EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 25 April 2017 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.*

*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
There are no attachments

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) A 3 W corn cob LED lamp uses four parallel strings of LEDs which need 29 V to operate and the regulator circuit R drops the voltage from the full-wave rectifier bridge as shown in Fig. 1. The ac input voltage is 230 V and 50 Hz.

(i) Estimate the conduction angle of the rectifier diodes and the average voltage appearing across the 100 nF capacitor. [30%]

(ii) With regard to the ac current waveform for one cycle of the supply, give three reasons why this is an attractive design. [15%]

(iii) Sketch a possible circuit for R, noting that it should work in an efficient manner. [15%]

(b) A triac dimmer switch is to be used with a cluster of three 3 W, 240 V LED lamps.

(i) Using sketches of typical voltage waveforms seen at the output of the dimmer, explain the operation of the dimmer switch. Circuit diagrams are not needed. [20%]

(ii) Explain carefully why LED lamps with the input circuit of Fig. 1 are safe for use with a dimmer switch, whereas simple capacitor smoothed LED lamps are not. [20%]

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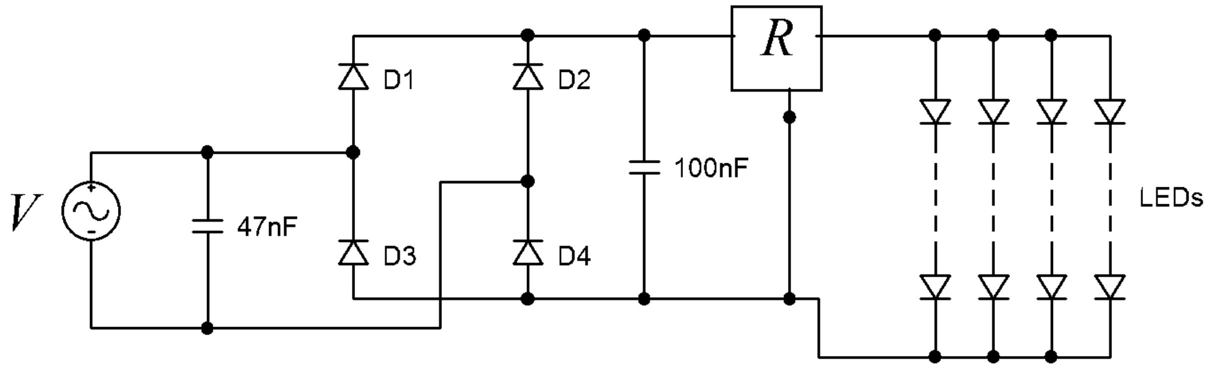

Fig. 1

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2 (a) The cross section of a typical power MOSFET structure is given in Fig. 2 (a).

(i) Making reference to the structure, explain carefully why the power MOSFET is widely used in automotive applications, but only in a few mains voltage applications. [20%]

(ii) Name the main capacitances found in a MOSFET and describe their effect on the switching process for the circuit shown in Fig. 2 (b). [20%]

(iii) On a plot of current versus voltage for a power MOSFET, draw the path from on to off when switching an inductive load as shown in Fig. 2 (b). Hence show that high speed switching is essential to reduce the power losses in the MOSFET. [20%]

(b) Draw the structure of an IGBT, which is a modified version of Fig. 2 (a). [30%]

(c) What further considerations are required when switching an IGBT in a high voltage, high current inductive load circuit? [10%]

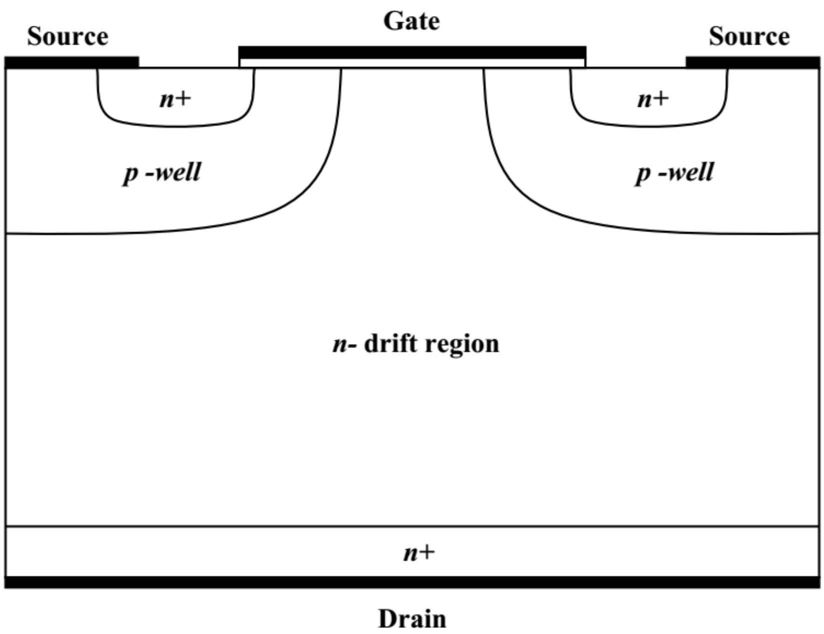

Fig. 2(a)

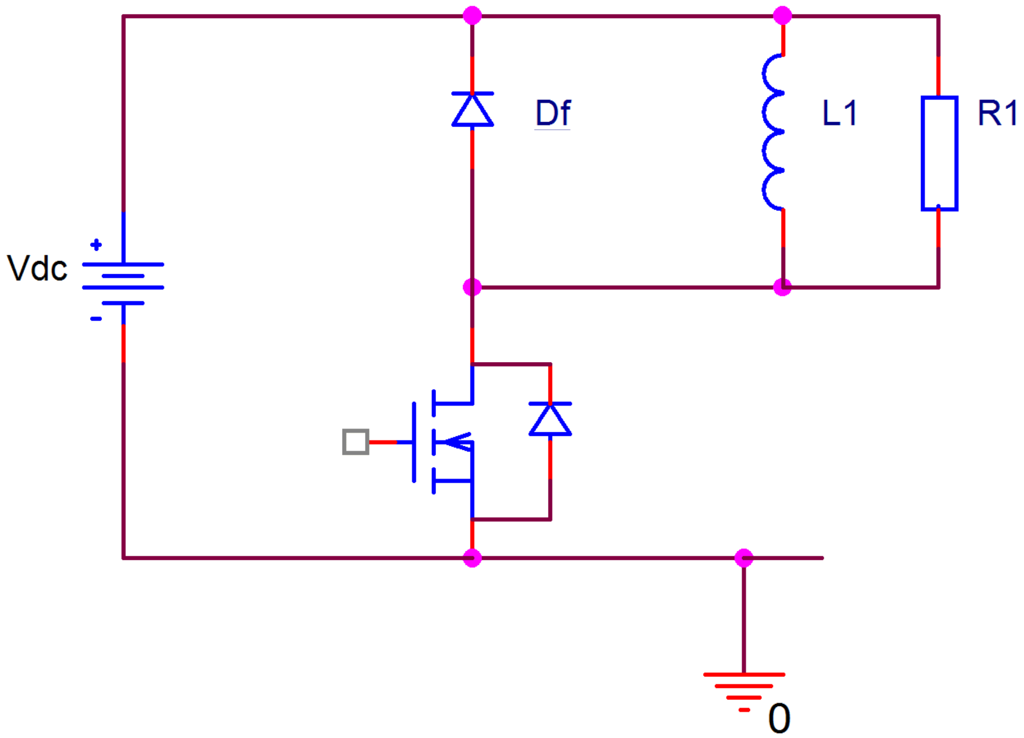

Fig. 2(b)

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3 (a) The circuit of Fig. 3(a) is used to apply a 1 kHz square wave ac voltage across the inductive load Z where $Z = (1 + j\omega)\Omega$.

(i) Give the switching sequence for the transistors T1, T2, T3, T4 and diodes D1, D2, D3, D4 for steady state operation. Dead time may be neglected. [20%]

(ii) For a peak current in Z of 40 mA, estimate the value of V_{dc} required. [20%]

(iii) By considering a few Fourier terms, determine whether the power dissipated in the load Z due to the higher harmonics is significant. [15%]

(b) By making use of a diagram of the switching signals for T1, T2, T3, T4, in the circuit of Fig. 3(a), explain how an improved sinusoidal load current may be achieved compared to that of part (a). [20%]

(c) Space Vector Modulation is applied to the inverter of Fig. 3(b).

(i) Sketch V_a, V_b and V_c, for a few cycles of switching, labelling the states. [15%]

(ii) Hence explain the use of the zero voltage states. [10%]

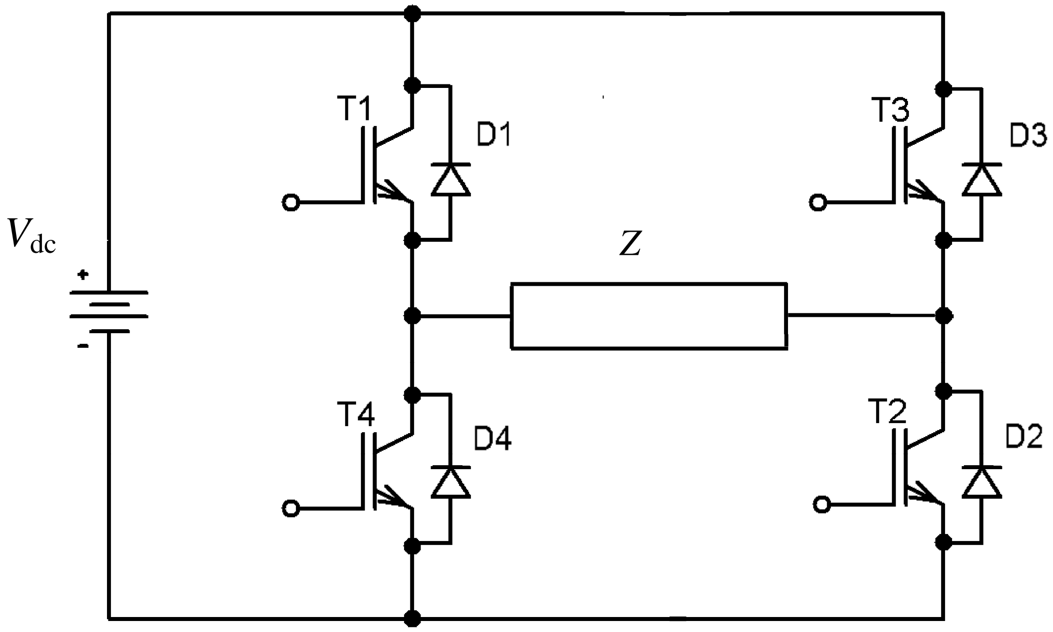

Fig. 3(a)

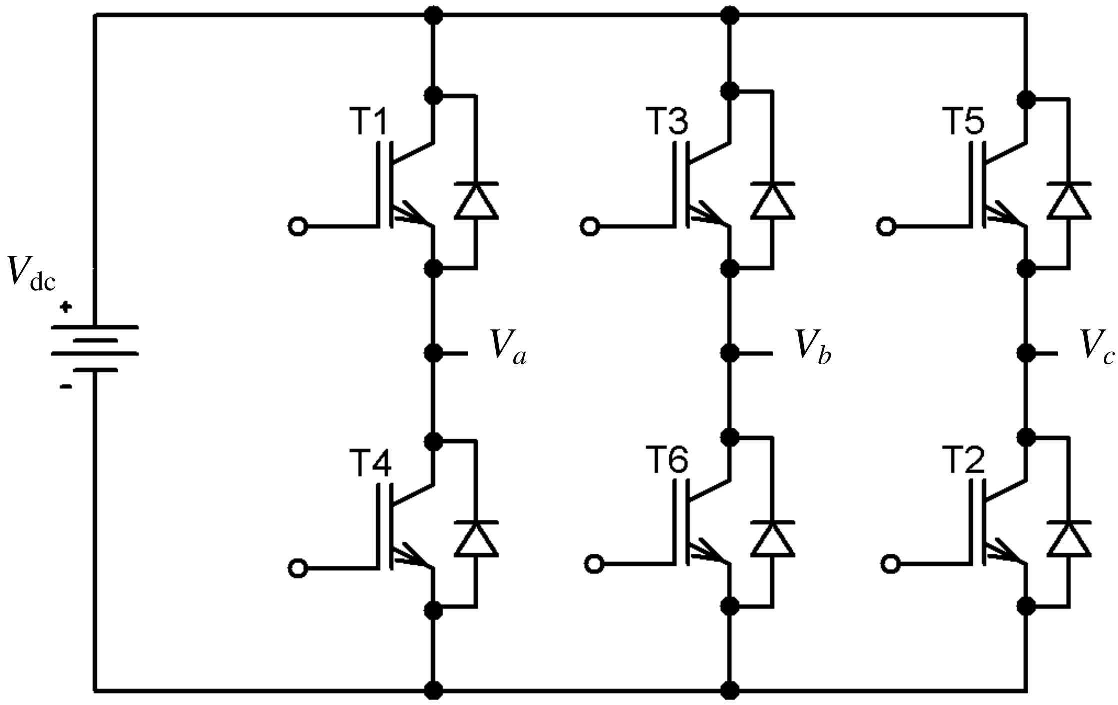

Fig. 3(b)

4 (a) Figure 4 shows a dc-dc converter circuit, where the output voltage V_O is related to the input voltage, V_{IN}. T_{ON} is the period during each cycle when the MOSFET transistor is on and f is the switching frequency.

(i) Derive a function relating V_O to V_{IN} using ρ, where ρ is given by $T_{ON} f$. Assume the transistor and diode are ideal, the inductor current is continuous and that V_{IN} is constant over the switching cycle. [20%]

(ii) For V_{IN} = 5 V and ρ = 2/3, find the voltage V_O . [10%]

(iii) When the average output power is 5 W, with the conditions above, find the minimum value of inductance L (shown in Fig. 4), if f is 100 kHz. [25%]

(b) Inductors of larger and smaller values than that calculated in part (a) are found in the catalogue of a supplier.

(i) Carefully sketch waveforms for the inductor currents you will expect for larger and smaller values of L, when the input and output voltages are the same as in part (a) (ii) with an average output power of 5 W. [25%]

(ii) Discuss carefully the implications for the choice of capacitor C, shown in Fig. 4, when operating with either inductor. [20%]

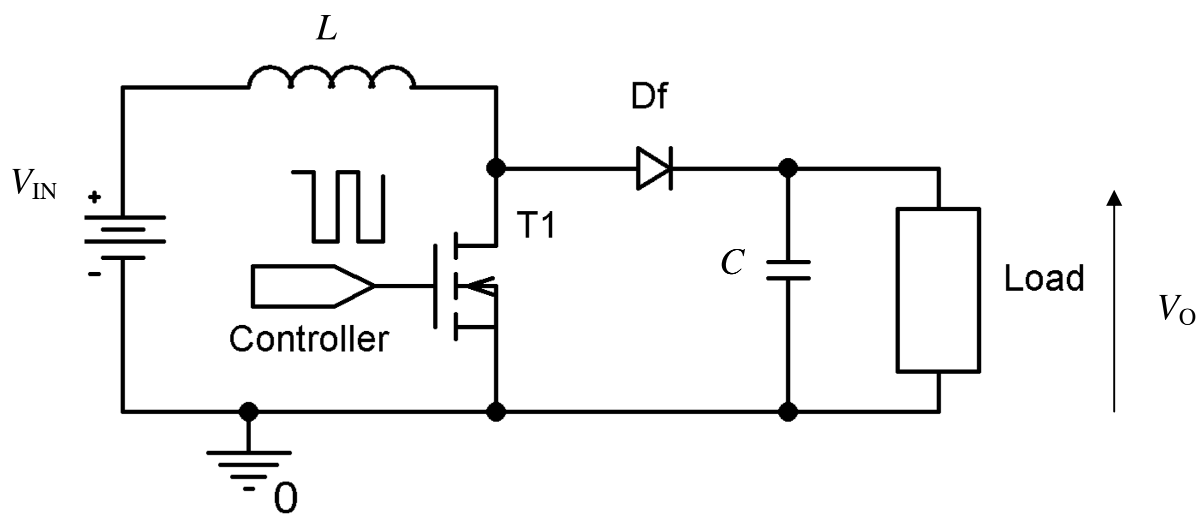

Fig. 4

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