



INTERNAL ASSESSMENT APPROVAL FORM (INCLUDING COLLABORATIVE PROVISION)

This form is used to ensure that assessment specifications have been through an internal review process prior to external examination/approval and release to students. It should be completed for each assessment for a particular module. The assessment tasks, criteria and marking scheme should accompany this form.

PARTNER (and taught location if relevant):	Coleg Sir Gar				
EXTERNAL EXAMINER NAME:	Dr Arfan Ghani				
ASSESSMENT AUTHOR :	Robert Davies				
MODULE TITLE:	Power Electronics and Drives				
MODULE CODE:	SGEE6001		MODULE LEVEL:	6	
COMPONENT NO. (e.g. 1 of 2):	2 of 2		COMPONENT WEIGHTING (e.g. 50% of the module):	50%	
ASSESSMENT PERIOD	☐ Semester 1	☐ Semester 1 <i>Re-sit</i>	☒ Semester 2	☐ Semester 2 <i>Re-sit</i>	<i>Other, please state</i>
TYPE OF ASSESSMENT:	☐ Coursework		☒ Examination		☐ Practical
LANGUAGE OF ASSESSMENT:	English		TRANSLATION REQUIRED (Y/N):	N	
FOR EXAMINATIONS ONLY. SPECIFY BELOW ANY ADDITIONAL MATERIAL(S) TO BE USED IN THE EXAMINATION					
<i>This box will expand as you type</i>					

INTERNAL MODERATOR PLEASE TICK TO INDICATE THAT THE ASSESSMENT INCLUDES:		<i>Please</i> ✓		Comments
		YES	NO	
1	Tasks that are specified clearly, accurately and comprehensibly, with appropriate use of language and neat presentation	☒	☐	
2	Tasks which enable the module learning outcomes to be demonstrated (as per the module syllabus)	☒	☐	
3	Tasks which conform to the assessment described in the module syllabus	☒	☐	
4	Tasks which are written at the appropriate level of the Framework for Higher Education Qualifications (see http://www.qaa.ac.uk/docs/qaa/quality-code/qualifications-frameworks.pdf?sfvrsn=170af781_14).	☒	☐	
5	Clear criteria for assessment and guidance about how marking/grading will be applied	☒	☐	
6	Guidance about expected evidence for submission, e.g. essay or report, word count, bibliography and references	☒	☐	
7	Reference to good academic conduct, for example referencing, plagiarism and Turnitin	☒	☐	
8	Actions to complete			
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SIGNATURE OF APPROVAL:	SIGNATURE	DATE
INTERNAL MODERATOR: I confirm that this version of the assessment specification is ready to be sent to the Partnership Team Leader		22/03/19

ONLY TO BE COMPLETED IF THE ASSESSMENT IS LINKED TO A COLLABORATIVE PARTNER

PARTNERSHIP TEAM LEADER PLEASE TICK TO INDICATE THAT THE ASSESSMENT INCLUDES:		Please ✓		Comments
		YES	NO	
1	Tasks that are specified clearly, accurately and comprehensibly, with appropriate use of language and neat presentation			
2	Tasks which enable the module learning outcomes to be demonstrated (as per the module syllabus)			
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SIGNATURE OF APPROVAL:	SIGNATURE	DATE
PTL: I confirm that this version of the assessment specification is ready to be sent to the External Examiner		

UWTSD PROVISION: please submit the completed document to the appropriate Programme Director.

COLLABORATIVE PROVISION: please submit the completed document (or make available electronically) to the Partnership Team Leader. This must be in accord with specific arrangements for sharing electronic documents (e.g. via SharePoint or similar).

The assessment tasks, criteria and marking scheme should accompany this form



LOCATION: COLEG SIR GAR

LLEOLIAD: COLEG SIR GAR

LEVEL 6

LEFEL 6

EXAMINATION PERIOD

CYFNOD ARHOLIADAU

MAY 2019

MAI 2019

BSc (HONS) ELECTRICAL AND ELECTRONIC ENGINEERING

MODULE CODE: PSDE6016 / SGEE6001

POWER ELECTRONICS AND DRIVES

TIME: 2.5 HOURS

ANSWER ANY FOUR OUT OF FIVE QUESTIONS

TOTAL MARKS = 100

NUMBER OF PAGES = 7

Equipment or materials required – Calculators are permitted

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QUESTION 1

- a) Figure Q1 shows a H-bridge circuit to be used as a four quadrant chopper drive controlling a DC motor fed from a DC supply. The motor is represented as a simple model equivalent circuit with field separately supplied and constant. Critically analyse the operation of the circuit in QUADRANTS 1 and 2 (forward motoring and forward braking) treating each switching device as ideal.

[12 marks]

- b) The system has the following parameters:

Armature inductance = 80mH;

Motor speed = 150 rad/s;

Chopper frequency = 2KHz;

Load torque = 6Nm;

Motor constant = 0.4V/rad/s (Nm/A);

Supply voltage = 84V.

Assuming that operation is in the first quadrant, armature resistance can be neglected, volt-drop across a MOSFET is 2V in its ON state, current is continuous and steady state conditions have been reached: Calculate,

- (i) The duty cycle and ON/OFF times of the chopper. [5 marks]
- (ii) The average armature current. [1 mark]
- (iii) The maximum and minimum armature currents. [7 marks]

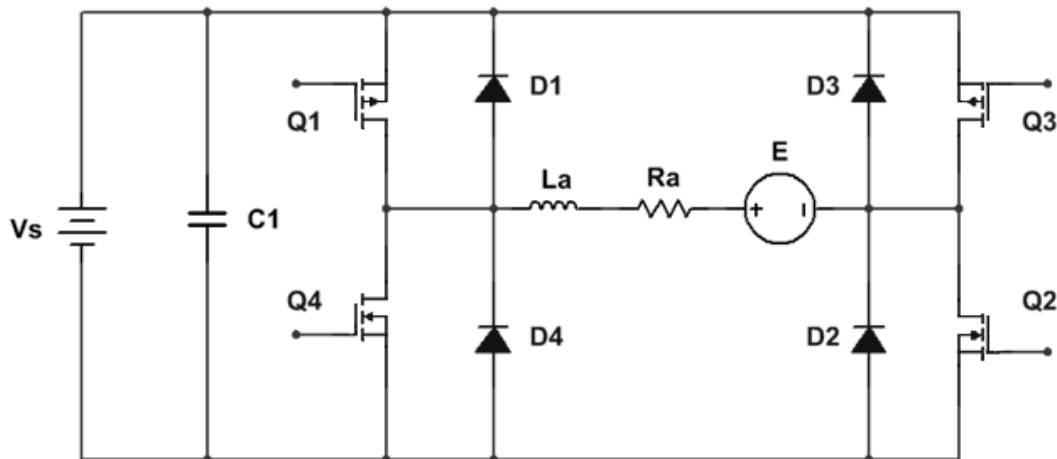


Figure Q1

Total for this question is 25 marks

QUESTION 2

- (a) Explain how each of the following stator tests can be used to determine the component values of the approximate per-phase equivalent circuit of a three-phase induction motor and derive suitable formulae for each parameter. (Stator is connected in DELTA).

- (i) DC test
- (ii) No load test
- (iii) Blocked rotor test

[12 marks]

- (b) A three-phase induction motor was connected in DELTA and the following results were obtained from the tests described in part (a).

$$\begin{aligned} V_{NL} &= 230V, & I_{NL} &= 8.45A, & P_{NL} &= 510W \\ V_{BR} &= 58.5V, & I_{BR} &= 22.1A, & P_{BR} &= 490W \\ V_{DC} &= 12V, & I_{DC} &= 41A \end{aligned}$$

Determine the values of the approximate equivalent circuit components.

[13 marks]

Total for this question is 25 marks

QUESTION 3

A buck converter has a source voltage of 40V and delivers a load current of 8A at a voltage of 16V. The switching frequency is 200kHz. The inductor current is just continuous and the components are assumed to be ideal.

- (a) Draw a circuit diagram of the converter and explain the function and operation of each component and parameter.

[7 marks]

- (b) Calculate the following converter values:

- (i) The duty cycle and the on-off times

[3 marks]

- (ii) The peak inductor current

[3 marks]

- (iii) The value of the inductor

[4 marks]

- (c) Determine and sketch the current waveforms of the converter for the load, source, inductor, diode and capacitor.

[8 marks]

Total for this question is 25 marks

QUESTION 4

The circuit of figure Q4 is to be used in a 3-phase quasi-square wave inverter for the speed control of a 3-phase squirrel cage, star connected induction motor as shown (assuming stator phases are perfectly balanced). The battery voltage is 300V and the inverter is to operate at 50Hz. The transistors used can be treated as ideal switches.

- (a) Draw the voltage waveforms for each of the transistor base signals, and derive the waveforms for the line and phase voltages for a, b and c against time, with one under the other to show the phase relationship between them. (Use the back page of this paper, detach and place in your answer booklet.) Provide an explanation for phase a.

[15 marks]

- (b) Using a suitable formula for the Fourier Series of the phase voltage up to the 11th harmonic,

- (i) Determine the RMS phase voltage spectrum.

[8 marks]

- (ii) Calculate the percentage phase total harmonic distortion.

[2 marks]

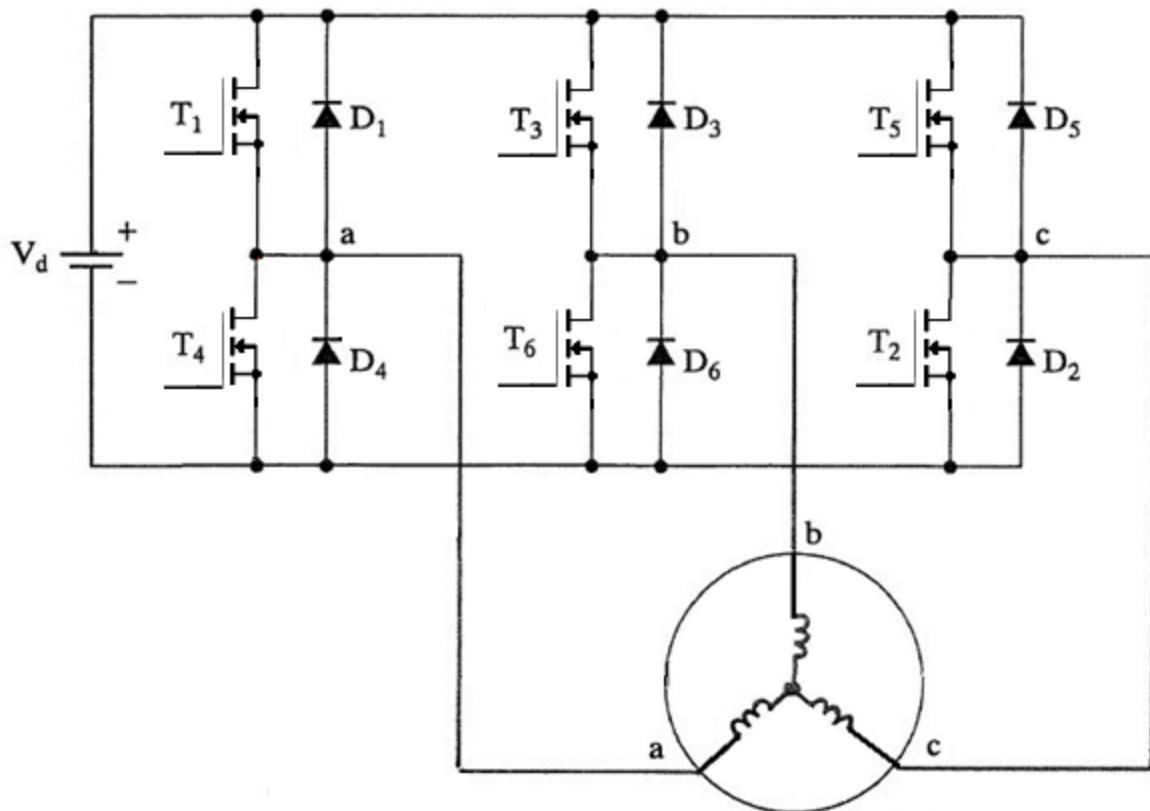


Figure Q4

Total for this question is 25 marks

QUESTION 5

- (a) Given that the resulting switched waveforms for figure 5a are shown in figure 5b, and that i_T is linear between $t = 0$ and $t = t_2$, derive expressions in terms of the circuit variables for each of the following:
- (i) The value of the capacitor [5 marks]
 - (ii) The switching energy loss [11 marks]
- (b) Calculate the value of the capacitor and the switching loss if $V_S = 150\text{V}$, $I = 40\text{A}$, $t_1 = 2.5\text{ms}$, $t_2 = 4\text{ms}$ [3 marks]
- (c) Explain the effect of C and D in the circuit of figure Q5 and suggest an appropriate method of protecting the power transistor from fault currents. [6 marks]

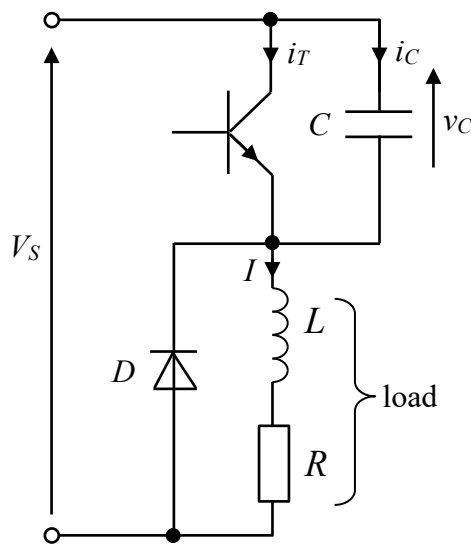


Figure 5a

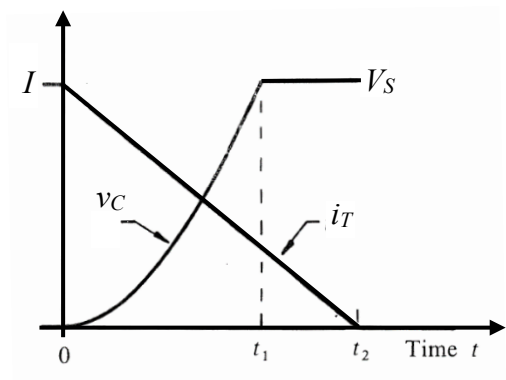
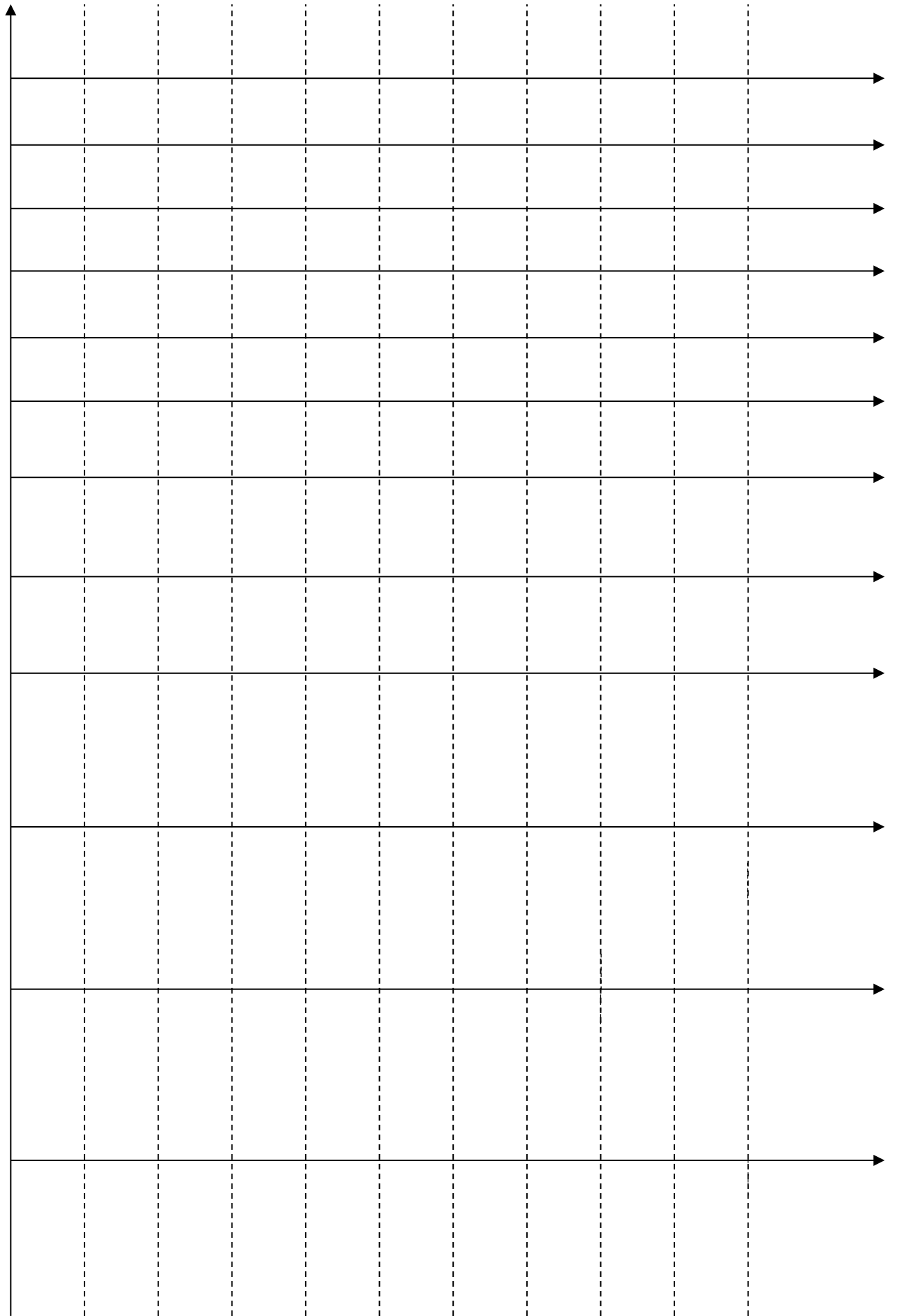


Figure 5b

Total for this question is 25 marks



LOCATION: COLEG SIR GAR

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LEVEL 6

LEFEL 6

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BSc (HONS) ELECTRICAL AND ELECTRONIC ENGINEERING

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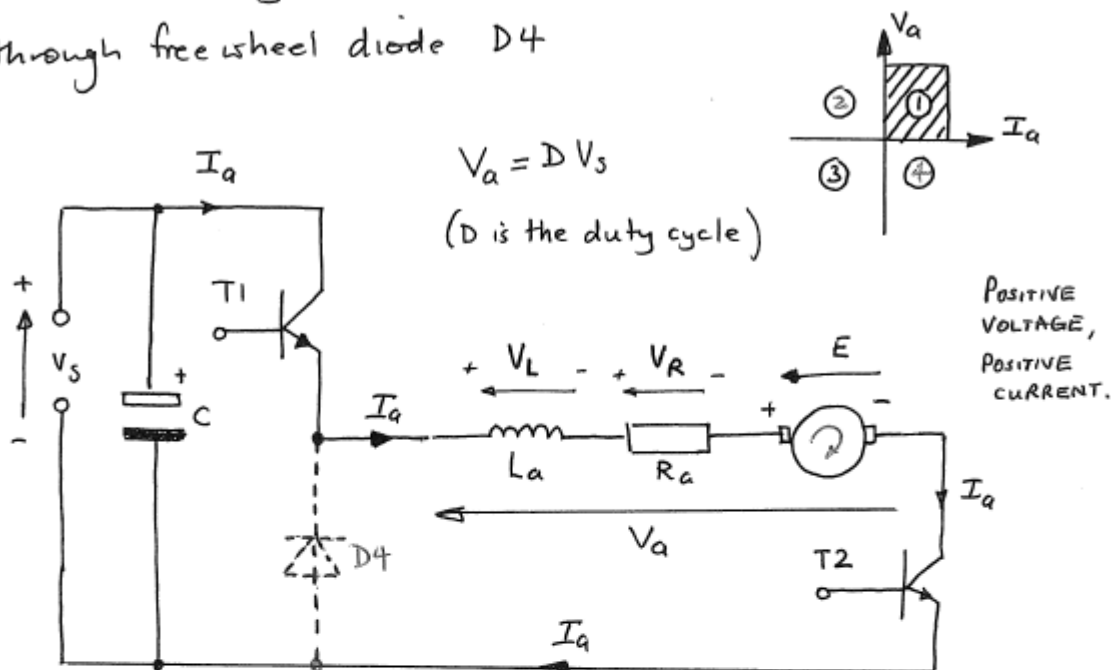
POWER ELECTRONICS AND DRIVES

SOLUTIONS

QUESTION 1

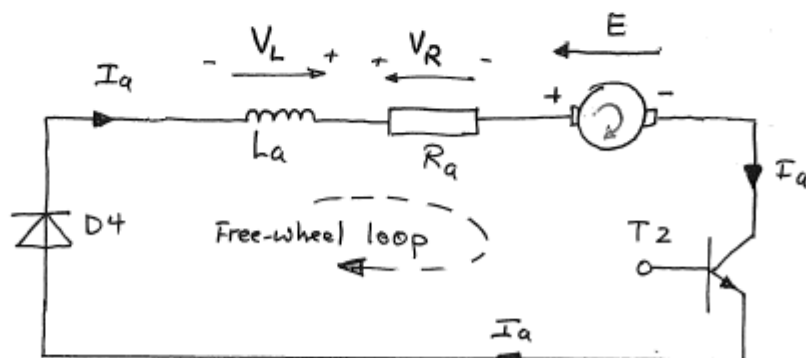
(a) Quadrant 1 – forward motoring

This is achieved by switching T1 and keeping T2 on constantly to allow inductance to dissipate energy through free wheel diode D4



When T_1 switches off, I_a continues in the same direction in the loop containing D_4 and T_2 as shown below

V_L reverses polarity as I_a reduces.



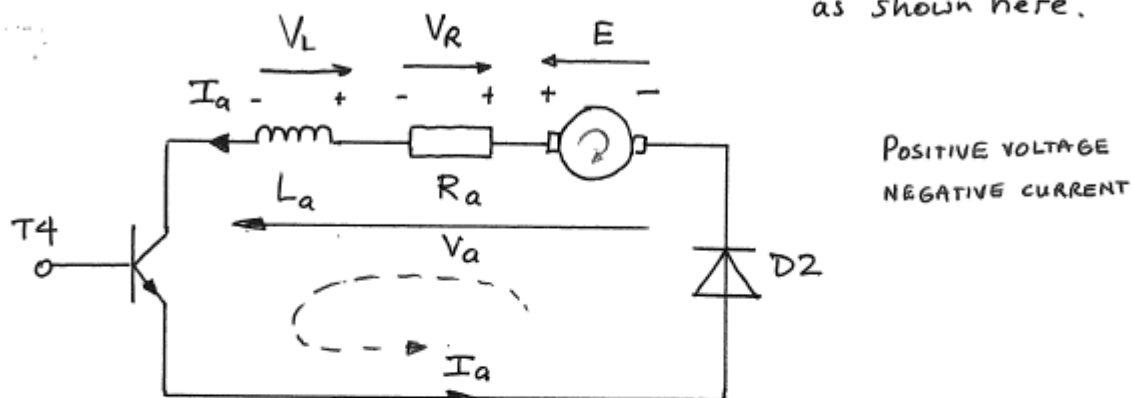
The same effect could be achieved by keeping T_1 on and switching off T_2 . Free-wheel loop would then be T_1 with D_3 .

[6 marks]

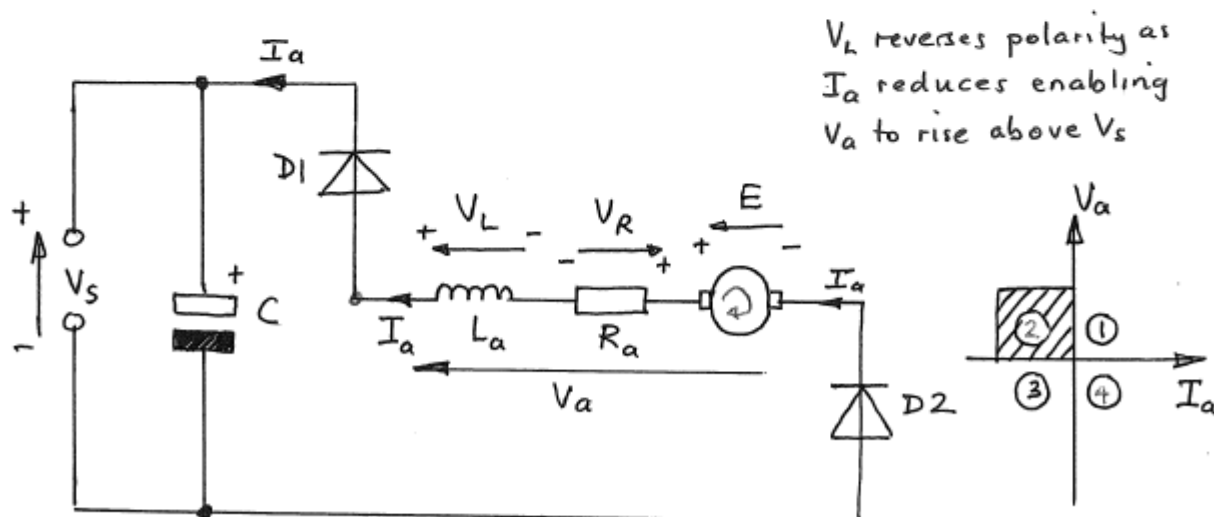
Q1 (a) continued

Quadrant 2 – forward braking

While the machine is motoring in the clockwise direction with positive armature voltage, after the effects of inductance had ceased T_2 could be switched off and T_4 switched on instead. Current flow would reverse as E drives current through the loop as shown here.



This has the effect of priming the inductor so that when T_4 is switched off, current is pumped back into the supply via D_1 as shown below.



Source receiving power from regenerative braking current loop. Duty cycle of switching T_4 determines average generated voltage.

[6 marks]

Q1 (b) (i)

Voltage supply to armature with 2 MOSFET
 $V_{on} = 84 - 4 = 80V$

$$L_a = 0.08 H$$

$$R_a = 0 \Omega$$

$$K = 0.4 V/rad/s \text{ (Nm/A)}$$

$t_1 = \text{ON time}$

$t_2 = \text{OFF time}$

$T = t_1 + t_2 = \text{period}$

$$t_1 + t_2 = \frac{1}{2000} = 0.5 \text{ ms}$$

$$\omega = 150 \text{ rad/s}$$

$$T_h = 6 \text{ Nm}$$

$$E = K \omega$$

$$= 0.4 \times 150 = 60V$$

$$V = E + I_a R_a + L_a \frac{di_a}{dt}$$

When $R_a = 0$, average inductor voltage = 0

$$\therefore V_{\text{mean}} = E$$

$$V_{\text{mean}} = 60$$

$$\text{but } V_{\text{mean}} = \frac{t_1}{t_1 + t_2} V_s = D V_s$$

$$\therefore D = \frac{V_{\text{mean}}}{V_s} = \frac{60}{80} = 0.75$$

$$t_1 = D(t_1 + t_2)$$

$$= 0.75 \times 0.5 \times 10^{-3} = 0.375 \text{ ms}$$

$$t_2 = (1 - D)(t_1 + t_2)$$

$$= 0.25 \times 0.5 \times 10^{-3} = 0.125 \text{ ms}$$

[5 marks]

Q1 (b) (ii)

$$T_L = k I_a(\text{mean})$$

$$6 = 0.4 I_a(\text{mean})$$

$$\begin{aligned}\therefore I_a(\text{mean}) &= \frac{6}{0.4} \\ &= 15 \text{ A}\end{aligned}$$

[1 mark]

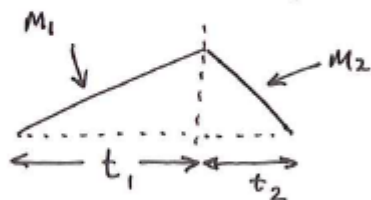
Q1 (b) (iii)

During t_1 ,

$$V_s - E = L_a \frac{di_a}{dt} = L_a m_1 \quad \begin{array}{l} \nearrow \\ \text{rising} \\ \text{gradient} \end{array}$$

$$\therefore m_1 = \frac{V_s - E}{L_a}$$

$$= \frac{80 - 60}{0.08} = 250 \text{ A/s}$$



$\nwarrow$
falling
gradient

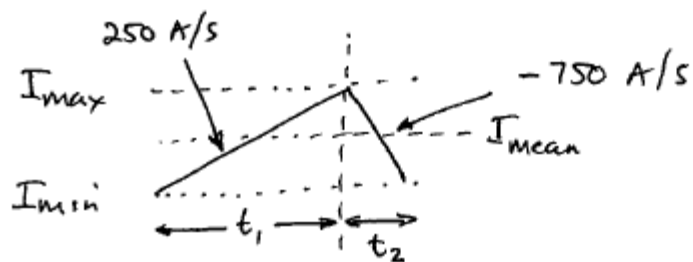
During t_2 , $V_s = 0$

$$\therefore -E = L_a \frac{di_a}{dt} = L_a m_2$$

$$\therefore m_2 = \frac{-E}{L_a} = \frac{-60}{0.08} = -750 \text{ A/s}$$

[3 marks]

Q1 (b) (iii) continued



$$I_{mean} = \frac{I_{max} + I_{min}}{2}$$

$$\therefore I_{max} + I_{min} = 2 I_{mean} = 2 \times 15$$

$$\therefore I_{max} + I_{min} = 30 \quad \text{--- (1)}$$

Using triangle for t_1

$$m_1 = \frac{I_{max} - I_{min}}{t_1}$$

$$\therefore I_{max} - I_{min} = m \times t_1 = 250 \times 0.375 \times 10^{-3}$$

$$\therefore I_{max} - I_{min} = 0.09375 \quad \text{--- (2)}$$

Adding equation (1) and (2)

$$2 I_{max} = 30 + 0.09375$$

$$\therefore I_{max} = 15.047 \text{ A}$$

$$\therefore \text{from (1)} \quad I_{min} = 30 - 15.047 \\ = 14.953 \text{ A}$$

[4 marks]

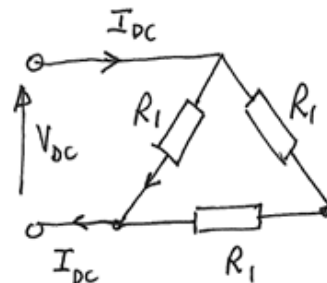
QUESTION 2 (a) (i)

DC Test

This is used to find R_1 by applying dc to the stator windings. If stator is connected in delta

$$I_{DC} = \frac{V_{DC}}{R_T}$$

$$\therefore R_T = \frac{V_{DC}}{I_{DC}}$$



$$R_1 = 3R_T / 2$$

Resistance looking in

= R_1 in parallel to $2R_1$

Giving a total resistance of

$$R_T = 2R_1/3$$

[2 marks]

Q2 (a) (ii)

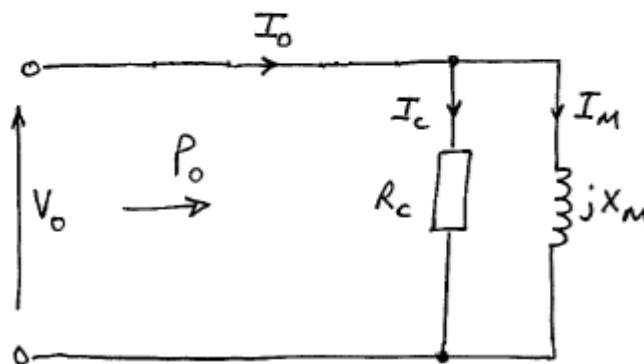
No Load test

This is used to find R_c and X_m

The motor must be coupled to a variable speed drive and driven at synchronous speed before applying rated voltage to the stator.

Since $s=0$, the rotor appears open circuit

$\therefore \frac{R_2'}{s} = \infty$. The equivalent circuit becomes



Q2 (a) (ii) continued

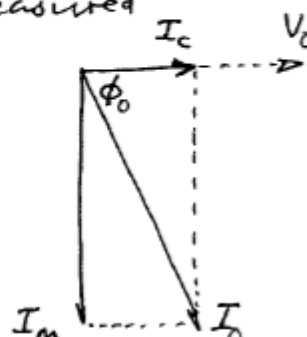
Since I_0 is small, stator impedance is ignored
 $I_0 = I_c + I_m$

Using a Wattmeter P_0 is measured

$$\cos(\phi_0) = \frac{P_0}{V_0 I_0}$$

$$R_c = \frac{V_0}{I_c} = \frac{V_0}{I_0 \cos(\phi_0)}$$

$$X_m = \frac{V_0}{I_m} = \frac{V_0}{I_0 \sin(\phi_0)}$$

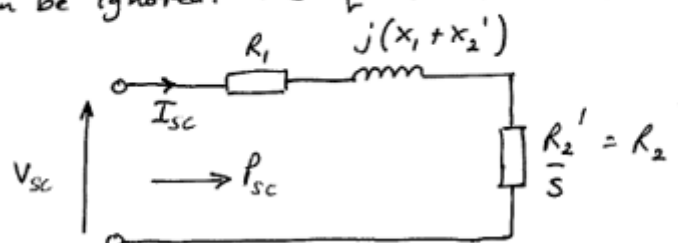


[5 marks]

Q2 (a) (iii)

Block rotor test

This is used to find R_2' and $X_1 + X_2'$
 Rotor is block ($s=1$), low voltage applied to stator V_{sc} . Since V_{sc} is small, core can be ignored. The equivalent circuit becomes



Power is measured by Wattmeter

$$\cos \phi_{sc} = \frac{P_{sc}}{V_{sc} I_{sc}}$$

$$\text{Block rotor impedance } Z_{sc} = \frac{V_{sc}}{I_{sc}}$$

$$\text{and } R_1 + R_2' = Z_{sc} \cos(\phi_{sc})$$

$$R_2' = Z_{sc} \cos(\phi_{sc}) - R_1$$

known from test 1

$$\text{and } X_1 + X_2' = Z_{sc} \sin(\phi_{sc})$$

[5 marks]

Q2 (b)

Using DC test values:

Therefore, $R_1 = 3 \times 0.293 / 2$

$$R_T = \frac{12}{41} = 0.293 \Omega$$

$$= 0.4395 \Omega$$

[1 mark]

From no load test :

$$V_o = V_{NL} = 230 \text{ V} \quad (\text{delta})$$

$$I_o = \frac{I_{NL}}{\sqrt{3}} = \frac{8.45}{\sqrt{3}} = 4.879 \text{ A}$$

$$P_o = \frac{P_{NL}}{3} = \frac{510}{3} = 170 \text{ W}$$

$$\cos \phi_o = \frac{170}{4.879 \times 230} = 0.1515$$

$$\phi_o = \cos^{-1}(0.1515) = 81.29^\circ$$

$$\sin \phi_o = 0.9885$$

$$R_c = \frac{230}{4.879 \times 0.1515} = 311.16 \Omega$$

$$X_m = \frac{230}{4.879 \times 0.9885} = 47.69 \Omega$$

[6 marks]

From blocked rotor test :

$$V_{sc} = V_{BR} = 58.5 \text{ V / phase}$$

$$I_{sc} = \frac{I_{BR}}{\sqrt{3}} = \frac{22.1}{\sqrt{3}} = 12.76 \text{ A}$$

$$P_{sc} = \frac{1}{3} P_{BR} = \frac{490}{3} = 163.3 \text{ W}$$

Q2 (b) continued

$$\begin{aligned}\cos \phi_{sc} &= \frac{P_{sc}}{V_{sc} I_{sc}} = \frac{163.3}{58.5 \times 12.76} \\ &= 0.2188\end{aligned}$$

$$\begin{aligned}\therefore \phi_{sc} &= \cos^{-1}(0.2188) \\ &= 77.36^\circ\end{aligned}$$

$$\sin \phi_{sc} = 0.9758$$

$$\begin{aligned}Z_{sc} &= \frac{V_{sc}}{I_{sc}} \\ &= \frac{58.5}{12.76} = 4.585 \Omega\end{aligned}$$

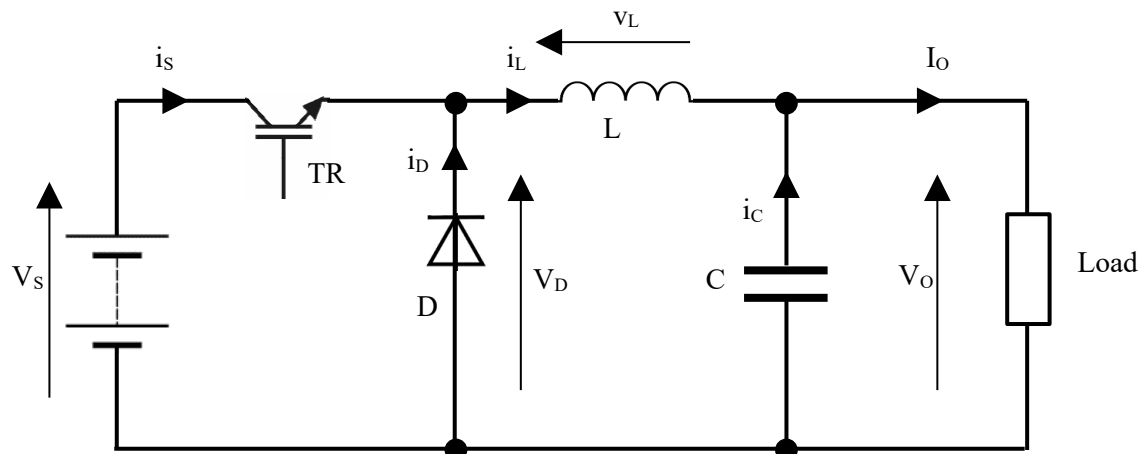
$$\begin{aligned}R_2' &= Z_{sc} \cos \phi_{sc} \\ &= 4.585 \times 0.2188 \\ &= 1.003 \Omega\end{aligned}$$

$$\begin{aligned}X_1 + X_2' &= Z_{sc} \sin \phi_{sc} \\ &= 4.585 \times 0.9758 \\ &= 4.474 \Omega\end{aligned}$$

[6 marks]

QUESTION 3

(a)



[3 marks]

The circuit is called a buck converter because it decreases voltage making $V_O < V_S$. The inductor acts as a filter providing constant voltage and current to the load.

When TR is closed, i_L is delivered by the source current i_S and this current builds up linearly in the inductor. The current in the capacitor will decrease (reducing discharging mode) and then reverses direction into charging mode. The diode will not be conducting at this time.

When TR is open, i_L reduces and the flywheel diode conducts allowing the current in the inductor to continue to flow when the transistor is off. The capacitor current reduces to zero and then reverses into discharge mode.

The load current I_O is approximately constant in both states of TR being supplied by a combination of i_L and i_C .

After a transient period, the output voltage is determined by the duty cycle of TR.

[4 marks]

Q3 (b)

- (i) The current waveforms for an inductor current that is just continuous are shown below. The cycle time at 200KHz = 5 μ s.

$$\text{The duty cycle} = V_O/V_S = 16/40$$

$$= 0.4$$

$$\text{Hence the on-time} = 0.4 \times 5\mu\text{s}$$

$$= 2\mu\text{s}$$

$$\text{And the off-time} = 3\mu\text{s}$$

[3 marks]

Q3 (b) continued

(ii) The charge into the capacitor must equal the charge out in each cycle, hence:

$$\text{The mean value of } i_C = 0$$

$$\begin{aligned} \text{And mean value of } i_L &= I_0 \\ &= 8A \end{aligned}$$

Because the current changes are linear, the source and inductor currents must peak at 16A

[3 marks]

(iii)

$$\begin{aligned} \text{During the ON time, the voltage across the inductor} &= 40 - 16 \\ &= 24V \end{aligned}$$

Since the voltage across the inductor = $L \, di/dt$

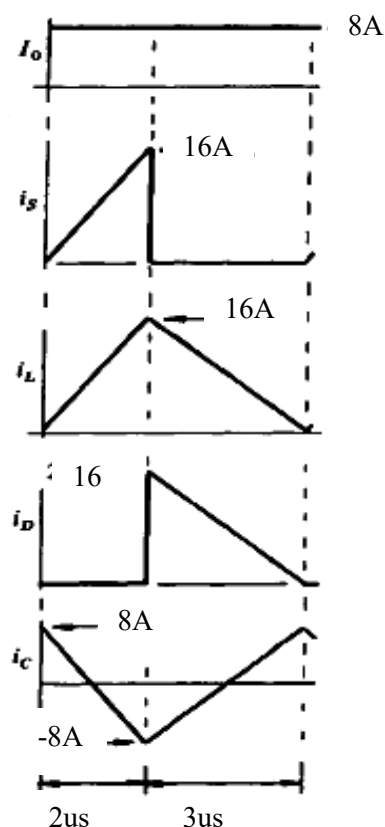
$$\begin{aligned} \text{And the gradient } di/dt &= 16/(2 \times 10^{-6}) \\ &= 8 \times 10^6 \text{ A/s} \end{aligned}$$

$$\begin{aligned} \text{Therefore, the inductor value } L &= 24 / 8 \times 10^6 \\ &= 3\mu\text{H} \end{aligned}$$

[4 marks]

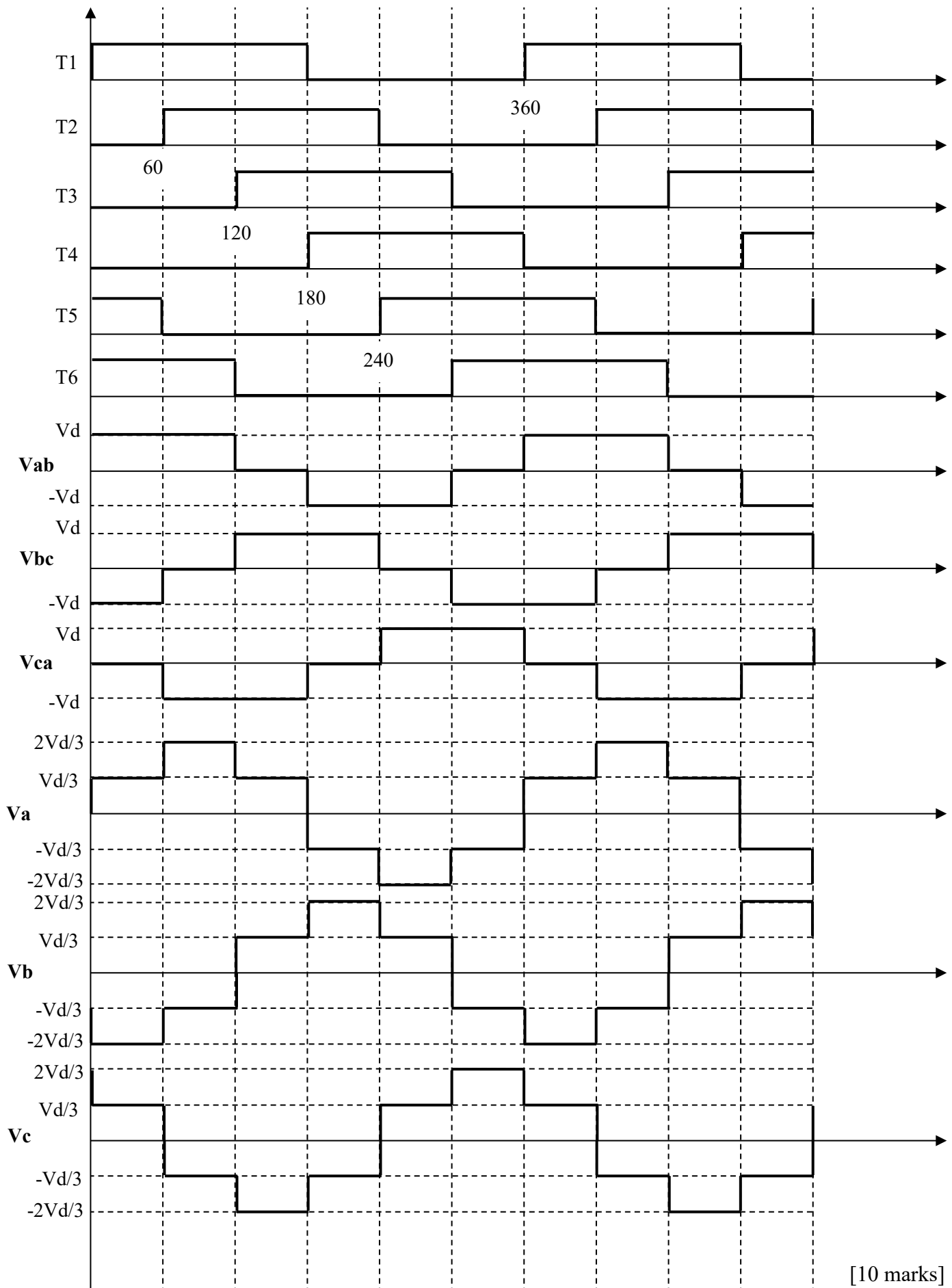
(c) In the circuit, $i_S + i_D = i_L$.

The capacitor current rises and falls to balance the difference between the constant load current and the inductor current.



[8 marks]

QUESTION 4 (a)



[10 marks]

Q4 (a) continued

Line voltages switch between V_d and $-V_d$ as shown for V_{ab} , V_{bc} and V_{ca} where

$$V_{ab} = V_a - V_b \quad \text{--- (1)}$$

$$V_{bc} = V_b - V_c \quad \text{--- (2)}$$

$$V_{ca} = V_c - V_a \quad \text{--- (3)}$$

(1) - (3) gives

$$V_{ab} - V_{ca} = 2V_a - (V_b + V_c) \quad \text{--- (4)}$$

Since the system is balanced

$$V_a + V_b + V_c = 0 \quad \text{--- (5)}$$

$$\therefore V_b + V_c = -V_a$$

$\therefore$ (4) becomes

$$V_{ab} - V_{ca} = 3V_a$$

$$\therefore V_a = \frac{1}{3} (V_{ab} - V_{ca}) \quad \text{--- (6)}$$

The following table shows the values of V_a

V_{ab}	V_d	V_d	0	$-V_d$	$-V_d$	0
V_{ca}	0	$-V_d$	$-V_d$	0	V_d	V_d
V_a	$V_d/3$	$2V_d/3$	$V_d/3$	$-V_d/3$	$-2V_d/3$	$V_d/3$

when $V_d = 300\text{ V}$, $\frac{V_d}{3} = 100\text{ V}$, $\frac{2V_d}{3} = 200\text{ V}$

[5 marks]

Q4 (b)

$$Q4(b)(i) \quad V_n = \frac{2V_d}{n\pi} \left\{ \cos\left(\frac{n\pi}{3}\right) + 1 \right\}$$

Using the formula for odd values of n only

$$\begin{aligned} V_1 &= \frac{2 \times 300}{\pi} \left\{ \cos\left(\frac{\pi}{3}\right) + 1 \right\} \\ &= 286.48 \text{ V} \quad \therefore R_{ms} = 202.57 \text{ V} \end{aligned}$$

$$\begin{aligned} V_3 &= \frac{2 \times 300}{3\pi} \left\{ \cos\left(\frac{3\pi}{3}\right) + 1 \right\} \\ &= 0 \end{aligned}$$

$$\begin{aligned} V_5 &= \frac{2 \times 300}{5\pi} \left\{ \cos\left(\frac{5\pi}{3}\right) + 1 \right\} \\ &= 57.30 \text{ V} \quad R_{ms} = 40.51 \text{ V} \end{aligned}$$

$$\begin{aligned} V_7 &= \frac{2 \times 300}{7\pi} \left\{ \cos\left(\frac{7\pi}{3}\right) + 1 \right\} \\ &= 40.93 \text{ V} \quad R_{ms} = 28.94 \text{ V} \end{aligned}$$

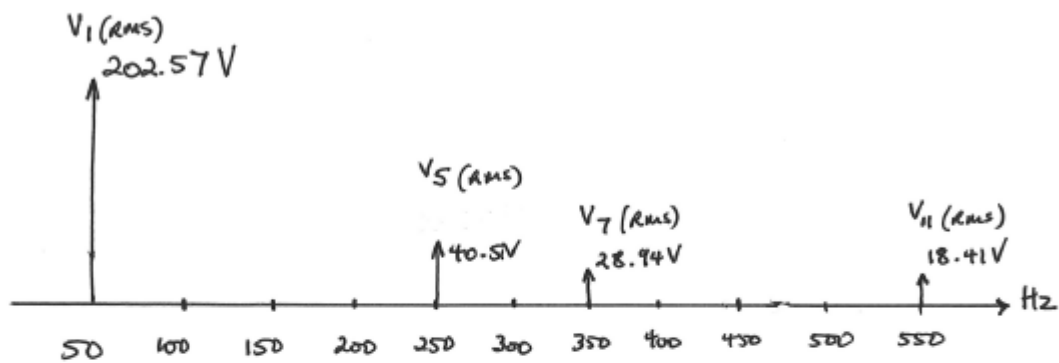
$$\begin{aligned} V_9 &= \frac{2 \times 300}{9\pi} \left\{ \cos\left(\frac{9\pi}{3}\right) + 1 \right\} \\ &= 0 \end{aligned}$$

$$\begin{aligned} V_{11} &= \frac{2 \times 300}{11\pi} \left\{ \cos\left(\frac{11\pi}{3}\right) + 1 \right\} \\ &= 26.04 \text{ V} \quad R_{ms} = 18.413 \end{aligned}$$

[6 marks]

Q4 (b) continued

For $f = 50 \text{ Hz}$, harmonics occur at
 50 Hz , 250 Hz , 350 Hz , 550 Hz



[2 marks]

$$\begin{aligned}
 \text{(ii) } \% \text{ THD} &= \frac{\sqrt{V_{5(RMS)}^2 + V_{7(RMS)}^2 + V_{11(RMS)}^2}}{V_{1(RMS)}} \times 100 \\
 &= \frac{\sqrt{40.51^2 + 28.94^2 + 18.41^2}}{202.57} \times 100 \\
 &= 26.2 \%
 \end{aligned}$$

[2 marks]

QUESTION 5

Q5 (a) (i)

Assuming i_T is linear between $t=0$, $t=t_2$

$$i_T = I - I \frac{t}{t_2} \quad \text{gradient} = \frac{I}{t_2}$$

$$\begin{aligned} i_c &= I - i_T \\ &= I - \left(I - I \frac{t}{t_2} \right) \\ &= I \frac{t}{t_2} \end{aligned}$$

At time t_1 , charge on capacitor $= q = C \cdot E$

$$\begin{aligned} \therefore C &= \frac{q}{E} = \frac{1}{E} \int_0^{t_1} i_c dt \\ &= \frac{1}{E} \int_0^{t_1} I \frac{t}{t_2} dt = \frac{I}{E t_2} \left[\frac{t^2}{2} \right]_0^{t_1} \end{aligned}$$

$$C = \frac{I t_1^2}{2 E t_2}$$

[5 marks]

Q5 (a) (ii)

$$\text{Switching loss} = \int_0^{t_2} v i_T dt$$

We need an expression for v at any time t

$$v = \frac{q}{C} \quad \text{but } q = \frac{I t^2}{2 t_2}$$

$$\therefore v = \frac{I t^2}{2 C t_2}$$

Substitute for C

$$v = \frac{I t^2}{2 t_2} \times \frac{2 E t_2}{I t_1^2}$$

$$= \frac{E t^2}{t_1^2}$$

$$\therefore \text{switching loss} = \int_0^{t_2} v i_T dt$$

$$= \int_0^{t_1} v i_T dt + \int_{t_1}^{t_2} v i_T dt$$

$$\left. \begin{array}{l} \text{between } 0 \text{ and } t_1 \\ v = \frac{E t^2}{t_1^2} \end{array} \right\} \text{ and } i_T = I - I \frac{t}{t_2}$$

between t_1 and t_2

$$v = E$$

$$\therefore \text{switching loss} = \int_0^{t_1} \frac{E t^2}{t_1^2} \times \left[I - I \frac{t}{t_2} \right] dt$$

$$+ \int_{t_1}^{t_2} E \left[I - I \frac{t}{t_2} \right] dt$$

[7 marks]

Q5 (a)(ii) continued

$$\begin{aligned}
 \text{Switching loss} &= \frac{EI}{t_1^2} \int_0^{t_1} t^2 - \frac{t^3}{t_2} dt \\
 &\quad + EI \int_{t_1}^{t_2} 1 - \frac{t}{t_2} dt \\
 &= \frac{EI}{t_1^2} \left[\frac{t^3}{3} - \frac{t^4}{4t_2} \right]_0^{t_1} + EI \left[t - \frac{t^2}{2t_2} \right]_{t_1}^{t_2} \\
 &= \frac{EI}{t_1^2} \left[\frac{t_1^3}{3} - \frac{t_1^4}{4t_2} - 0 \right] + EI \left[t_2 - \frac{t_2^2}{2t_2} - t_1 + \frac{t_1^2}{2t_2} \right] \\
 &= EI \left[\frac{t_1}{3} - \frac{t_1^2}{4t_2} + t_2 - \frac{t_2}{2} - t_1 + \frac{t_1^2}{2t_2} \right] \\
 &= EI \left[\frac{t_2}{2} - \frac{2t_1}{3} + \frac{t_1^2}{4t_2} \right]
 \end{aligned}$$

[4 marks]

Q5 (b)

$$V_s = 150V, I = 40A, t_1 = 2.5ms, t_2 = 4ms$$

$$C = 40 \times (2.5 \times 10^{-3})^2 / (2 \times 150 \times 4 \times 10^{-3})$$

$$C = 208.3\mu F$$

[1 marks]

$$\begin{aligned}
 \text{loss} &= 150 \times 40 \times \left[\frac{4 \times 10^{-3}}{2} - \frac{2 \times 2.5 \times 10^{-3}}{3} + \frac{(2.5 \times 10^{-3})^2}{2 \times 4 \times 10^{-3}} \right] \\
 &= 6000 \times \left[2 \times 10^{-3} - 1.667 \times 10^{-3} + 0.781 \times 10^{-3} \right] \\
 &= 6.684 \text{ J}
 \end{aligned}$$

[2 marks]

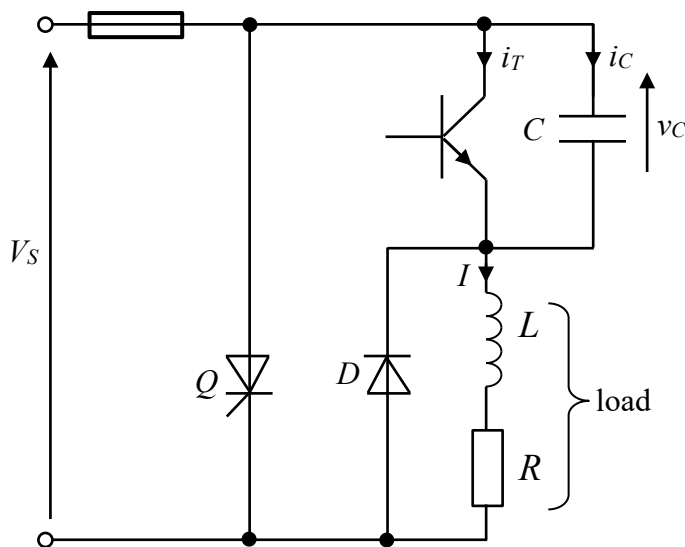
Q5 (c)

The capacitor is used to limit the rate of voltage rise when the transistor is switching as the voltage across the capacitor corresponds to its charging, it cannot rise instantly. When switching off, the polarity of the voltage across the inductor changes as the field collapses and D provides a freewheel loop diverting the current away from the transistor enabling it to switch off.

[2 marks]

The collector current in a BJT transistor depends on the base current ($h_{FE} = I_C/I_B$) which is delivered by a driver circuit. Power transistors have low values of h_{FE} . If a fuse was added to protect the transistor under fault conditions, the extra large current drawn through the transistor would require an extra large base current. The base drive circuit may not be able to deliver the corresponding base current thus the transistor would be destroyed. Therefore, a crowbar thyristor Q is employed, as shown below, so that when a fault current is detected, the thyristor is fired, shorting out the supply and blowing the fuse.

[2 marks]



[2 marks]