ENGINEERING TRIPOS PART IIA

Tuesday 26 April 2011 9 to 10.30

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.*

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

1 (a) A battery powered mobile X-Ray machine employs a resonant inverter to produce the high dc voltage required by the X-Ray head, as shown in Fig. 1. The *resonant tank* can be assumed to produce an ideal full wave rectified voltage of 140 kV peak at 10 kHz. The output power required is 10 kW for 100 ms and the high voltage cable has a capacitance of 50 pf m^{-1} . It is proposed that the cable capacitance is used as the smoothing capacitor. Stating your assumptions, estimate how much cable is required for 10 % ripple in the dc voltage. Give two ways by which the specification may be achieved using less cable. [50%]

(b) A battery powered electric vehicle has a three phase IGBT inverter with a nominal voltage rating of 300 V driving the main propulsion motors. To charge the batteries overnight, the inverter is disconnected from the motor and connected to the household mains through the inductors L , as shown in Fig. 2. Show that simple rectification of the three phase mains would produce a voltage considerably in excess of the normal operating voltage of the inverter. [10%]

Operation from a single phase supply, simply requires one phase to be unused, as shown in Fig. 2. The mains current is to be sinusoidal and at unity power factor. For a dc link voltage of 400 V , amplitude modulation ratio of one and a mains current of 30 A find the value of L required, stating your assumptions. Making reference to a phasor diagram, describe briefly the control method required. [30%]

By considering your value of L or otherwise choose a switching frequency for the inverter in this mode stating the basis of your choice. [10%]

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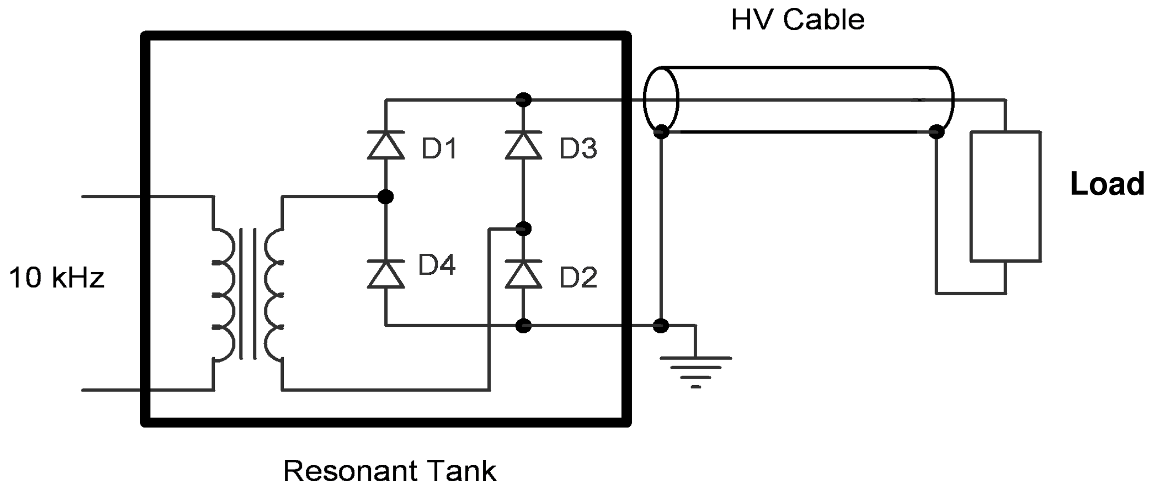

Fig. 1

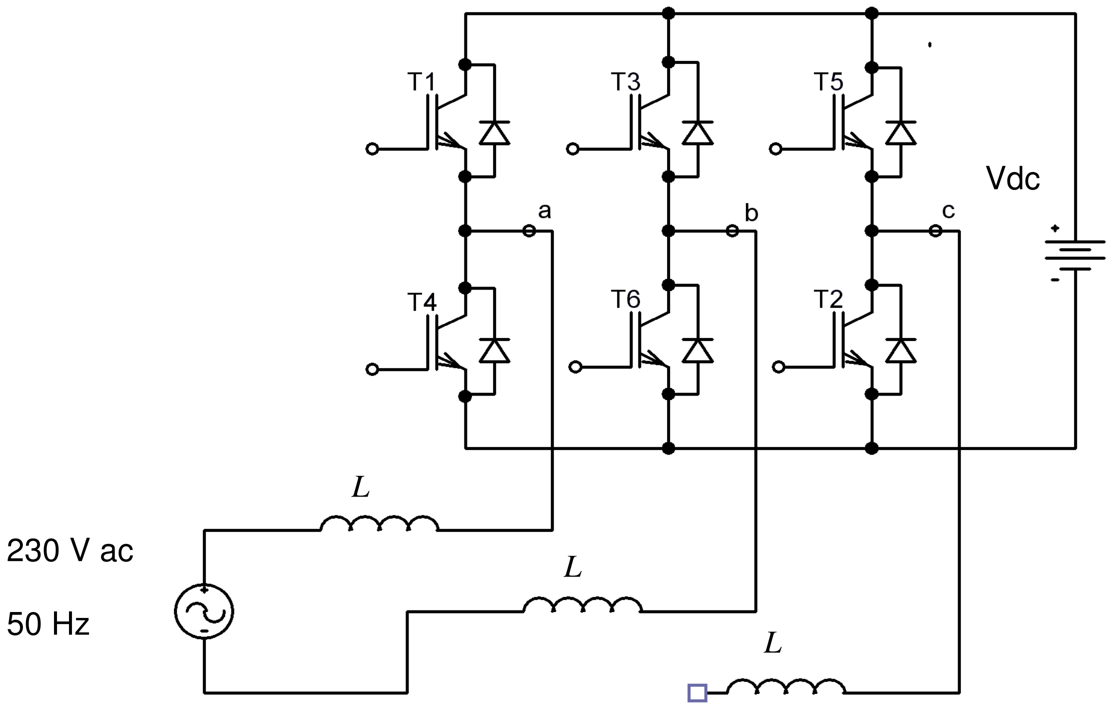

Fig. 2

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2 (a) Make a sketch showing how conventional PWM may be produced using *natural sampling*. For the three phase inverter bridge shown in Fig. 3 (a), make a detailed sketch for two cycles of the switching frequency showing how naturally sampled PWM may produce phase output waveforms, as illustrated by Fig. 3 (b). Carefully explain why a frequency modulation ratio of integer multiple of three is an attractive combination in such an inverter and describe briefly how this may be achieved in practice. [45%]

(b) A space vector modulation (SVM) scheme based on the Direct - Inverse use of the zero state vector is applied to the three phase inverter bridge shown in Fig. 3 (a). The modulation depth is adjusted by a controller and it is noted that at a particular depth of modulation pulses are dropped. For the first switching cycle when this occurs, the duty ratios are $\rho_a = 1$, $\rho_b = 0.25$ and $\rho_c = 0$, where ρ_a , ρ_b and ρ_c are defined in Fig. 3 (b). Hence find the magnitude of the voltage vector relative to the inverter's dc supply voltage and the angle of the voltage vector with respect to any of the state vectors at which it occurs. [40%]

Explain, making reference to a sketch of the voltage vector diagram for one segment, what will happen if an attempt is made to maintain this voltage magnitude at an angle of 30 degrees from the start of any segment. Find the resulting magnitude of the voltage vector relative to the inverter's dc supply voltage. [15%]

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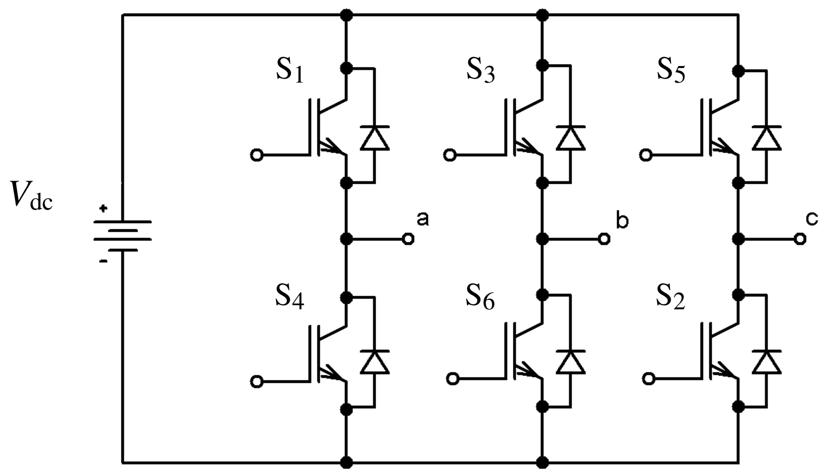

Fig. 3 (a)

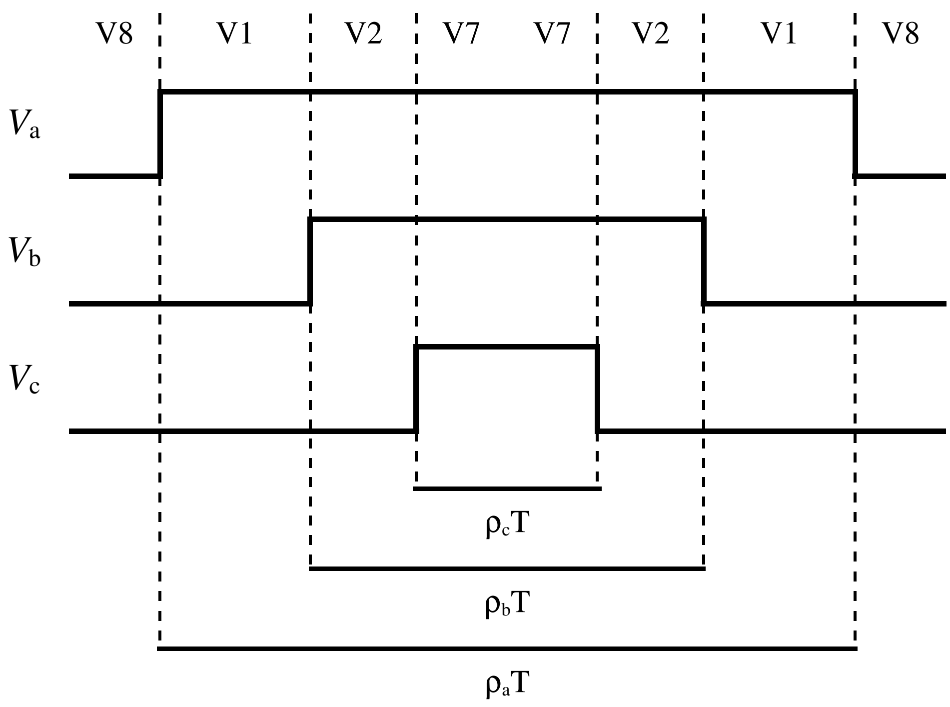

Fig. 3 (b)

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3 (a) An electric vehicle requires a dc-dc converter between the battery pack and the main drive inverter. The battery pack has a nominal voltage rating of 200 V and the inverter has a nominal dc supply rating of 500 V with considerable capacitor smoothing. By sketching current paths for the circuit of Fig. 4, show that adjusting the duty ratio of the IGBTs can control power flow to or from the batteries.

The continuous power required is 30 kW. Give three reasons why the discontinuous mode of operation is attractive when using IGBTs in this circuit at a switching frequency of 5 kHz . [40%]

(b) In the vehicle of Part (a), the inverter supply voltage is dynamically adjusted during operation. *Discontinuous mode* is to be retained at 30 kW when the inverter input is at 300 V and the battery is 200 V. Find the duty ratio of T_2 and value of L required on the boundary of discontinuous conduction for power flow to the inverter. [30%]

By sketching or otherwise, show that the current will remain discontinuous at 30 kW with an inverter input voltage of 500 V and find the new duty ratio. [25%]

Explain briefly how the direction of the power flow is controlled. [5%]

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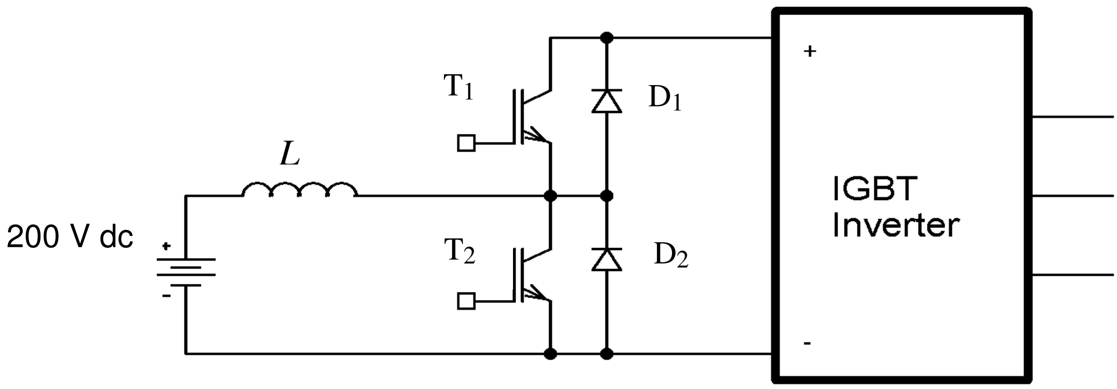

Fig. 4

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4 (a) The backlight for a display is based on a fluorescent lamp driven by a resonant inverter employing a piezoelectric transformer (PZT). The PZT can be represented by the equivalent circuit of Fig. 5 (a), where the capacitive nature of the PZT is represented by C_P and the mechanical resonance is represented by L and C. Give two reasons why the half bridge topology shown in Fig. 6 is appropriate for driving the PZT and lamp load and identify a drawback of this design. [15%]

Before the lamp is on it appears as an open circuit and a high voltage is required to *strike* the arc turning the lamp on. When the lamp is on it acts as a $100\ \mathrm{k\Omega}$ resistive load. The corresponding loaded and unloaded characteristics of the PZT are shown in Fig. 5 (b). Stating your reasoning, suggest how the PZT and lamp of should be operated to strike the arc and then dim the light. [25%]

The recommended design for the circuit of Fig. 6 suggests that the inductor L_D should be chosen to give a natural resonant frequency of L_D with C_P which is above the mechanical natural resonance of the PZT. In this case L_D and C_P act to filter the inverter output. The inductor L_D is $15\ \mu\mathrm{H}$ and C_P is $200\ \mathrm{nF}$. Find the maximum output voltage possible when the light is on if the dc supply voltage is $10\ \mathrm{V}$ and the MOSFETs are ideal. [35%]

(b) Draw an alternative alternative circuit for driving the PZT and lamp of Fig. 5, where the only power transistors are NMOS. State the advantages of your design over the circuit of Fig. 6. [25%]

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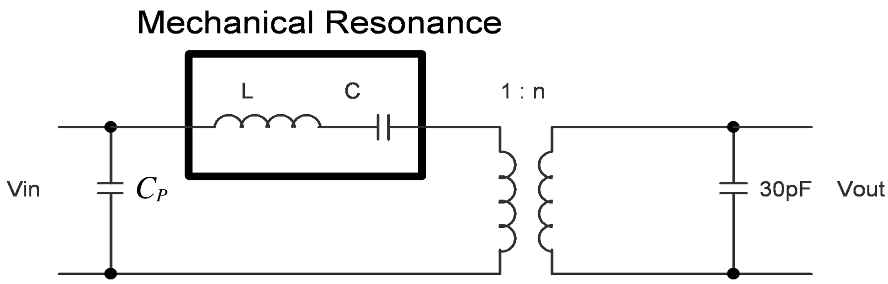


Fig 5 (a)

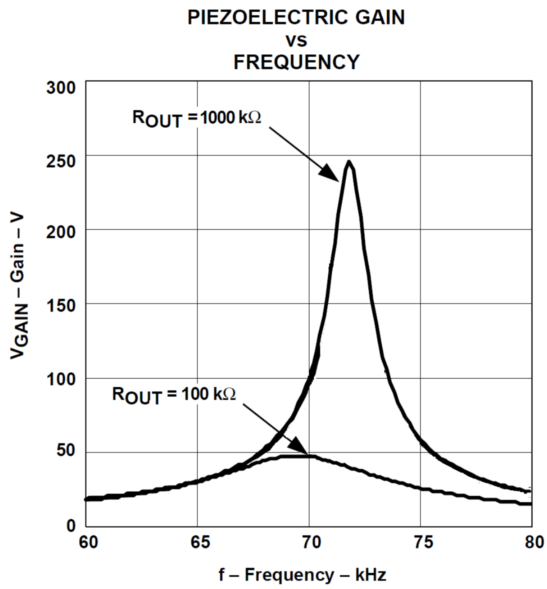
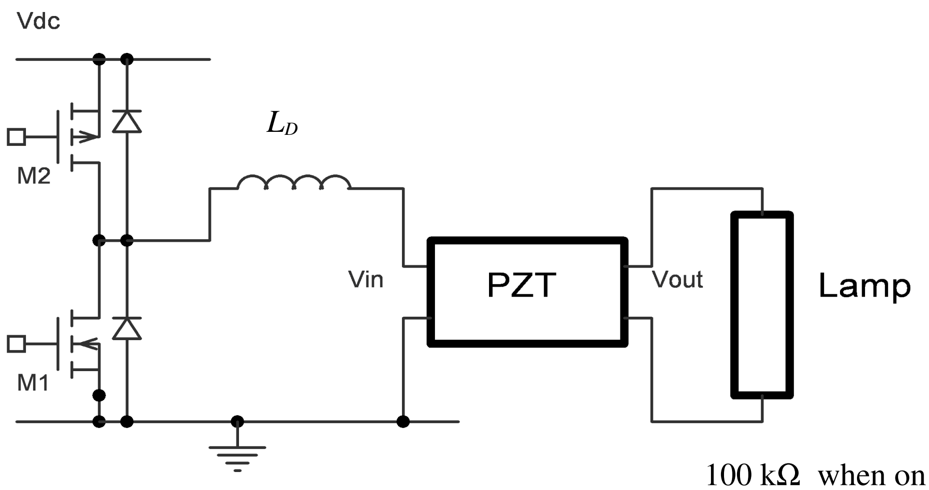


Fig. 5 (b)



100 kΩ when on

Fig. 6

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ANSWERS

1.(a)	5 m		
(b)	8.7 mH	20kHz	
2.(b)	0.913.9^{O}	0.866	
3.(b)	0.333	44.4 µH	0.447
4.(a)	1400V		

P.R. Palmer
October 2011