

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2003

MSc and EEE PART III/IV: M.Eng., B.Eng. and ACGI

POWER ELECTRONICS AND MACHINES

Friday, 16 May 10:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer FOUR questions.

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible

First Marker(s) : T.C. Green

Second Marker(s) : B.C. Pal

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1. A switch-mode power supply (SMPS) is required to form a -15 V supply (V_o) from an original source of 5 V (V_I). Two possible solutions are examined in this question. The circuit is required to supply output currents between 0.1 A and 2.0 A. The switching frequency chosen is 25 kHz and the output voltage ripple must be less than 100 mV (peak to peak)
 - (a) For a flyback SMPS
 - (i) Draw a circuit diagram of the SMPS [2]
 - (ii) Give the expression for the ratio of output voltage to input voltage for continuous operation [1]
 - (iii) Choose an inductor value to ensure the circuit remains in continuous operation. [4]
 - (iv) Specify the effective series resistance of the capacitor [3]
 - (b) For a Ćuk SMPS
 - (i) Draw a circuit diagram of the SMPS [2]
 - (ii) Give the expression for the ratio of output voltage to input voltage for continuous operation [1]
 - (iii) Choose inductor values to ensure the circuit remains in continuous operation. [4]
 - (iv) Specify the effective series resistance of the capacitor [3]

2.

- (a) Figure Q2a shows the drain-source voltage and drain current of the transistor in figure Q2b. The parameters marked in the figure have the following values:

$$\begin{aligned} T &= 20 \mu\text{s} \\ t_{On} &= 16 \mu\text{s} \\ V_{DC} &= 550 \text{ V} \\ V_{DS(On)} &= 2.5 \text{ V} \\ I_L &= 25 \text{ A} \\ t_{ri} &= 150 \text{ ns} \\ t_{fv} &= 30 \text{ ns} \\ t_{rv} &= 30 \text{ ns} \\ t_{fi} &= 200 \text{ ns} \end{aligned}$$

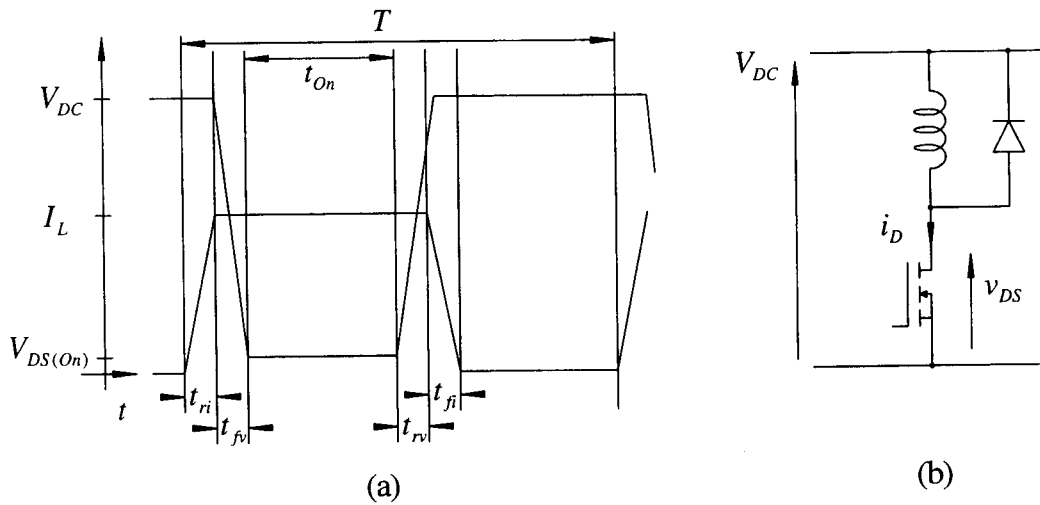


Figure Q2

Calculate the power loss in the transistor.

[6]

- (b) A turn-off snubber is to be added to the circuit of Figure Q2b to reduce the power loss in the transistor. The capacitor is to be chosen so that the voltage across it rises in exactly the fall time of the drain current (t_{fi}).

- Sketch the circuit to be used
- Sketch the waveforms of the current in the collector and voltage across the snubber capacitor
- Calculate the value of capacitor required
- Choose a suitable discharge resistor
- Calculate the turn-off power loss in the transistor and the loss in the reset resistor

[2]

[2]

[4]

[2]

[4]

- 3.
- (a) For a single-phase DC to AC converter (inverter):
 - (i) Sketch the circuit diagram of the circuit [2]
 - (ii) Describe its operation and in particular describe how the signals to control the switches are obtained [2]
 - (iii) Sketch the AC voltage waveform in the time domain [1]
 - (iv) Sketch the frequency spectrum of the AC voltage and describe its features [2]

 - (b) For a single-phase rectifier (AC to DC converter) using a diode bridge and a large valued smoothing capacitor:
 - (i) Sketch the circuit diagram of the circuit [1]
 - (ii) Describe its operation and in particular what determines the shape of the current waveform [2]
 - (iii) Sketch the AC current waveform in the time domain [1]
 - (iv) Sketch the frequency spectrum of the AC current and describe its features [2]

 - (c) For a single-phase AC to DC converter using a boost switch-mode circuit:
 - (i) Sketch the circuit diagram of the circuit [2]
 - (ii) Describe its operation and in particular describe how the signals to control the switch is obtained [2]
 - (iii) Sketch the AC current waveform in the time domain [1]
 - (iv) Sketch the frequency spectrum of the AC current and describe its features [2]

4.

- (a) Sketch a circuit diagram of a DC to DC converter suitable for running a DC machine in all 4 quadrants of the torque-speed plane. [2]
- (b) Derive an equation relating the torque produced by a DC machine to its speed [3]
- (c) Figure Q4 shows the typical limits of operation of a DC machine in terms of torque and speed. Explain why the limits have this shape [4]
- (d) A particular machine has the following properties:
- Maximum DC input voltage 100 V
 - Armature resistance 0.5Ω
 - Field flux at maximum field current 18 mWb
 - Armature constant $12.5 \text{ V.s.rad}^{-1}.\text{Wb}^{-1}$ (or $\text{N.m.A}^{-1}.\text{Wb}^{-1}$)
 - Rated armature current 8 A
- (i) Calculate the difference in speed between the no load speed and the speed when the maximum armature current is being drawn at maximum field current. [2]
- (ii) Calculate the maximum speed the machine can achieve under full load with maximum field current. [3]
- (iii) Calculate the maximum speed the machine can achieve under full load with field current at half of its maximum value [3]
- (iv) Compare the torque and power available under the conditions under parts (ii) and (iii) [3]

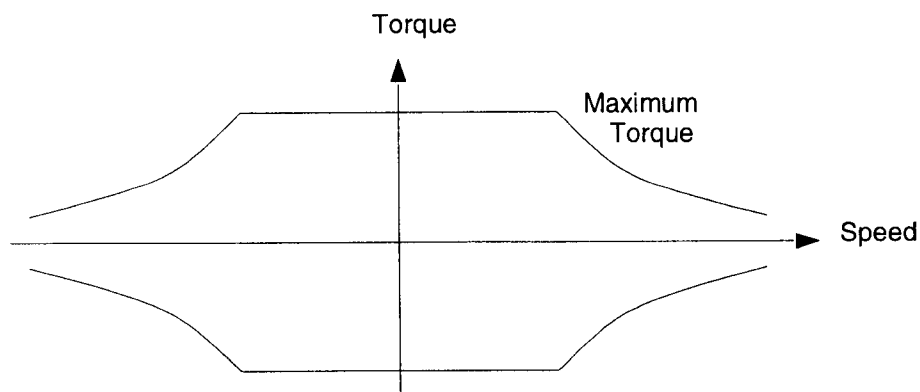


Figure Q4

5. Figure Q5 shows a Zero-voltage switched (ZVS) quasi resonant converter. The operation of the circuit occurs in four stages:

- I MOSFET on
- II MOSFET off; C_R pre-charging
- III C_R and L_R in resonance; MOSFET not conducting
- IV MOSFET on; L_R discharging

(a) Sketch the shape of the waveforms of i_{L_R} and v_{C_R} [6]

(b) Describe the conditions under which the MOSFET is turned on and turn off in terms of the drain current and drain-source voltage that exists during the switching action and explain why this leads to low power loss during switching. [6]

(c) Resonant action is governed by the equations:

$$i_{L_R} = I_o \cos(\omega_R t)$$

$$v_{C_R} = V_I + \frac{I_o}{\omega_R C_R} \sin(\omega_R t)$$

For a conversion of 12 V to 5 V with an output current of 5 A; choose values of L_R and C_R such that the circuit as a whole operates with a period of 2 μ s. [8]

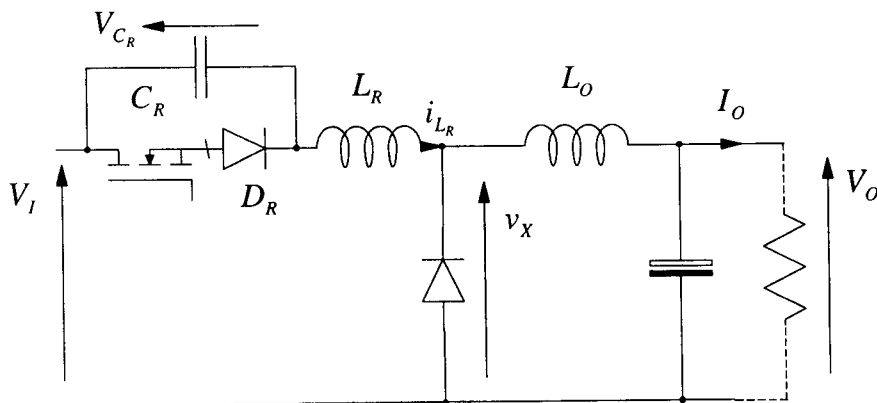


Figure Q5

6.

- (a) Uninterruptable power supplies, UPS are installed by electricity consumers to overcome power quality problems. Discuss the range of problems that a UPS can solve and state any limitations that the design of the UPS may place on its effectiveness. [8]
- (b) Explain why a double diffused vertical structure is used for high voltage, high current MOSFETs in place of the lateral structure adopted for general purpose MOSFETs. Sketch the structure of both devices. [8]
- (c) Describe how and why the double diffused MOSFET structure is modified to form an IGBT (Insulated-gate bipolar transistor) [4]