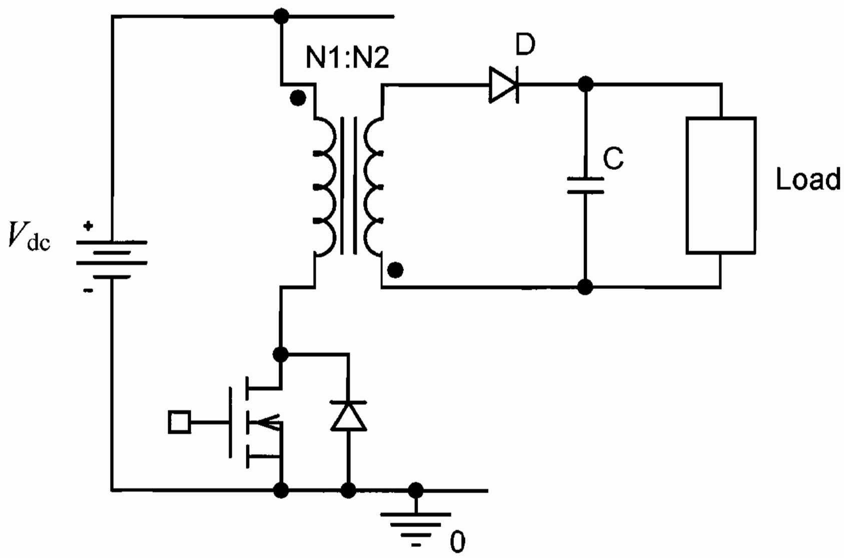

Fig. 3

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4 (a) State four considerations when choosing a bipolar transistor for use in the inverter for a compact fluorescent lamp operating at 40 kHz. . [20%]

(b) Fig. 4 shows the main circuit components for a 240V, 11 W compact fluorescent lamp. The tube is driven by the transistor inverter at 40 kHz. Give two reasons why the resonant mode is chosen for the inverter. [10%]

(c) The tube in the lamp of Part (b) contains a pair of resistive elements placed at either end of the tube, which is filled with gas. When operating an arc is drawn between the resistive elements. At the desired operating point the arc has a resistance of $224\ \Omega$ between points X and Y.

When starting there is no arc and the resistive elements pass current via the capacitor C4 and the circuit operates at or near resonance. Each resistive element in the tube is $192\ \Omega$. For this condition, carefully sketch the waveforms of current in the capacitor C4 and the voltage across it. If the smoothed dc supply voltage for the inverter has a value of 300 V, estimate the voltage appearing across nodes X and Y and comment on your result. [35%]

Once the arc is formed, the capacitor C4 can be neglected. The circuit continues to be driven at 40 kHz. For this condition, sketch the waveform of the transistor current and find its maximum value.

Suggest one means by which the efficiency of the circuit may be improved. [35%]

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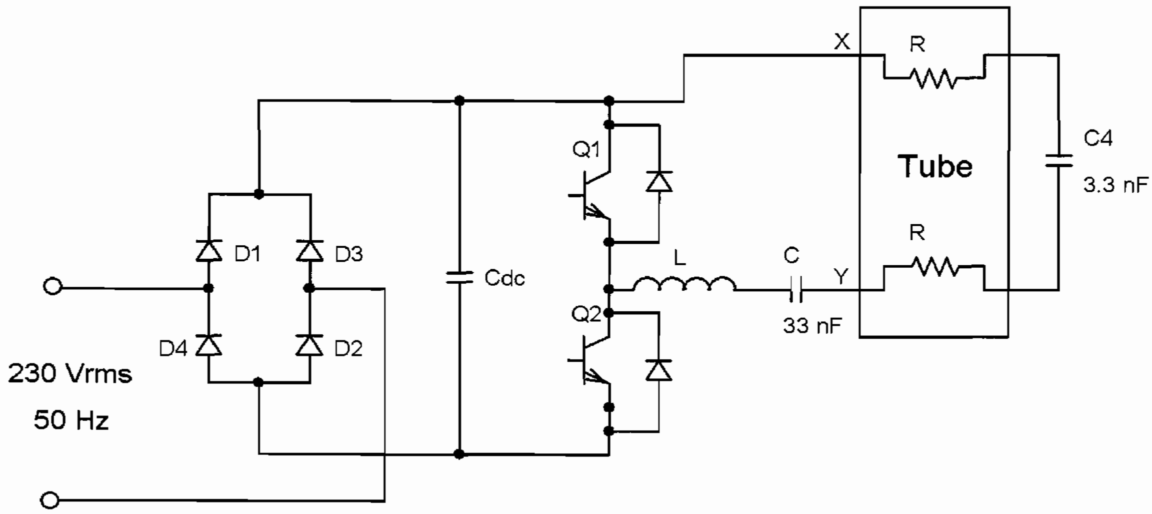

Fig. 4

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