UNIVERSITY OF SWAZILAND

MAIN EXAMINATION, SECOND SEMESTER MAY 2015

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

TITLE OF PAPER:	POWER ELECTRONICS
COURSE CODE:	EE422
TIME ALLOWED:	THREE HOURS

INSTRUCTIONS:

1. **There are five questions in this paper. Answer any FOUR questions. Each question carries 25 marks.**
2. **If you think not enough data has been given in any question you may assume any reasonable values.**
3. **A drawing sheet is included at the end of the paper.**

THIS PAPER SHOULD NOT BE OPENED UNTIL PERMISSION HAS BEEN GIVEN BY THE INVIGILATOR

THIS PAPER CONTAINS SIX (6) PAGES INCLUDING THIS PAGE

QUESTION ONE *(25 marks)*

(a) A power BJT used as a switch has the following parameters. You may assume usual notation.

$V_{CE(sat)} = 1.5V$ $\quad t_{ri} = t_{fi} = 150ns$ $\quad t_{rv} = t_{fv} = 100ns$

$t_{d(on)} = t_{d(off)} = 100ns$

In this application, the collector voltage at the OFF state is $200V$ and the load current is $50A$. The duty cycle is 50% and the transistor is driven by a square wave signal of $20kHz$.

(i) Draw the linearised voltage and current waveforms of the switch for one switching cycle marking the relevant parameters.

(5 marks)

(ii) Calculate the energy dissipated in the switch during each of the transient and steady state phases in one switching cycle. Hence determine the device power loss.

(10 marks)

(b) A converter uses a BJT as the switch. The BJT dissipates a $50W$ of power and is mounted on a heat sink. You may assume the following data.

$\theta_{jc} = 1^0 \frac{C}{W}$ $\quad T_{j(max)} = 125^0C$ $\quad T_{amb} = 50^0C$

(i) Find the optimum thermal specification of the heat sink required, if the thermal resistance of the mounting insulator is $0.3^0 \frac{C}{W}$

(6 marks)

(ii) Calculate the temperature of the case and the heat sink under the steady state of operation.

(4 marks)

QUESTION TWO ***(25 marks)***

A single phase fully controlled bridge rectifier is shown in Figure-Q2 and the data given below can be used.

$V_s = 230V_{rms}$ at $50Hz$, $R = 15\Omega$, $L = 150mH$ and the delay angle = α.

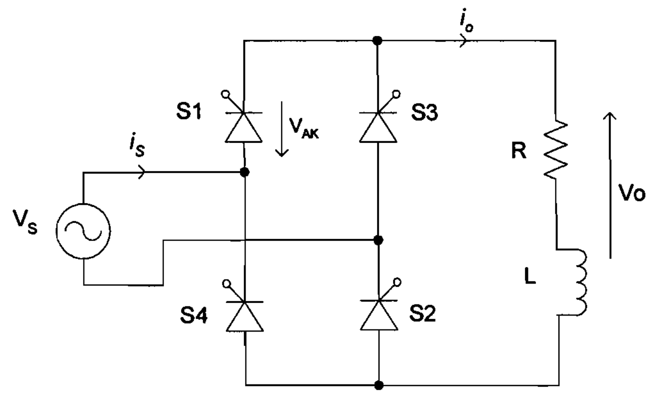

Figure - Q2

(a) Derive an relationship between the delay angle α, ω, L, and R to have the load current to be non zero. What is the limiting value of α in this case? (3 marks)

(b) Draw the following waveforms with reference to V_S, assuming that the $\alpha = 50^0$.

(i) Load current i_O. (ii) Load voltage v_O.

(iii) Currents in the thyristors. (iv) Source current i_S.

(v) Voltage V_{AK} of thyristor S_1. (6 marks)

(c) Show that the average value of the load voltage is given by $V_{o(av)} = 0.9V_S cos\alpha$.

(5 marks)

(d) If $\alpha = 50^0$, calculate the average load voltage and the average load current. (2 marks)

(e) Calculate the power dissipation in the load and the power factor seen by the source when $\alpha = 50^0$. You may consider the effects up to 2nd harmonic. (9 marks)

Note:

$$v_O(\omega t) = V_O + \sum_n^\infty V_n cos(n\omega_O t + \theta_n) \; ; \qquad V_n = \sqrt{a_n^2 + b_n^2}$$

$$a_n = \frac{2V_m}{\pi}\left[\frac{\cos(n+1)\alpha}{(n+1)} - \frac{\cos(n-1)\alpha}{(n-1)}\right]$$

$$b_n = \frac{2V_m}{\pi}\left[\frac{\sin(n+1)\alpha}{(n+1)} - \frac{\sin(n-1)\alpha}{(n-1)}\right] \qquad n = 2, 4, 6, \ldots\ldots$$

$$i(\omega t) = K\left[sin(\omega t - \theta) - sin(\alpha - \theta)e^{-\frac{(\omega t - \alpha)}{\omega\tau}}\right] \qquad K = constant, \quad \theta = tan^{-1}\left(\frac{\omega L}{R}\right),$$

and $\tau = \frac{L}{R}$.

QUESTION THREE *(25 marks)*

A half wave three phase uncontrolled rectifier driving a L, R load is shown in Figure-Q3. The line to line voltage is $380V_{rms}$ at $50Hz$. Assume that the phase sequence is a, b, c and $R = 10\Omega$.

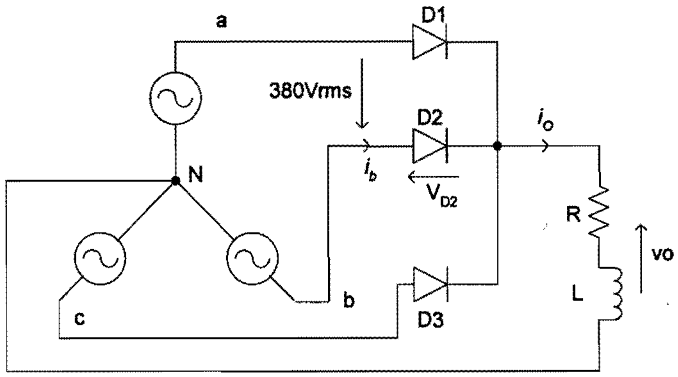

Figure - Q3

(a) Draw the following waveforms using the sheets provided at the end of the question paper. Drawings should cover more than one input period.

(i) The output voltage v_o and the output current i_o. (2 marks)

(ii) The phase voltage and the phase current of phase $'b'$. (4 marks)

(iii) The diode voltage v_{D2}. (4 marks)

(b) Derive the following voltages and currents.

(i) The average output voltage V_{DC} and the average output current I_{DC}. (3 marks)

(ii) The average current in a diode. (2 marks)

(c) Find the value of L, which will limit the p-p ripple current at the output to be less than 3% of the I_{DC}. State your assumptions. (10 marks)

Note: $v_o = V_m \frac{3}{\pi} sin\frac{\pi}{3}\left(1 - \sum_n^{\infty} \frac{2}{n^2-1} cos\left(\frac{n\pi}{3}\right) \cos n\omega t\right)$

Where $n = 3, 6, 12, \ldots\ldots$

QUESTION FOUR (*25 marks*)

A dc to dc boost converter circuit is shown in Figure-Q4. The switching frequency is f_S and the duty ratio is D.

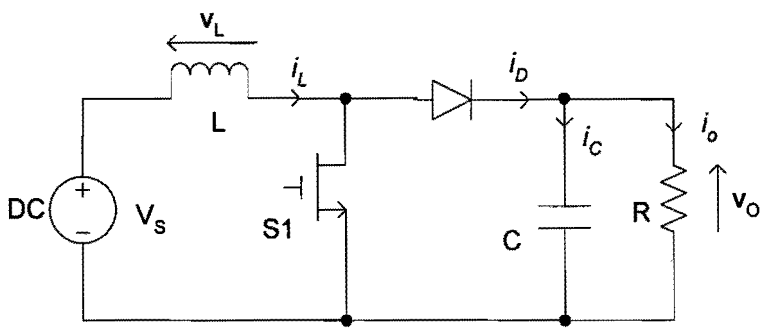

Figure-Q4

(a) (i) Draw the waveforms of v_L, i_L, i_D and i_C to a common time scale assuming that the C is large.

(4 marks)

(ii) Show that the maximum inductor current is given by $V_S\left[\frac{1}{R(1-D)^2}+\frac{D}{2Lf_S}\right]$.

(6 marks)

(iii) Derive an expression for the amplitude of the ripple voltage at the output in terms of V_s, D, R, C and f_s.

(5 marks)

(iv) It is required to design this circuit to operate under continuous inductor current for the following specifications.

$V_S = 5V$ $\quad V_o = 15V$ $\quad R = 20\Omega$ $\quad f_s = 40\ kHz$

Output ripple amplitude $\leq 1\%$ of V_o

Inductor peak current $= 3.75A$

Calculate the following design values.

(i) Duty ratio. (2 marks)

(ii) Minimum value of L and a justification of continuous inductor current.

(5 marks)

(iii) Minimum value of C. (3 marks)

QUESTION FIVE (25 *marks*)

An IGBT full bridge circuit is shown in Figure-Q5. The load consists with a R and a L in series.

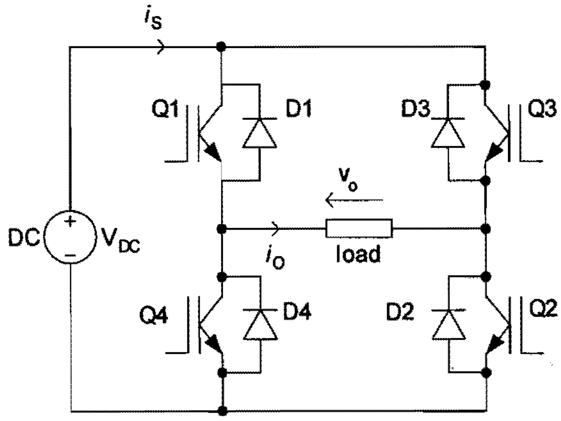

Figure-Q5

(a) Assume that the output voltage of the bridge is a low frequency square wave.
Draw a complete output voltage cycle with the corresponding output current, marking the devices which are 'ON' in each sub-interval of the cycle. (5 marks)

(b) Define the terms 'amplitude modulation ratio' and the 'frequency modulation ratio' with respect to a bipolar PWM switching signal based on a sinusoidal reference. (4 marks)

(c) A bipolar PWM switching signal based on a sinusoidal reference is used to control the bridge circuit shown above. Assume that the amplitude modulation ratio $= 0.7$, frequency modulation ratio $= 31$, fundamental frequency of the output $= 40Hz$, $V_{DC} = 315V$, $R = 15\Omega$ and $L = 25mH$.

(i) Find the rms value of the fundamental component in the output voltage. (2 marks)

(ii) Find the amplitude of the fundamental component in the output current. (3 marks)

(iii) Calculate the power absorbed by the load. (8 marks)

(iv) Total harmonic distortion (THD) in the load current. (3 marks)

Normalized Fourier coefficients $\frac{V_n}{V_{DC}}$ for bipolar PWM:

	m_a=1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
$n=1$	1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.10
$n=m_f$	0.60	0.71	0.82	0.92	1.01	1.08	1.15	1.20	1.24	1.27
$n=m_f\pm2$	0.32	0.27	0.22	0.17	0.13	0.09	0.06	0.03	0.02	0.00

Question Three

Reg No: ....