

CITY UNIVERSITY OF HONG KONG

Course code & title : EE 6427 Modern Power Electronics
Session : Semester B 2010/2011
Time allowed : Three hours

This paper has SIX pages (including this page).

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1. This paper consists of 5 questions.
 2. Choose **ANY FOUR** questions. (25 marks per question)
 3. The full mark of this paper is 100.
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Materials, aids & instruments permitted to be used during examination:

1. Approved calculator
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Answer any FOUR questions:

Q1

(a) Fig.Q1a shows a simplified circuit of a 2-level power inverter. Given that a switching pattern (or voltage vector) refers to the labeling of the conducting switches for each switching state, write down the 6 non-zero voltage vectors and the 2 zero-vectors.

(6 marks)

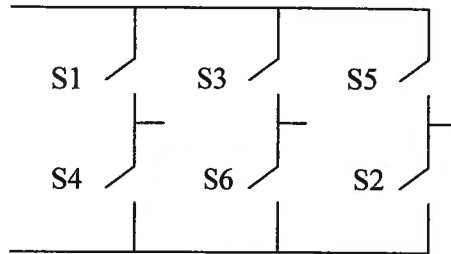


Fig.Q1a

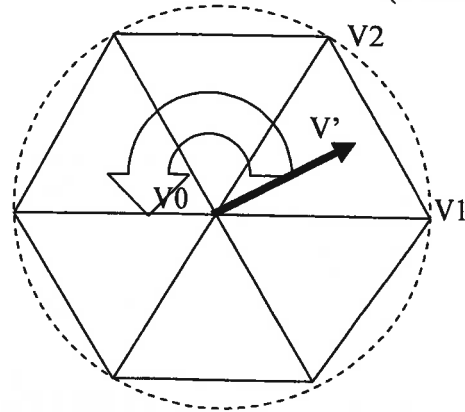


Fig. Q1b

(b) Label the non-zero voltage vectors in the 6 vertices of the hexagon as V1 to V6 and the 2 zero vectors V0 and V7 in the centre. With the help of the vector diagram in Fig.Q1b, and given that the space vector switching period is T_s , and switching times for V0 to V6 are T_0 to T_6 , respectively, write down the 6 sets of "general" voltage-vector equations for the large vector V' (shown in Fig.Q1a.) as it moves into the 6 triangular sectors (i.e. each 60-degree sections)

Hint: use the right vectors for each triangular sector.

(12 marks)

(c) The overall electric load of an installation can be represented as an inductive-resistive load with inductance of 200mH and resistance of $10\ \Omega$ as shown in Fig.Q5c.

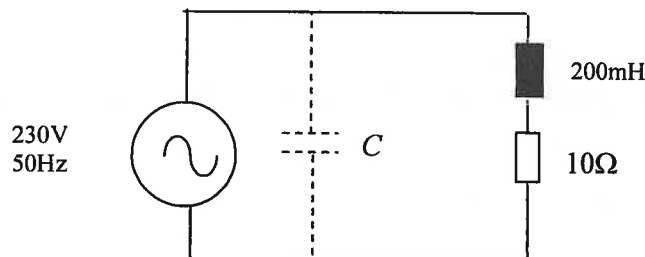


Fig.Q1c

(i) Determine the input power factor (3 marks)

(ii) Determine the value of the capacitor C needed to raise the power factor to unity.

(4 marks)

Q.2

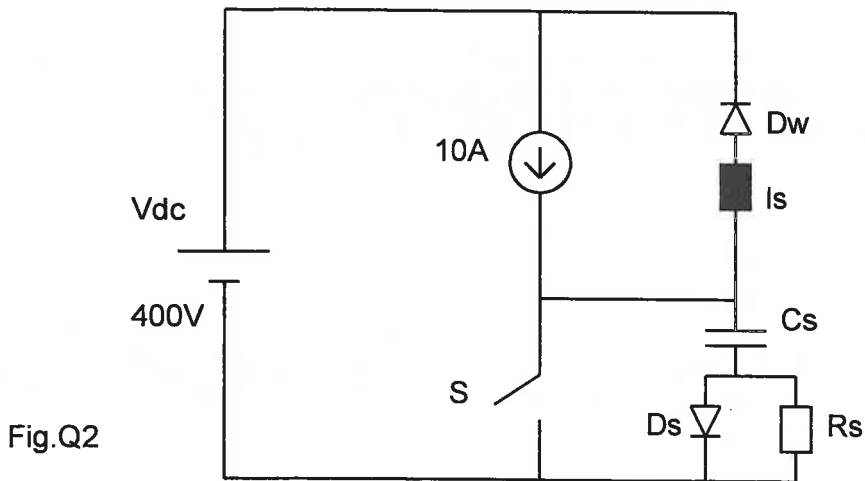


Fig.Q2 shows a power electronic switching circuit consisting of a highly inductive load represented as a current source of 10A, a power switch S and a free wheeling diode D_w . Components (l_s , R_s , C_s , D_s) are added to this circuit to ensure safe operation.

Given that the rate of change of voltage (dv/dt) and the rate of change of current (di/dt) of the switch are to be limited at $200V/\mu s$ and $20A/\mu s$, respectively, and that the minimum ON time of the switch S is $10\mu s$,

- explain the functions of the components l_s , R_s , C_s and D_s ; (4 marks)
- determine suitable values for l_s , R_s and C_s ; (6 marks)
- estimate the peak voltage across the switch S immediately after its turn-off. (5 marks)
- If the free-wheeling diode D_w has a stored charge Q_{rr} of $2\mu C$ and its snappiness factor is $1/4$, calculate the reverse recovery time t_{rr} of and peak reverse current I_{rr} in the diode D_w . (8 marks)
- What is the power dissipation in the resistor R_s if the switching frequency of S is $1kHz$? (2 marks)

Q3

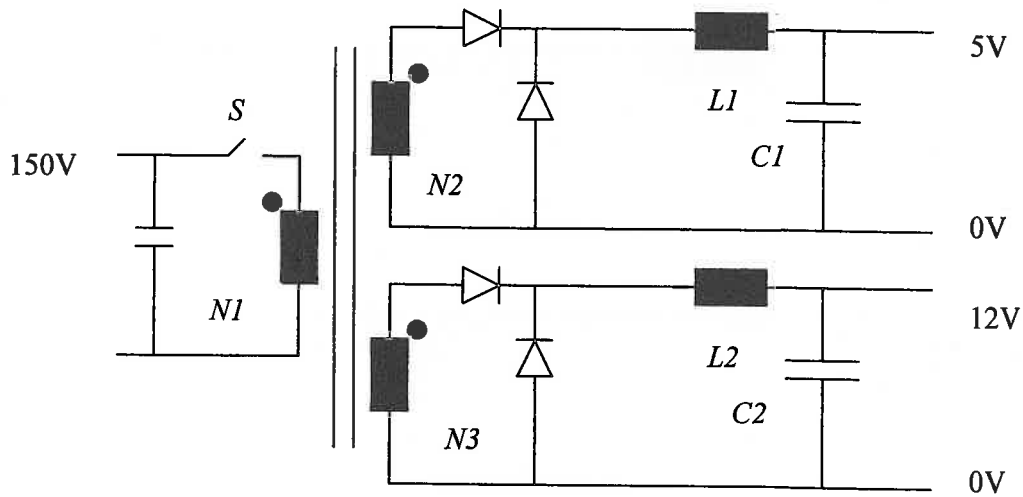


Fig.Q3

A forward converter (Fig.Q3) is required to provide two isolated dc voltage outputs of 5V and 12V. The input dc voltage is 150V. The switching frequency is set at 200kHz. The maximum duty cycle d must not exceed 0.6. The primary winding of the transformer has 100 turns (i.e. $N1=100$). The inductor currents become discontinuous when the load is reduced to 20% of the rated load. The 5V power supply is rated at 25W. The 12V power supply is rated at 60W.

- (a) Determine the number of turns for the two secondary windings, i.e. $N2$ and $N3$.
(6 marks)
- (b) If the duty cycle d is set at about 0.56, calculate the filter inductances $L1$ and $L2$.
(6 marks)
- (c) Determine the peak switch current.
(8 marks)
- (d) If the transformer is not ideal and the leakage and magnetizing inductances have to be considered, explain how the circuit should be modified in order to recover the energy stored in the magnetizing inductance.
(5 marks)

Q4

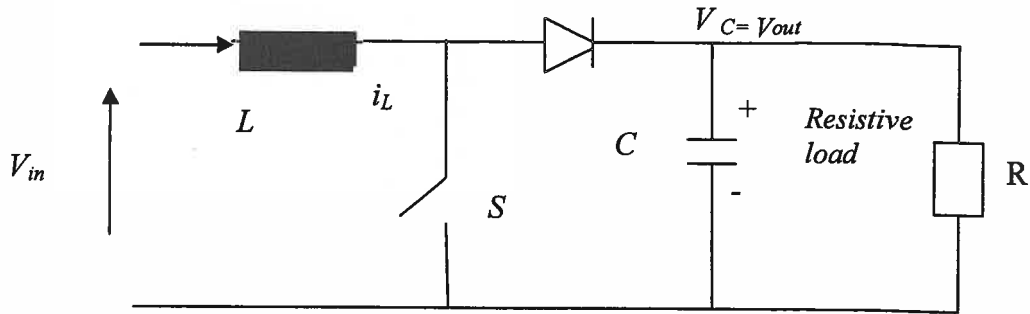


Fig.Q4

Fig.Q4 shows the schematic of a boost (step-up) converter.

The general form of its state-space equation in time domain is

$$\frac{dX}{dt} = AX + BU$$

$$Y = CX$$

where X is the state vector, U is the forcing function and Y is the output; A, B and C are matrixes describing the characteristics of the system. Let the state vector be $X = \begin{bmatrix} i_L \\ v_C \end{bmatrix}$ and the output Y is the output voltage of the boost converter v_C .

(a) Assuming that the inductor current is continuous, sketch the equivalent circuits for the conducting paths and derive the state-space equations (using i_L and v_C as state variables) in the time domain for the circuit shown in Fig.Q4 (including the effect of the load) when the

- (i) power switch S is turned on;
- (ii) power switch S is turned off.

(14 marks)

(b) Using the results in (a) and for a nominal switching duty cycle of d , derive the “averaged” state-space equation in the time domain for the converter.

(6 marks)

(c) Derive the steady-state voltage gain equation of the boost converter in terms of V_{in} , V_{out} and the steady-state duty cycle D .

(5 marks)

Q5

- (a) Sketch a typical safe operating area (SOA) of a power MOSFET and explain the reasons for the limitations of the SOA of a power MOSFET. (3 marks)
- (b) Briefly explain why power MOSFETs can be used in parallel to increase the current capability. (4 marks)
- (c) In terms of the structures of the devices, briefly explain why power MOSFETs generally have lower current capability than power Bipolar Transistors (BJTs) (5 marks)
- (d) Fig.Q5 shows a half-bridge power inverter feeding an inductive load. With the aid of the circuit diagrams showing the current path, explain how soft-switching can be achieved in this circuit.

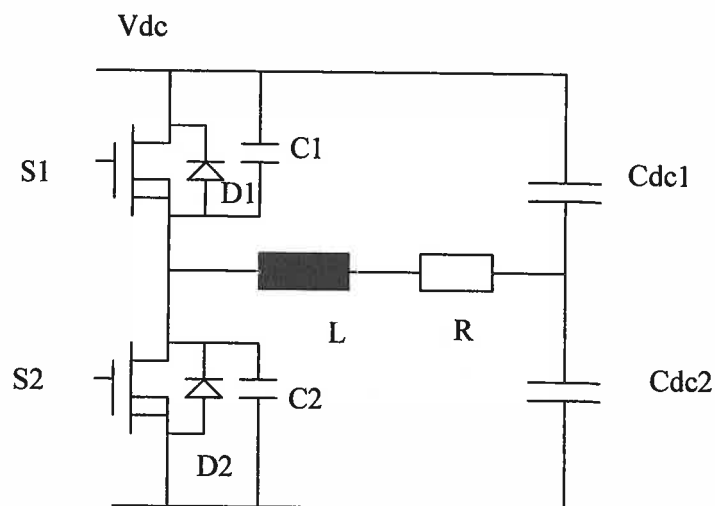


Fig.Q5

- (i) Sketch typical switching waveforms of the gating signals of power switches $S1$ and $S2$. (3 marks)
- (ii) With the aid of equivalent circuits and the switching waveforms in (d-i), explain the six operating modes of this inverter in order that both $S1$ and $S2$ be zero-voltage-switched. (6 marks)
- (iii) Give one condition that may not allow soft-switching to occur in the circuit and suggest one solution to solve this problem. (4 marks)