University of Glasgow

DEGREES OF MENG, BENG AND BSC (HONS) IN ENGINEERING

POWER ELECTRONICS (UETSC3022)

2018

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.

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:

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

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) List the primary differences between ideal semiconductor power switches and actual semiconductor power switches. [5]

(b) The basic technical specifications of a power electronic converter for wind turbines are output rated power – 1MW, the rated voltage – 690V, switching frequency – 2kHz. Choose an appropriate fully-controllable power switch devices for the construction of the power converter circuit, and briefly give the reasons for your choice. [5]

(c) List and briefly describe the advantages and disadvantages of switching power electronic converters over linear voltage regulators. [5]

(d) Draw a polarized current (i.e. turn-on) snubber circuit for the power switches, and briefly describe how does the circuit operate. [5]

(e) Assuming a voltage signal is given as $V_1 = 10\sin(100\pi t) + 10$.

1) Calculate the RMS value of the voltage signal. [3]

2) Calculate the form factor for the voltage signal. [2]

Q2 For the full-wave diode rectifier circuit shown in Figure Q2-1, assuming the input voltage is $V_{AC} = 60\sin(100\pi t)$, the conduction angle of the diode is 30°, and the load resistance R_L = 10Ω, and the capacitor C_S = 15,000μF. We assume that all components are perfect and neglect the voltage drop across the diodes.

(a) Estimate 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. [5]

(b) If the output filter capacitor C_s is removed, sketch and label the voltages across the load R_L and the diode D separately, showing the time scale clearly. Calculate the RMS value of the output voltage V_R. [5]

(e) If the ripple voltage across the load resistance R_L must not exceed 1V peak-to-peak. Calculate the value of smoothing capacitance required. You may assume that the capacitor provides current to the load for each complete cycle of the rectified voltage. [5]

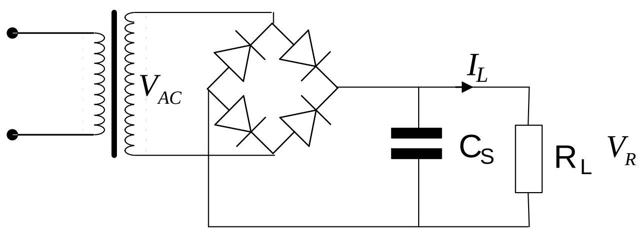

Figure Q2-1

For the half-wave SCRs based rectifier shown in Figure Q2-2, assuming the supply voltage is $V_{AC} = 10\sin(100\pi t)$, the delay angle of the SCR is 30°, and the load resistance R_L = 10Ω.

(a) Sketch the waveform for the output voltage V_R, indicating the delay angle and the time scale clearly. [5]

(b) Calculate the RMS value for the output voltage V_R and the average power consumption for the load resistance R_L respectively. [5]

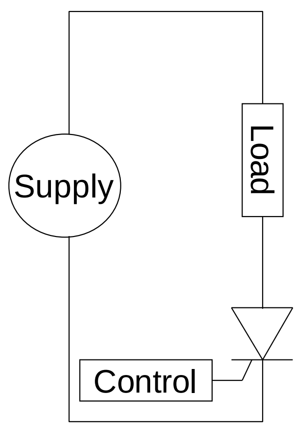

Figure Q2-2

Q3 A transistor is mounted on a heatsink, with the thermal resistances being given in the table below.

(a) Draw the thermal circuit diagram for the transistor, indicating the names of every thermal resistance clearly. [4]

(b) Calculate the heatsink temperature, case temperature and junction temperature for the transistor if the ambient temperature is 25°C and the heatsink thermal resistance is 1°C/W? [6]

Name	Transistor
Junction-Case resistance	θ_{JC}=0.2°C/W
Case-Sink resistance	θ_{CS}=0.1°C/W
Power loss heat	60W

Table 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 duty cycle D and average value for this load current waveform. [4]

(b) Calculate the average power consumption by the load. [3]

(d) Calculate the average conduction loss in the MOSFET, taking the channel resistance to be $R_{DS(on)} = 20\text{m}\Omega$. [4]

(e) Calculate the average switching loss in the MOSFET, taking both the switching-on and switching-off times to be $T_{on} = T_{off} = 20$ ns. [4]

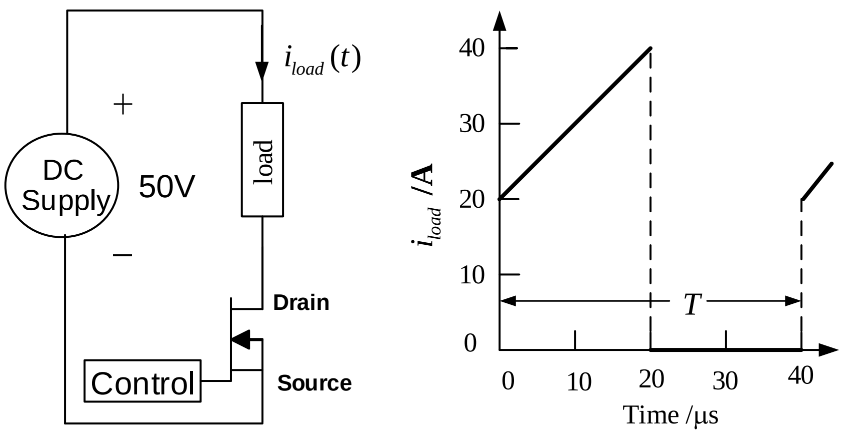

Figure Q3

Q4 A switched-mode boost converter is required to deliver 15.0V at 1A from a 5.0V supply. It runs in continuous conduction mode at 50 kHz. The circuit is shown in Figure Q4-1 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. [2]

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

(c) Calculate the inductor voltages during charging and discharging of the inductor respectively [4]

(e) Calculate the minimum and maximum values of $i_L(t)$ [4]

(f) Sketch $i_L(t)$ and $v_L(t)$. An accurate scale drawing is not required but you must show the numerical values at all important points. [4]

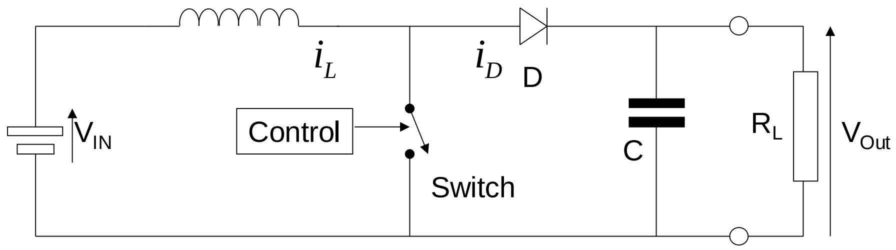

Figure Q4-1

Figure Q4-2 shows a single-phase PWM converter with its bipolar PWM drive circuit, where and dc bus voltage V_d=100V, the carrier frequency $f_{carrier}$ is much higher than the control signal frequency f, the control signal $v_{control} = m_a \sin(2\pi ft)$, and the peak values of the triangle carrier signal are 1 and -1.

(g) When $m_a = 0.5$, determine the output voltage v_o of the single-phase converter. We assume the high frequency harmonic components in the voltage v_o is neglected. [3]

(h) When $m_a >> 1$, what will happen to the converter? Indicating its benefits and disadvantages. [3]

(i) If the control signal is changed to $v_{control} = 0.6$ V, determine the average output voltage v_o of the single-phase converter. We assume the high frequency harmonic components in the voltage v_o is neglected. [3]

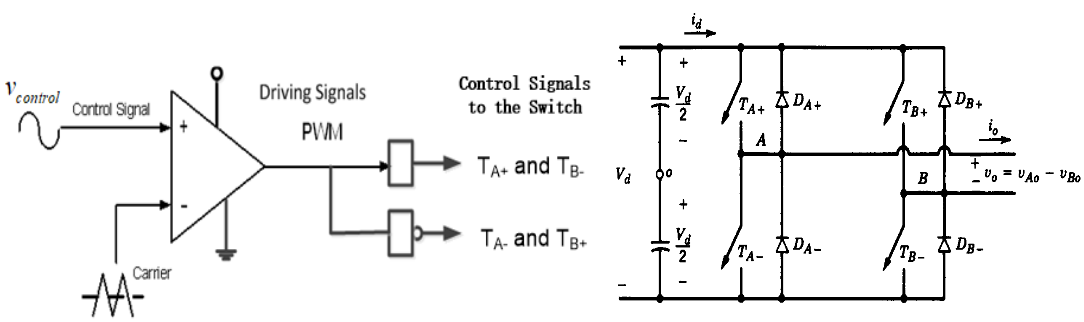

Figure Q4-2