ENGINEERING TRIPOS PART IIA

Monday 19 April 2010 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

Final Version

1 (a) An industrial inverter is to be used in a remote location which only has a single phase supply. The circuit of Fig. 1 (a) has been proposed for the ac-dc rectifier to give approximately the required dc link voltage. Stating your assumptions obtain an expression for the ripple voltage assuming a constant current is drawn from the dc link by the inverter.

Using your equation for a dc current of 6 A, find a value of capacitance C required for a ripple voltage of 5 % of the nominal 650 V. [40%]

(b) A three phase rectifier supplies an inverter for a ship propulsion system, as shown in Fig. 1 (b). The maximum current drawn by the inverter is 2000 A. The smoothing capacitance is 16.2 mF and the ac supply to the rectifier is 50 Hz. Assuming the current drawn in the worst case is dc, perform detailed calculations to find the ripple voltage in the dc link and the conduction time of the diodes. [40%]

Carefully sketch the ac supply current waveform for the conditions described above.

Explain briefly why detailed calculations are necessary in this case. [20%]

(cont.

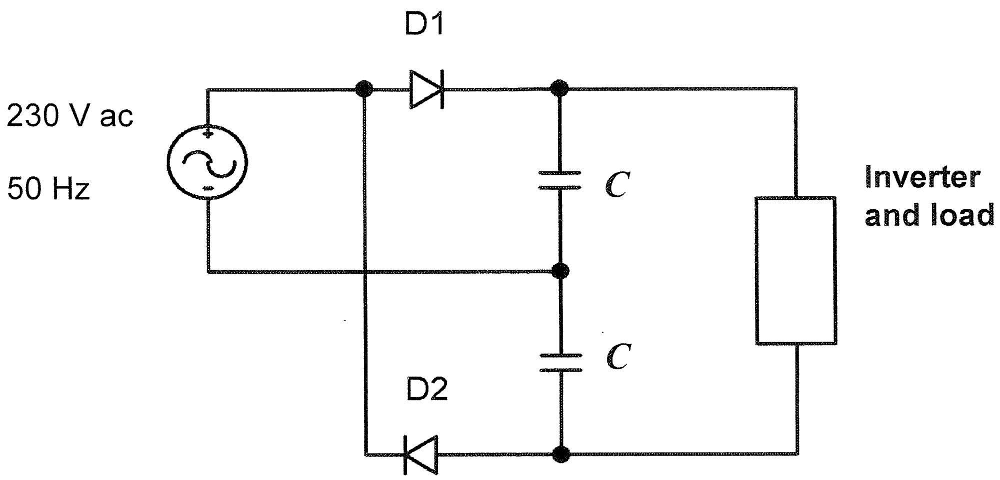

Fig. 1(a)

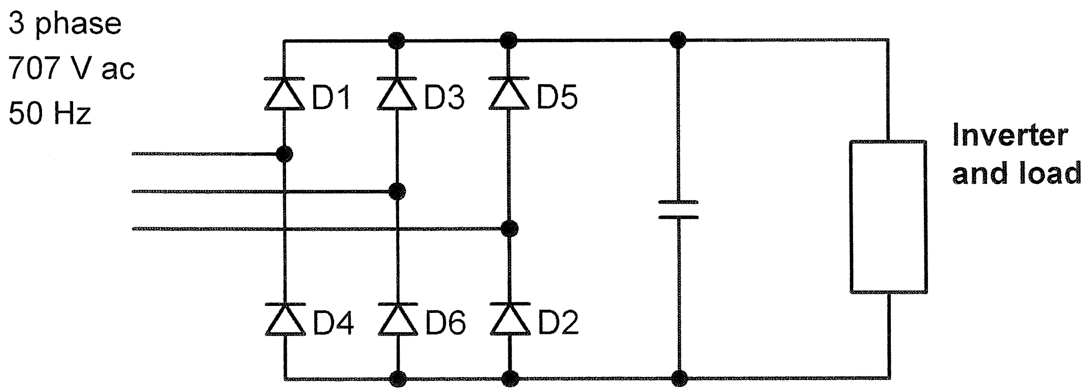

Fig. 1(b)

(TURN OVER

2 (a) IGBTs are a common choice in inverter electric arc welders, for which a block diagram is shown in Fig. 2 (a). Explain briefly why IGBTs are a good choice for such a welder with 160 A output current and a switching frequency of 10 kHz.

It is proposed to increase the switching frequency to 50 kHz. List three considerations which should be made in the design. [25%]

The output inverter shown in Fig. 2 (a) can be adjusted to give a variable ac output voltage and a dc component. Simple *unipolar* switching is employed as a sinusoidal pwm output is not wanted. Making reference to the switching states for the bridge show that a simple adjustable ac output voltage with a dc component may be produced. Carefully sketch a waveform for a 50% ac waveform (50% of a full square wave) with an approximately 20% dc component. Mark on your sketch the period of the positive pulse and the period of the negative pulse. [35%]

(b) A space vector modulation (SVM) scheme is to be applied to the three phase bridge shown in Fig. 2 (b). The modulation scheme is described by its programmer as *centre aligned*, as shown in Fig. 2 (c). Making reference to a similar sketch of an alternative scheme, for the same output conditions, state two reasons why centre aligned is usually considered to be the best scheme. Suggest why the zero state period is split evenly between 111 and 000 ?

Consider the geometry required in the sector of the SVM hexagon bounded by the space vectors 100 and 110 for an arbitrary rotating space vector. Show that a sine pulse width modulation scheme performed in a microprocessor can be easily adapted to produce SVM. [40%]

(cont.

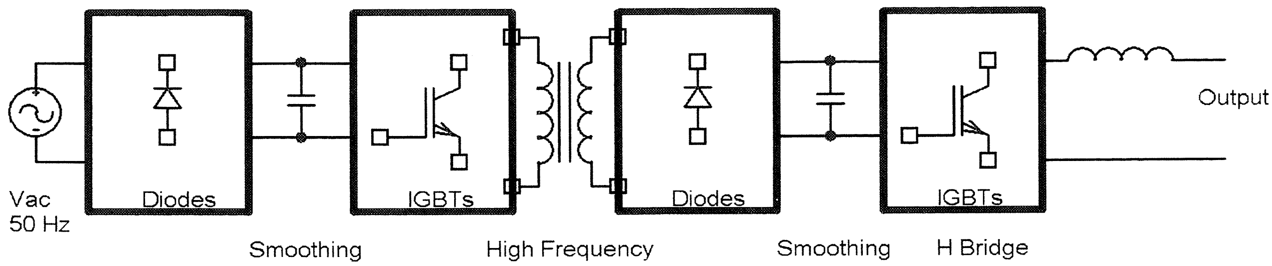

Fig. 2 (a)

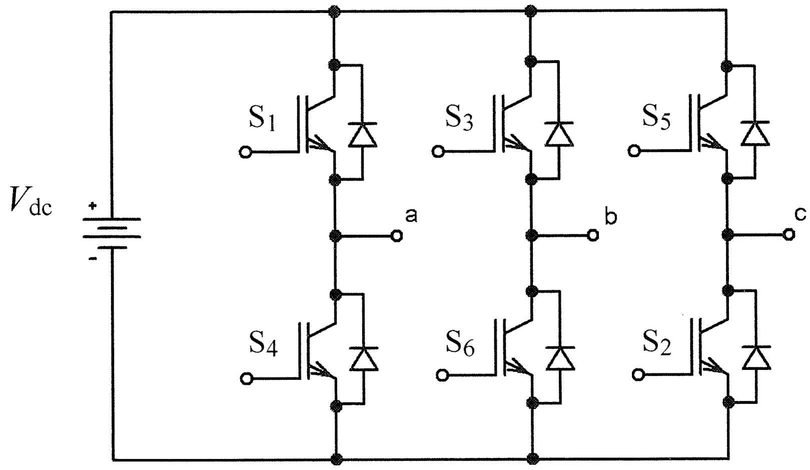

Fig. 2 (b)

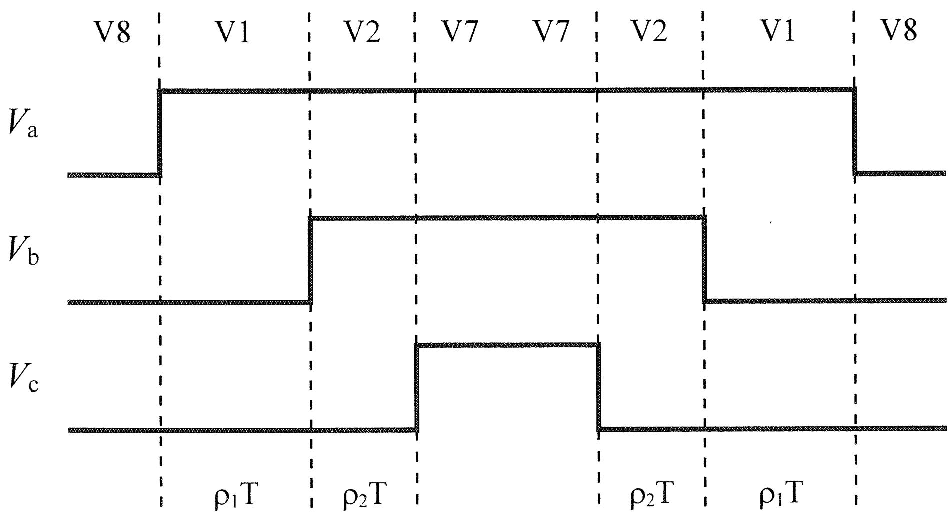

Fig. 2 (c)

(TURN OVER

3 (a) The switched mode power supply integrated circuit LTM4607 has a MOSFET output stage as shown in Fig. 3. It functions as a step-up step-down converter with a wide input voltage range. Here the LTM4607 is set to maintain an output of 12 V dc for automotive use. The inductor L and capacitor C shown are external components. Step down is performed by duty ratio modulation ρ_A of T_1, with T_2 off. Step up is performed by duty ratio modulation ρ_B of T_2 with T_1 on constantly. Discuss briefly the choice of integrated MOSFET transistors for this application, noting that all the MOSFETs shown are n channel.

Explain the various purposes of D_3, D_4, T_3 and T_4. [30%]

(b) The converter circuit of part (a) has one inductor L for both step up and step down operation. The manufacturer's application note suggests that the ripple current in the inductor should be limited to 30 % of the steady inductor current at maximum load for all input voltages, when using a switching frequency of 400 kHz and a maximum output current of 5 A. The design must accommodate a dc input voltage range of 8 - 32 V.

(i) Sketch the inductor current for the step down mode showing that the ripple in this mode is greatest at an input of 32 V. Write down the peak inductor current and find the value of L required. [35%]

(ii) For the step-up mode, find an expression for the ripple current in L which depends only on the output voltage and ρ_B for the chosen inductor size and switching frequency. Show that an input of 8 V gives the greatest ripple current and hence find the peak current at the maximum load. [35%]

(cont.

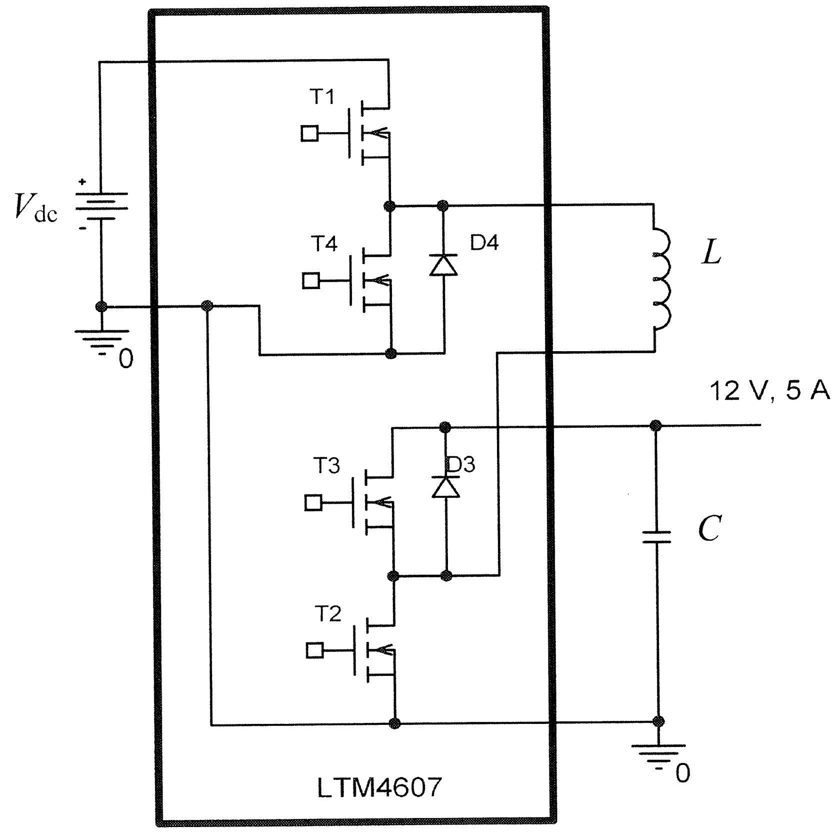

Fig. 3

(TURN OVER

4 (a) The resonant inverter circuit of Fig. 4 has been proposed for a new microwave oven design. The magnetron is to be supplied with a nominal 4000 V dc. Give two reasons why a microwave oven using such a circuit will perform better than the conventional oven based on a 50 Hz transformer with a triac controlled ac input.

Sketch the current in the primary of the transformer for the mode where the inverter is switched at a frequency which is less than half the resonant frequency. Hence or otherwise, explain why there are three distinct operating modes associated with the choice of switching frequency.

Make a table of the three modes of operation defined by the switching frequency and compare the switching stress, if any, applied to the IGBTs and diodes for the three modes. [50%]

(b) The inverter for the circuit of Fig. 4 is driven between 10 and 30 kHz. The transformer is near ideal with a 1:50 turns ratio and only the leakage inductance on the primary need be accounted for. Find the value of the leakage inductance if the inverter operates on resonance when switched at 10 kHz.

The inverter frequency is increased to reduce the power when the microwave oven has contents. Carefully sketch the current waveform in the inverter leg output for operation at 20 kHz at a magnetron output of 3000 V if the dc supply voltage for the inverter has a value of 325 V (at the peak of the ac supply voltage). [25%]

By considering the fundamental frequency component of the transformer current, find an approximate value for the power delivered to the contents. [25%]

(cont.

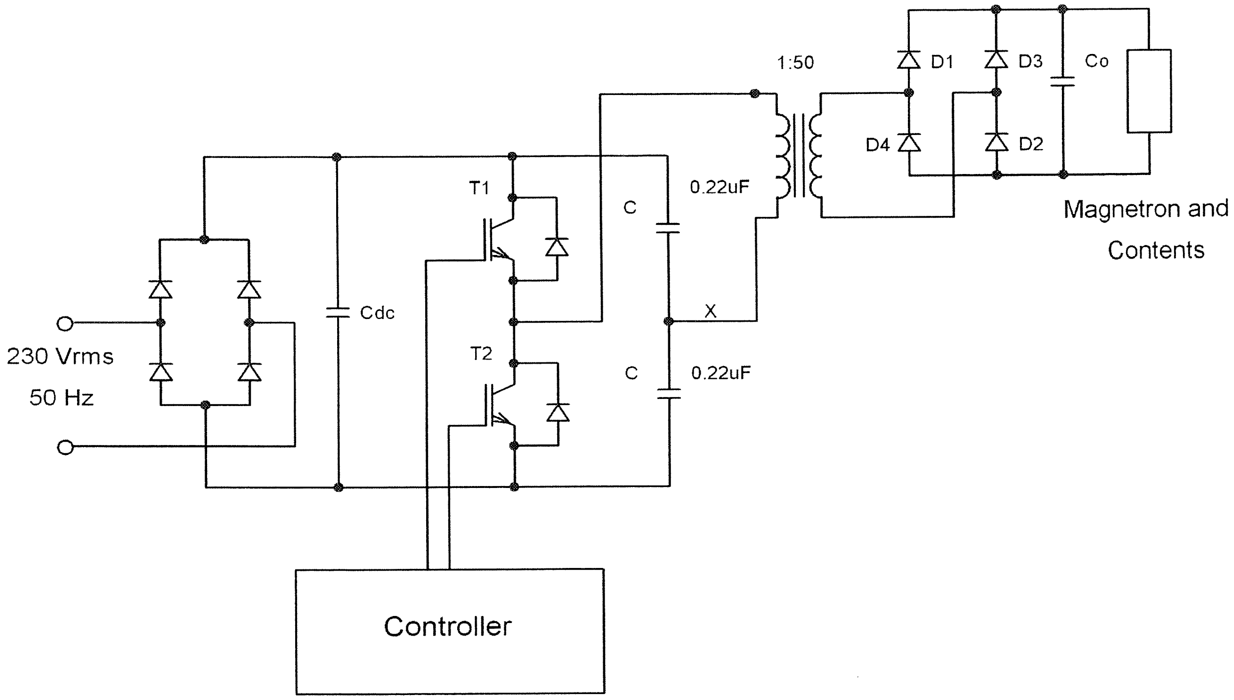

Fig. 4

END OF PAPER