UNIVERSITY OF GLASGOW
Glasgow College UESTC

Degrees of MEng, BEng, MSc and BSc in Engineering

POWER ELECTRONICS (UETSC3022)

Monday 19 December 2016

10:00–12:00

Attempt all questions

Total 100 marks

The numbers in square brackets in the right-hand margin indicate the marks allotted to the part of the question against which the mark is shown. These marks are for guidance only.

DATA SHEET IS PROVIDED AT THE END OF PAPER

An electronic calculator may be used provided that it does not have a facility for either textual storage or display, or for graphical display.

Unless otherwise stated, full credit will be given only where the solution contains sufficient working with supporting explanation to justify the answer. Marks will be deducted for missing units.

A list of formulae is provided on the reverse of this title page.

Power Electronics 2 Formulae List

For an inductor: $v_L(t) = L\dfrac{di_L(t)}{dt}, \quad i_L(t) = \dfrac{1}{L}\int v_L(t)dt, \quad E_L(t) = \dfrac{1}{2}L\left[i_L(t)\right]^2$

For a capacitor: $v_C(t) = \dfrac{1}{C}\int i_C(t)dt, \quad i_C(t) = C\dfrac{dv_C(t)}{dt}, \quad E_C(t) = \dfrac{1}{2}C\left[v_C(t)\right]^2$

Average value: $V_{ave} = \dfrac{1}{T}\int_0^T v(t)dt$

RMS value: $V_{rms} = \sqrt{\dfrac{1}{T}\int_0^T v(t)^2 dt}$

Duty cycle: $D \equiv \phi = \dfrac{T_{on}}{T_{on}+T_{off}} = \dfrac{T_{on}}{T_{period}}$

Amplitude modulation index of SPWM:

$$m_a = \frac{\hat{V}_{control}}{\hat{V}_{carrier}}$$

Frequency modulation index of SPWM:

$$m_f = \frac{f_{carrier}}{f_{control}}$$

Instantaneous power:

$$p(t) = \frac{v^2(t)}{R} = i^2(t)R = v(t)\times i(t) = force \times velocity = torque \times angular\ velocity$$

Average power:

$$P = \int_0^T v(t)i(t)dt = \frac{V_{rms}^2}{R} = I_{rms}^2 R$$

reverse recovery power loss in a diode:

$$P_{RR} = Q_{RR} \times V_{R(blocking)} \times f_{switching}$$

MOSFET switching loss:

$$P_{switching} = \frac{f_{switching}V_{DS(off)}}{2}\left(T_{on}I_{on} + T_{off}I_{off}\right)$$

Thermal circuit:

$$\Delta T = P_{\text{device}} \times \Sigma\theta_{\text{XY}} \quad \text{or} \quad \Delta T(°\text{C}) = \frac{power \times time}{thermal\ capacitance}$$

Junction temperature of device:

$$T_{\text{junction}} = T_{\text{sink}} + P_{\text{device}}\left(\theta_{\text{juntion-case}} + \theta_{\text{case-sink}}\right)$$

Calculus:

$$\cos 2\theta = 2\cos^2\theta - 1 = 1 - 2\sin^2\theta$$

$$\int \cos(a\theta)d\theta = \frac{1}{a}\sin\theta \qquad \int \cos(a\theta)d\theta = -\frac{1}{a}\sin\theta$$

Q1 (a) Draw the symbols of any three typical fully-controllable power switches, clearly labeling their names, and briefly compare their maximum power ratings and switching frequency. [6]

(b) List and briefly describe at least four advantages of power electronic conversion over other power conversion ways (e.g. transformers) [4]

(c) Draw an unpolarized voltage (i.e. turn-off) snubber circuit for the power switches, and briefly describe how the circuit operates. [4]

(d) For an inductor load L=1mH, the steady-state inductor current waveform is shown in Figure Q1,

1) Calculate the average current and RMS current for the inductor. [3]

2) Derive and sketch the corresponding inductor voltage, labelling the axes clearly. [3]

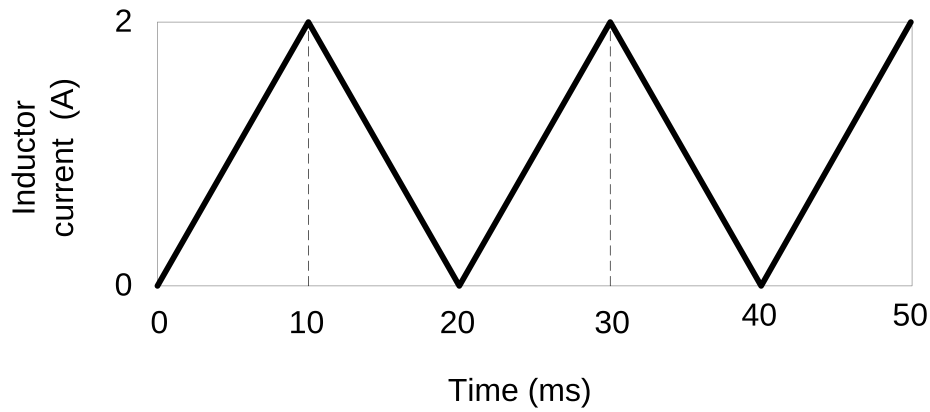

Figure Q1

Q2 For the half-wave diode rectifier circuit shown in Figure Q2, assuming the input voltage at the secondary side of the transformer is $V_{AC} = 10\sin(100\pi t)$, the capacitance C_s is 20000μF, the load resistance R_L is 10Ω.

(a) If the conduction angle of diode D is 30°, calculate the peak-to-peak ripple voltage in the output voltage V_R and the peak inverse voltage in the voltage drop V_D for the diode D. Assume the diode D is ideal for this question. [4]

(b) If the output filter capacitor C_s is removed, and the conduction voltage drop for the diode D is $V_{D(on)} = 1\text{V}$, sketch and label the voltages across the load R and the diode D separately, showing the time scale clearly. You should include the voltage drop in the diode. [6]

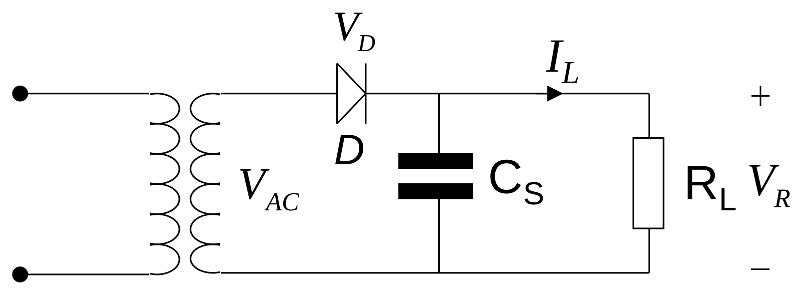

Figure Q2

(c) If the output filter capacitor C_s is removed, and the diode D in Figure Q2 is replaced with an SCR (Thyristor) with delay angle α=30° and assume the SCR is ideal for this question.

1) Briefly describe why SCRs are called half-controllable switches. [2]

2) Are SCRs unsuitable for use in systems that are purely DC? Why? [3]

3) Sketch the waveform for the output voltage V_R, indicating the delay angle α and the time scale clearly. [4]

4) Derive and calculate the average value and RMS value for the output voltage V_R respectively. [6]

Q3 Figure Q3 shows a load whose current is switched periodically with a MOSFET. It also shows a plot of the current $i_{load}(t)$ through the load for one cycle of period T. The switch may be assumed to behave ideally.

(a) Calculate the value of the duty cycle D for this waveform. [1]

(b) Calculate the average value of the current through the load. [3]

(c) Calculate the RMS value of the current through the load. [6]

(d) Calculate the average power absorbed by the load. [3]

(e) Calculate the average conduction loss in the MOSFET, taking the channel resistance to be $R_{DS(on)} = 50\text{m}\Omega$. [3]

(f) Calculate the average switching loss in the MOSFET, taking both the switch-on and switch-off times to be $T_{on} = 20$ ns and $T_{off} = 30$ ns respectively. [3]

(g) Assume the MOSFET is bolted to a heatsink of thermal resistance θ_{SA}=1.5°C/W, the thermal resistance θ_{CS} of the contact between the MOSFET case and the heatsink is 0.4°C/W, the MOSFET's junction-to-case thermal resistance θ_{JC} is 1°C/W and the MOSFET is operating in free air with an ambient temperature of 25°C, draw the thermal circuit diagram of the MOSFET and calculate the heatsink temperature, case temperature and junction temperature. [6]

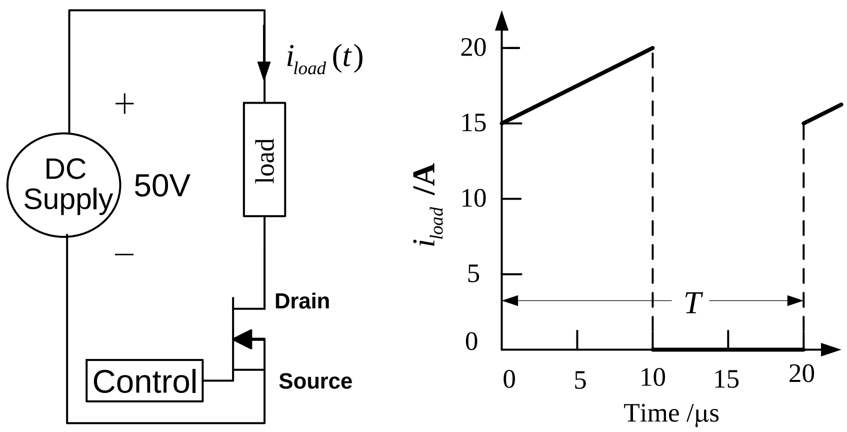

Figure Q3

Q4 A switched-mode buck-boost converter is required to deliver 12.0V at 500mA from a 5.0V supply. It runs in continuous conduction mode at 50 kHz. The circuit is shown in figure Q4 and has a 100 µH inductor. You may assume that all components are ideal and that the input and output are smoothed so effectively that their voltages may be treated as constant.

(a) Calculate the duty cycle required for the converter. [1]

(b) Calculate the average input current from the supply. [2]

(c) What are the voltages across the inductor during charging and discharging? [2]

(d) Calculate the values of di_L/dt during charging and discharging. [2]

(e) What is the value of the average current through the inductor? [3]

(f) What are the minimum and maximum values of $i_L(t)$ [4]

(g) Sketch $i_L(t)$, $i_{in}(t)$, and $v_L(t)$. An accurate scale drawing is not required but you must show the numerical values at all important points. [6]

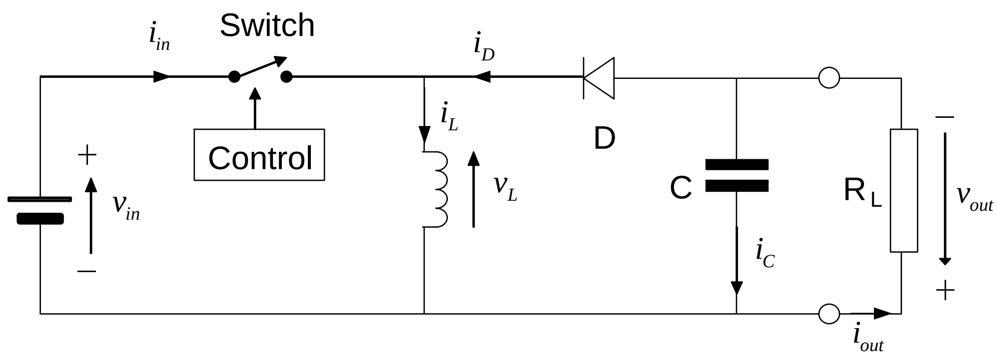

Figure Q4

Q5 Figure Q5 shows a single-phase PWM inverter with its bipolar PWM drive circuit, where the carrier frequency $f_{carrier}$ is much higher than the control signal frequency f, the control signal voltage $v_{control} = m_a \sin(2\pi ft)$, and the peak values of the triangle carrier signal are 1 and -1.

(a) If $0 < m_a \le 1$, determine the output voltage v_o of the single-phase inverter. We assume the high frequency harmonic components in the voltage v_o are neglected. [6]

(b) What is the 'square-wave' operation mode of the inverter? Indicating its benefits and disadvantages. [4]

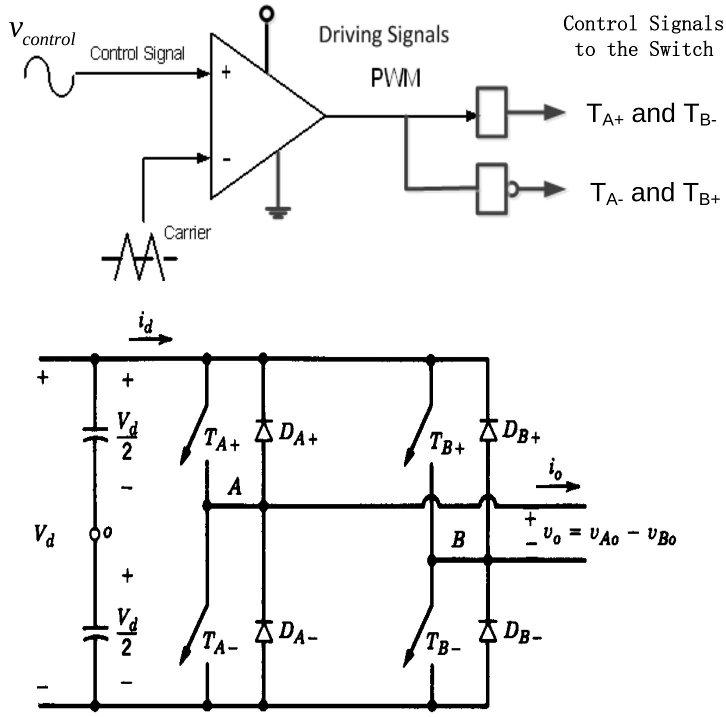

Figure Q5