EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 4 May 2021 1.30 to 3.10

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 and at the top of each answer sheet.*

STATIONERY REQUIREMENTS
Write on single-sided paper.

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed.
You are allowed access to the electronic version of the Engineering Data Books.

10 minutes reading time is allowed for this paper at the start of the exam.

The time taken for scanning/uploading answers is 15 minutes.

Your script is to be uploaded as a single consolidated pdf containing all answers.

1 A single phase, full-wave, diode rectifier is shown in Fig. 1. The input AC voltage has a Root-Mean-Square (RMS) value V and a frequency f. The AC source is considered as an ideal power supply without internal impedance. The load is purely resistive and the resistance is R. The diodes are assumed to be ideal.

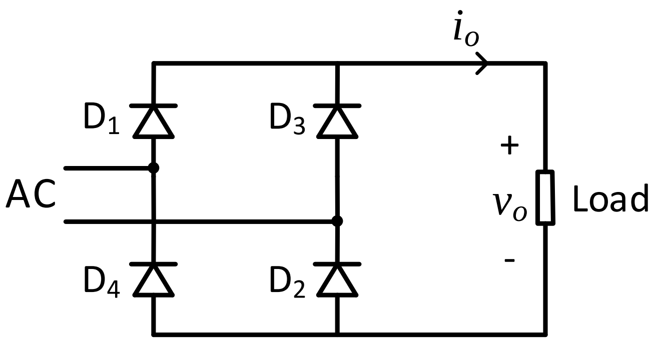

Fig. 1: Single phase diode rectifier

(a) Sketch waveform of load voltage v_o and load current i_o. Derive the expression of the average load current and the peak value of the largest harmonic of the load current. [30%]

(b) A capacitor C can be connected at the output to smooth the load voltage. By using the simplified method, sketch the waveform of the load voltage v_o and state your assumptions. Derive the expression of the peak-to-peak value of the load voltage v_o. [20%]

(c) A Flyback converter can be connected to the output of this rectifier. Sketch the circuit of the Flyback converter and give two advantages of the Flyback converter over the Buck-Boost converter. [20%]

(d) The combined rectifier and Flyback converter is connected to a 230 V mains to supply a 50 W load. If the power electronic switch of the Flyback converter is required to operate at 40% duty ratio in continuous current mode, calculate the transformer turns ratio of the Flyback in order to have the load current as 10 A. The circuit is considered as lossless and all voltage ripples are neglected. [30%]

2 (a) Draw the cross-section structures of a Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFET) and an Insulated-Gate Bipolar Transistor (IGBT) and explain briefly the structural and operational difference between the two. [30%]

(b) Explain the differences between saturation in a MOSFET and saturation in a bipolar device. Draw schematically the charge distribution within the layers of a power Bipolar Junction Transistor (BJT) in four cases: (i) active region, (ii) quasi-saturation region, (iii) saturation region, and (iv) hard saturation. [30%]

(c) A power device is formed of an IGBT rated for 1.2 kV placed in parallel with a MOSFET rated for 600 V. Assume that gate terminal is common and the IGBT and the MOSFET have the same threshold voltage and same surface area. The cathode of the IGBT is connected to the source of the MOSFET and the anode of the IGBT is connected to the drain of the MOSFET.

(i) Briefly analyse the behaviour of the power device in terms of breakdown voltage and leakage current during the off-state (blocking mode). [20%]

(ii) Describe briefly the operation of the power device during the reverse conducting mode (the current flowing from the source/cathode terminal of the power device to the drain/anode terminal of the power device). Assume that in this mode the gate is shorted to the source/cathode terminal. [20%]

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3 A Boost converter has an input voltage V_d, input current I_d, output voltage V_o, and output current I_o. The load of this Boost converter is R and the inductor is L. The power electronic switch of this Boost converter has a duty ratio D and the switching period is T_s. The current conduction coefficient K is given as $K = 2L/RT_s$.

(a) Sketch the circuit of the Boost converter and derive the voltage transfer function $M(D)$ when the Boost converter operates in continuous current mode. [20%]

(b) Prove that when

$$K < D(1-D)^2$$

is met, the Boost converter operates in discontinuous current mode. [30%]

(c) Prove that the voltage transfer function is

$$M(K,D) = \frac{1+\sqrt{1+\frac{4D^2}{K}}}{2}$$

when the Boost converter operates in discontinuous current mode. [30%]

(d) This Boost converter operates in 100 kHz switching frequency with the load $R = 1$ kΩ. Figure 2 shows the voltage conversion ratio V_o/V_d (Y-axis) versus the duty ratio D (X-axis) from 0.5 to 0.8 while the curve changes its shape when D is 0.6. Calculate the value of L, and calculate the value of V_o/V_d when D is 0.5 and 0.7, respectively. [20%]

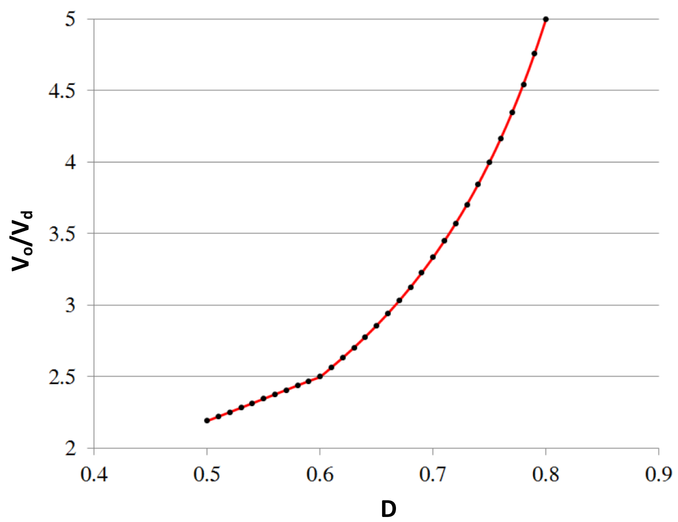

Fig. 2

4 An H-bridge inverter is used to invert the input DC voltage V_d to the output AC voltage v_{AB} as shown in Fig. 3 where power transistors are IGBTs. The load consists of an inductor L and a resistor R.

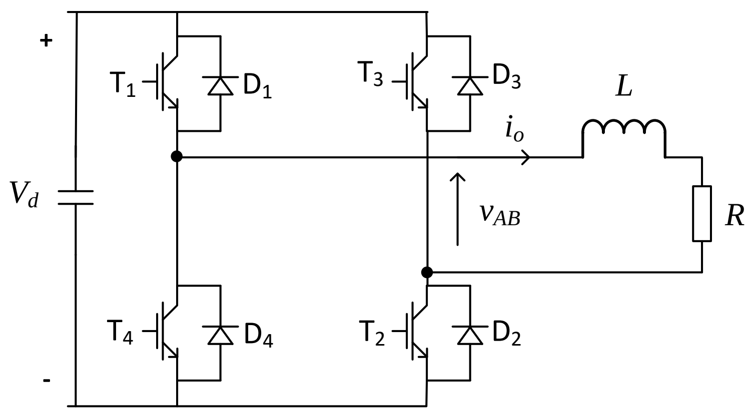

Fig. 3: H-bridge inverter circuit

(a) Sketch the gate signals of T_1 and T_4 for switching on and off events to show the dead time and explain the purpose and working principles of the dead time. [20%]

(b) The H-bridge is operated in bipolar switching with a 50% duty ratio. State the current path and status (ON or OFF) of each IGBT in each interval of one period of time in the steady state. Sketch the waveforms of output voltage v_{AB} and current i_o. [20%]

(c) All IGBTs in this circuit have zero switch-on loss. Explain the reason (hint: consider the current path during intervals of the dead time). [20%]

(d) Derive the RMS value of the fundamental output voltage v_{AB1} when using bipolar switching with a 50% duty ratio and neglecting the dead time. Comment on the effect of the dead time on the output voltage if the dead time is not neglected. [20%]

(e) Calculate the RMS value of the fundamental output voltage of the inverter when modulation is 90% and the dead time is neglected. An inductor is connected between the inverter output and load as a filter. Comment on the filter inductance L_f for the bipolar and unipolar Pulse Width Modulation (PWM) switching schemes if both schemes use the same switching frequency. [20%]

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