

EXAMINATION INTERNAL VERIFICATION FORM (2017-2018)

MODULE :	PSDE6016 Power Electronics and Drives	LEVEL:	6
PROGRAMME :	BSc (hons) Electrical and Electronic Engineering	TERM OF EXAM: (SPRING OR SUMMER)	Summer
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		EXAMINATION AUTHOR :	R. Davies

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☒	Conforms to the assessment pattern described in the module syllabus
☒	Tests the module learning outcome(s) appropriately

SIGNATURES OF FINAL APPROVAL:	SIGNATURE	DATE
INTERNAL VERIFIER: I confirm that this version of the exam paper is ready to be sent to the external examiner		7/03/2018
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**UNIVERSITY OF WALES:
TRINITY SAINT DAVID**



**PRIFYSGOL CYMRU:
Y DRINDOD DEWI SANT**

LOCATION: COLEG SIR GAR

LLEOLIAD: COLEG SIR GAR

LEVEL 6

LEFEL 6

**EXAMINATION PERIOD
MAY 2018**

**CYFNOD ARHOLIADAU
MAI 2018**

BSc ELECTRICAL AND ELECTRONIC ENGINEERING

MODULE CODE: PSDE6016

POWER ELECTRONICS AND DRIVES

TIME: 2 HOURS

ANSWER THREE QUESTIONS OUT OF FOUR

TOTAL MARKS = 102

NUMBER OF PAGES = 5

Equipment or materials required – Calculators are permitted

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QUESTION 1

- (a) Analyse and explain the operation of the rectifier circuit shown in figure Q1 with the aid of waveform diagrams for input and output voltages and currents for a firing angle of around 30° .

[14 marks]

- (b) Derive the following average load voltage formula for the circuit of figure Q1 from first principles:

$$V_{mean} = 3 \frac{V_{RMS}}{\sqrt{2} \pi} \cos \alpha$$

[12 marks]

- (c) Define the term **regenerative braking** for a separately excited dc motor and explain, with the aid of an additional diagram, how this rectifier can be used to achieve this mode of operation.

[8 marks]

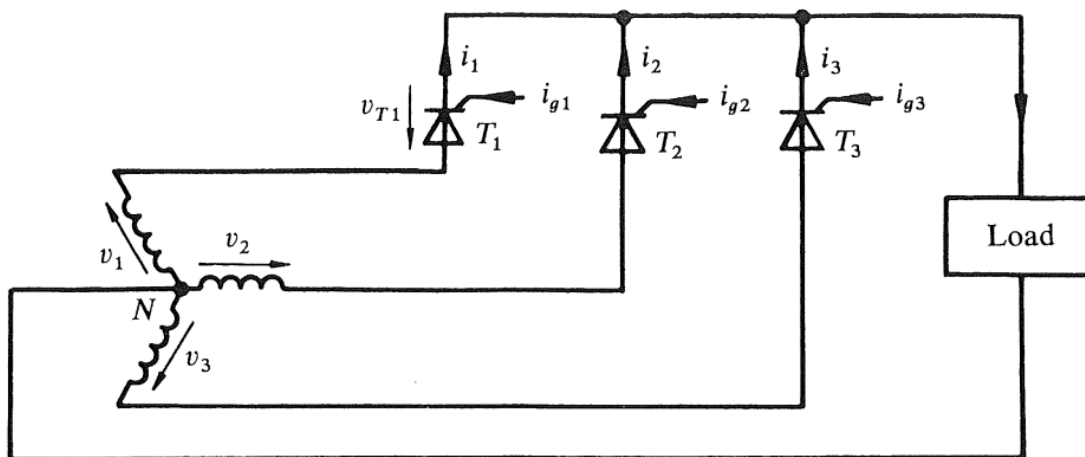


Figure Q1

Total for this question is 34 marks

QUESTION 2

- (a) Draw an approximate per-phase equivalent circuit for an induction motor referred to the stator, and derive expressions for the per-phase **stator current** and **torque** produced.

[12 marks]

- (b) Using the formula derived in part (b), calculate the **stator current** and the **total torque** of a star connected three-phase induction motor with the following parameters:

Poles = 6

Stator line voltage = 415V@ 60Hz

Rotor speed = 1140rpm

Stator leakage impedance = $(0.7 + j1.9)\Omega/\text{phase}$

Rotor standstill impedance (referred to stator) = $(0.6 + j1.9)\Omega/\text{phase}$

No load current = $(1.7 - j6.6)\text{ A}/\text{phase}$

[11 marks]

- (c) With the aid of a **torque-speed curve** for fractional slip values between 2 and -1, evaluate the regions of operation of a three-phase cage rotor induction motor.

[11 marks]

Total for this question is 34 marks

QUESTION 3

A quasi-square wave inverter supplies a three-phase balanced delta-connected load. Figure Q3 shows the voltage for one phase of the load. The inverter is supplied from a battery voltage V_b .

- (a) Using the Fourier series expansion equations below, derive the following expression for the voltage of Figure Q3 up to the 7th harmonic:

$$v(t) = \frac{2}{\pi} V_b \left\{ \sin \omega t + \frac{1}{5} \sin 5 \omega t + \frac{1}{7} \sin 7 \omega t \right\}$$

[18 marks]

- (b) Given that the battery voltage is 420V, the load resistance and inductance per-phase are 0.3Ω and 4mH respectively and the inverter is operating at 35Hz, determine the spectrum of the RMS phase voltage and current harmonics and calculate the total RMS current.

[16 marks]

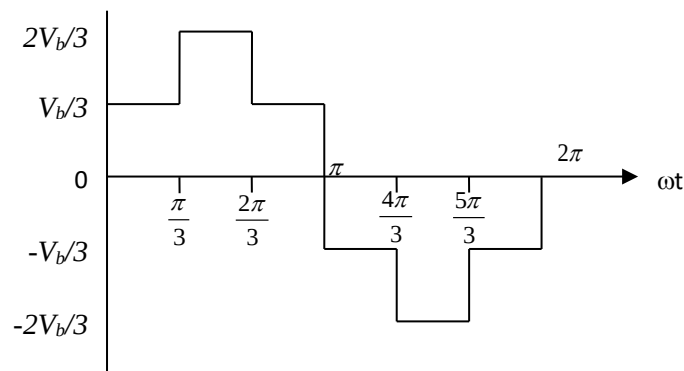


Figure Q3

The general Fourier series expansion is:

$$v(t) = A + a_1 \sin \omega t + a_2 \sin 2 \omega t + \dots + a_n \sin n \omega t \\ + b_1 \cos x + b_2 \cos 2x + \dots + b_n \cos nx$$

where:

$$A = \frac{1}{2\pi} \int_0^{2\pi} v(\theta) d\theta$$

$$a_n = \frac{1}{\pi} \int_0^{2\pi} v(\theta) \sin n\theta d\theta$$

$$b_n = \frac{1}{\pi} \int_0^{2\pi} v(\theta) \cos n\theta d\theta$$

Total for this question is 34 marks

QUESTION 4

- (a) Explain the function and operation of the converter circuit shown in Figure Q4 and suggest a control strategy for maintaining output voltage under load. [5 marks]
- (b) For the circuit of figure Q4: the source voltage $V_s = 40V$, the load current $I_o = 9A$, the load voltage $V_o = 15V$ and the switching frequency is $125kHz$. The current flow in the inductor is just continuous. Assuming ideal components, calculate:
- The duty cycle and the on-off times [4 marks]
 - The peak inductor current [3 marks]
- (c) Determine and sketch the waveforms of I_o , i_s , i_L , i_D and i_C . [11 marks]
- (d) Calculate the value of the inductor. [4 marks]
- (e) Calculate the peak-to-peak ripple in the load voltage if the value of the capacitor is $150\mu F$. [7 marks]

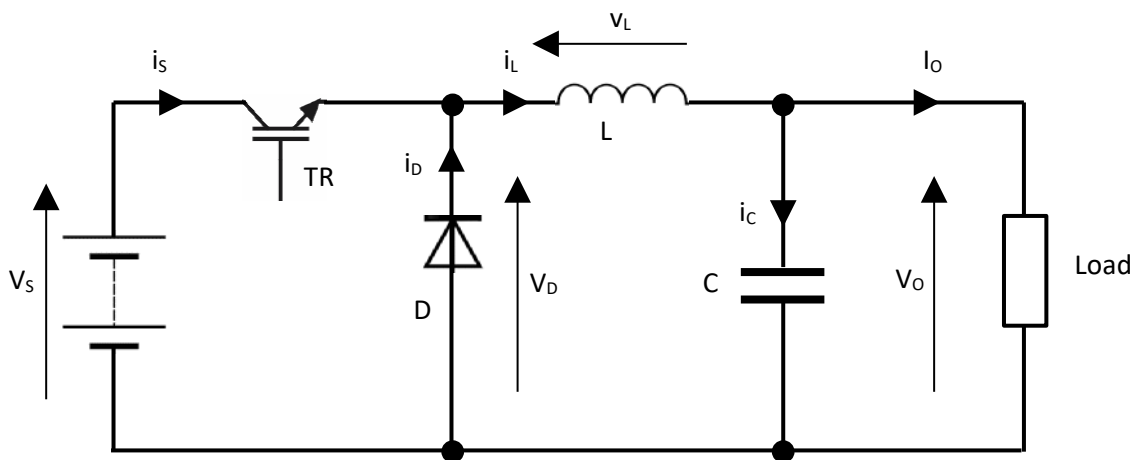


Figure Q4

Total for this question is 34 marks

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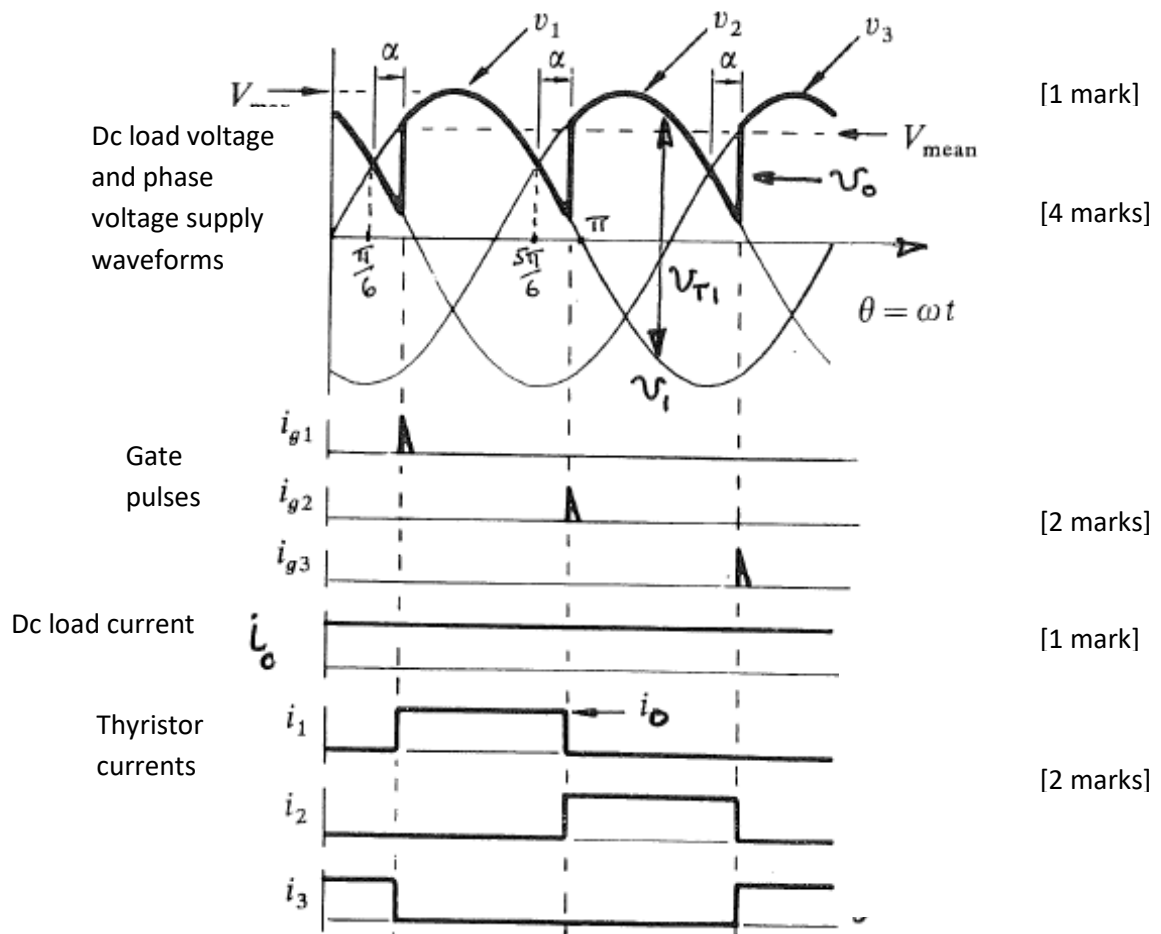
**CYFNOD ARHOLIADAU
MAI 2018**

**MODULE CODE: PSDE6016
POWER ELECTRONICS AND DRIVES**

MAIN SOLUTIONS

QUESTION 1

- (a) Let the dc output load voltage be v_o , and the dc load current i_o . The waveforms are shown below, for $\alpha = 30^\circ = \pi/6$ rad



The load current is assumed to be constant and is made up of the 3 thyristor currents, only one thyristor will conduct at a time.

$$i_o = i_1 + i_2 + i_3$$

[2 marks]

The delay angle for firing each thyristor α is measured from the cross-over point of phases which occurs $\theta = 30^\circ = \pi/6$ rad as shown. Conduction continues until next thyristor is fired, after $120^\circ = 4\pi/6$ rad.

[2 marks]

QUESTION 1 (continued)

(b)

The average d.c voltage can be calculate
by integrating from $\pi/6 + \alpha$ to $5\pi/6 + \alpha$

$$V_{\text{mean}} = \frac{1}{4\pi/6} \int_{\pi/6 + \alpha}^{5\pi/6 + \alpha} V_{\text{max}} \sin \theta \, d\theta \quad [2 \text{ marks}]$$

$$= \frac{3V_{\text{max}}}{2\pi} \left[-\cos \theta \right]_{\pi/6 + \alpha}^{5\pi/6 + \alpha} \quad [1 \text{ mark}]$$

$$= \frac{3V_{\text{max}}}{2\pi} \left[-\cos \left(\frac{5\pi}{6} + \alpha \right) - -\cos \left(\frac{\pi}{6} + \alpha \right) \right] \quad [1 \text{ mark}]$$

$$= \frac{3V_{\text{max}}}{2\pi} \left[-\cos \left(\frac{5\pi}{6} + \alpha \right) + \cos \left(\frac{\pi}{6} + \alpha \right) \right] \quad [1 \text{ mark}]$$

using the expansion

$$\cos(A+B) = \cos A \cos B - \sin A \sin B$$

$$\therefore \cos \left(\frac{5\pi}{6} + \alpha \right) = \cos \frac{5\pi}{6} \cos \alpha - \sin \frac{5\pi}{6} \sin \alpha$$

$$= -\frac{\sqrt{3}}{2} \cos \alpha - \frac{1}{2} \sin \alpha$$

$$\therefore \cos \left(\frac{\pi}{6} + \alpha \right) = \cos \frac{\pi}{6} \cos \alpha - \sin \frac{\pi}{6} \sin \alpha$$

$$= \frac{\sqrt{3}}{2} \cos \alpha - \frac{1}{2} \sin \alpha$$

$$\therefore V_{\text{mean}} = \frac{3V_{\text{max}}}{2\pi} \left[-\cancel{-\frac{\sqrt{3}}{2} \cos \alpha} - \cancel{-\frac{1}{2} \sin \alpha} + \frac{\sqrt{3}}{2} \cos \alpha - \frac{1}{2} \sin \alpha \right] \quad [1 \text{ mark}]$$

$$V_{\text{mean}} = \frac{3\sqrt{3}}{2\pi} V_{\text{max}} \cos \alpha \quad [1 \text{ mark}]$$

$$V_{\text{mean}} = \frac{3}{\sqrt{2\pi}} V_{\text{RMS(LINE)}} \cos \alpha \quad [1 \text{ mark}]$$

$$\sin \frac{\pi}{6} = \frac{1}{2}$$

[1 mark]

$$\sin \frac{5\pi}{6} = \frac{1}{2}$$

[1 mark]

$$\cos \frac{\pi}{6} = \frac{\sqrt{3}}{2}$$

[1 mark]

$$\cos \frac{5\pi}{6} = -\frac{\sqrt{3}}{2}$$

[1 mark]

QUESTION 1 (continued)

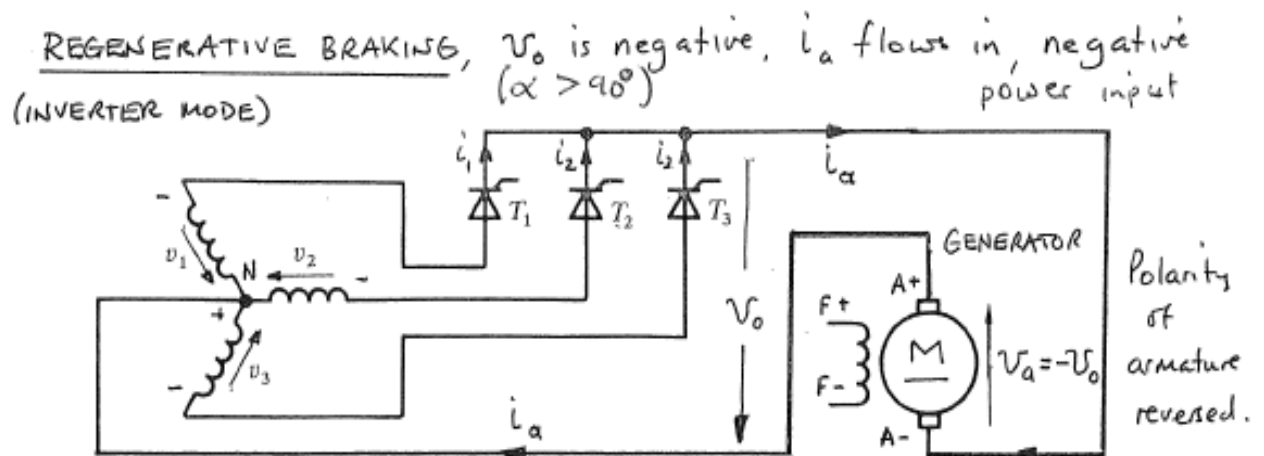
(c)

When the flow of power to the motor becomes negative, energy is recovered from the load and if the converter has the correct circuitry, this energy can be delivered back into the supply producing a braking effect. This is achieved when the voltage and current have different polarities.

[2 marks]

This is achieved in the half-wave three-phase rectifier by reversing the armature connections while at the same time setting the firing angle above 90° , making the armature voltage negative, while at the same time maintaining the direction of the current into the armature. The product of volts and amps is negative thus producing regenerative braking as shown in the diagram below.

[2 marks]

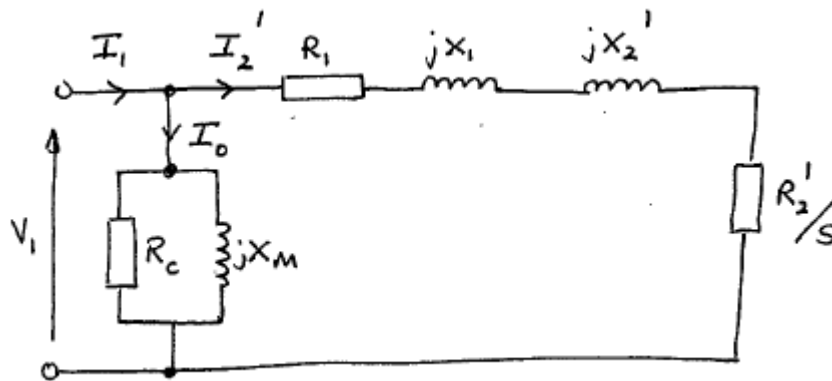


[4 marks]

Total marks for this question = 34

QUESTION 2

(a)



[2 marks]

Where I_0 is the per-phase no load stator current and I_2' is the balancing current.

[1 mark]

power transferred to the rotor = $|I_2'|^2 \frac{R_2'}{s}$
 subtracting rotor loss $|I_2'|^2 R_2'$
 gives the mechanical power at the shaft per phase at any speed.

[1 mark]

$$= |I_2'|^2 \frac{R_2'}{s} - |I_2'|^2 R_2'$$

[1 mark]

$$P = |I_2'|^2 \frac{(1-s)}{s} R_2' \quad \text{per-phase}$$

[1 mark]

Torque is found by dividing by rotor speed ω_R

$$T = |I_2'|^2 \frac{(1-s)}{s} R_2' \times \frac{1}{\omega_R}$$

[1 mark]

$$\text{Since } \omega_R = (1-s) \omega_s$$

[1 mark]

$$T = \frac{|I_2'|^2 R_2'}{s \omega_s} \quad \text{per phase.}$$

Total stator-rotor impedance

$$= \left(R_1 + \frac{R_2'}{s} \right) + j(X_1 + X_2')$$

$$\therefore I_2' = \frac{V_1}{\left(R_1 + \frac{R_2'}{s} \right) + j(X_1 + X_2')}$$

[1 mark]

QUESTION 2 (continued)

The stator current is then given by $I_1 = I_0 + I_2'$

[1 mark]

$$|I_2'| = \frac{V_1}{\sqrt{(R_1 + \frac{R_2'}{s})^2 + (X_1 + X_2')^2}}$$

[1 mark]

$$\therefore T = \frac{V_1^2 R_2'}{s \omega_s \left[(R_1 + \frac{R_2'}{s})^2 + (X_1 + X_2')^2 \right]}$$

per phase

[1 mark]

(b)

$$N_s = \frac{60 \times 60}{3} = 1200 \text{ RPM}$$

$$\begin{aligned} \omega_s &= 1200 \times \frac{2\pi}{60} \\ &= 125.664 \text{ rad/s} \end{aligned}$$

[1 mark]

$$s = \frac{N_s - N_R}{N_s} = \frac{1200 - 1140}{1200} = 0.05$$

[1 mark]

$$V_1 = \frac{415}{\sqrt{3}} = 239.6 \text{ V}$$

[1 mark]

using

$$\begin{aligned} I_2' &= \frac{V_1}{(R_1 + \frac{R_2'}{s}) + j(X_1 + X_2')} \\ &= \frac{239.6}{(0.7 + \frac{0.6}{0.05}) + j(1.9 + 1.9)} \\ &= \frac{239.6}{12.7 + j3.8} \text{ Amps} \end{aligned}$$

[1 mark]

[1 mark]

QUESTION 2 (continued)

$$|12.7 + j3.8| = \sqrt{12.7^2 + 3.8^2} = 13.26$$

$$\angle = \tan^{-1}\left(\frac{3.8}{12.7}\right) = 16.66^\circ \quad [1 \text{ mark}]$$

$$\therefore I_2' = \frac{239.6}{13.26 \angle 16.66^\circ} = 18.07 \angle -16.66^\circ$$

$$= 17.311 - j5.181 \text{ Amps} \quad [1 \text{ mark}]$$

$$\therefore I_1 = I_0 + I_2'$$

$$= 1.7 - j6.6 + 17.311 - j5.181 \quad [1 \text{ mark}]$$

$$= 19.011 - j11.781 \text{ Amps.}$$

$$I_1 = 22.37 \angle \tan^{-1}\left(\frac{-11.781}{19.011}\right)$$

$$= 22.37 \angle -31.79^\circ \text{ Amps} \quad [1 \text{ mark}]$$

$$\text{Total torque} = 3 \times \frac{V_1^2 R_2'}{s \omega_s \left[\left(R_1 + \frac{R_2'}{s} \right)^2 + (X_1 + X_2')^2 \right]}$$

$$= \frac{3 \times 239.6^2 \times 0.6}{0.05 \times 125.664 \left[12.7^2 + 3.8^2 \right]} \quad [1 \text{ mark}]$$

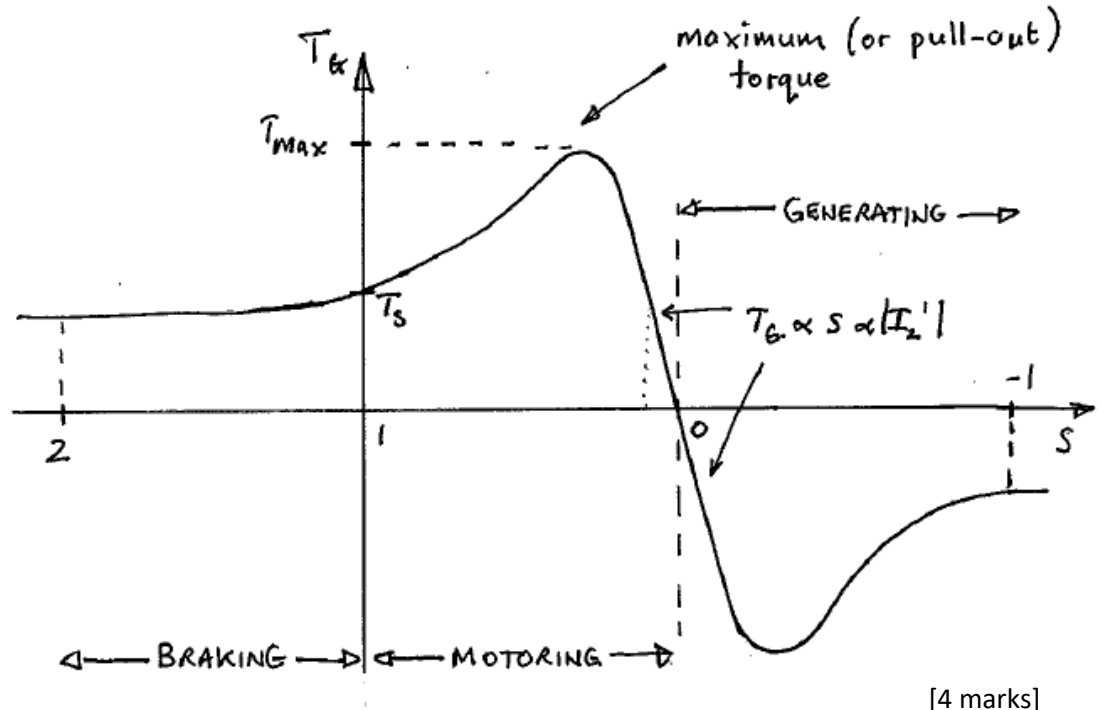
$$= \frac{103334.7}{1104.15}$$

$$= 93.59 \text{ Nm} \quad [1 \text{ mark}]$$

QUESTION 2 (continued)

(c)

The torque speed curve for values of S between 2 and -1 is shown below:



[4 marks]

For small values of S (between ± 0.1)

$$T_g = \frac{3V_1^2}{\omega_s R_2'} S \quad \text{and} \quad |I_2'| = \frac{V_1}{R_2'} S$$

[1 mark]

Therefore $T_g \propto S \propto |I_2'|$

For high efficiency, the value of S must be kept low and within this region for best operation.

[1 mark]

Motoring Region

This occurs for values of S between 1 and 0 where stator field is travelling faster than the rotor. Torque is positive in the forward direction. Motor will stall if load torque exceeds the pull-out torque.

[1 mark]

Generating Region

This occurs for values of S between 0 and -1 where rotor is being driven faster than stator field. Torque is negative in the forward direction giving a braking effect and energy is delivered back to the supply. Generator will stall if braking torque exceeds the pull-out torque. This method is often used in commercial wind generators.

[2 marks]

Braking Region

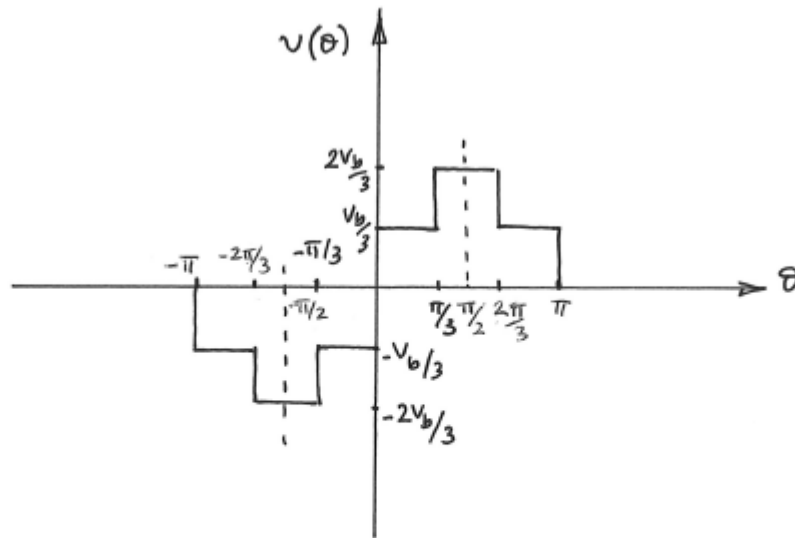
If the rotor is driven in the opposite direction to the stator field, S becomes greater than 1 producing a braking effect but no recovery of energy back to the supply. This is called plugging. The effect also occurs when two of the supply phases are swapped. This is a wasteful method of braking and should be avoided.

[2 marks]

Total marks for this question = 34

QUESTION 3

(a)



Since waveform has odd symmetry

[1 mark]

$$A = 0, \quad b_n = 0$$

$$a_n = \frac{2}{\pi} \int_{-\pi/2}^{\pi/2} v(\theta) \sin(n\theta) d\theta$$

[1 mark]

Between $-\pi/2$ and $-\pi/3$, $v(\theta) = -\frac{2V_b}{3}$

Between $-\pi/3$ and 0 , $v(\theta) = -\frac{V_b}{3}$

Between 0 and $\pi/3$, $v(\theta) = \frac{V_b}{3}$

Between $\pi/3$ and $\pi/2$, $v(\theta) = \frac{2V_b}{3}$

[2 marks]

a_n is made up of 4 parts as follows:

QUESTION 3 (continued)

$$a_n = \frac{2}{\pi} \left\{ \int_{-\pi/2}^{-\pi/3} -\frac{2V_b}{3} \sin(n\theta) d\theta + \int_{-\pi/3}^0 -\frac{V_b}{3} \sin(n\theta) d\theta \right. \\ \left. + \int_0^{\pi/3} \frac{V_b}{3} \sin(n\theta) d\theta + \int_{\pi/3}^{\pi/2} \frac{2V_b}{3} \sin(n\theta) d\theta \right\}$$

[1 mark]

$$= \frac{2}{\pi} \left\{ -\frac{2V_b}{3} \left[-\frac{\cos(n\theta)}{n} \right]_{-\pi/2}^{-\pi/3} - \frac{V_b}{3} \left[-\frac{\cos(n\theta)}{n} \right]_{-\pi/3}^0 \right. \\ \left. + \frac{V_b}{3} \left[-\frac{\cos(n\theta)}{n} \right]_0^{\pi/3} + \frac{2V_b}{3} \left[-\frac{\cos(n\theta)}{n} \right]_{\pi/3}^{\pi/2} \right\}$$

[2 marks]

$$= \frac{2V_b}{3\pi n} \left\{ 2 \left[\cos\left(-\frac{n\pi}{3}\right) - \cos\left(-\frac{n\pi}{2}\right) \right] + \left[\cos(0) - \cos\left(-\frac{n\pi}{3}\right) \right] \right. \\ \left. - \left[\cos\left(\frac{n\pi}{3}\right) - \cos(0) \right] - 2 \left[\cos\left(\frac{n\pi}{2}\right) - \cos\left(\frac{n\pi}{3}\right) \right] \right\}$$

[2 marks]

Cosine is symmetrical

$$\therefore \cos\left(-\frac{n\pi}{3}\right) = \cos\left(\frac{n\pi}{3}\right) \quad \text{and} \quad \cos\left(-\frac{n\pi}{2}\right) = \cos\left(\frac{n\pi}{2}\right)$$

and since n is odd, $\cos\left(\frac{n\pi}{2}\right) = 0$

and $\cos(0) = 1$.

[1 mark]

QUESTION 3 (continued)

$$\therefore a_n = \frac{2V_b}{3n\pi} \left[2 \left(\cos\left(\frac{n\pi}{3}\right) - 0 \right) + \left(1 - \cos\left(\frac{n\pi}{3}\right) \right) - \left(\cos\left(\frac{n\pi}{3}\right) - 1 \right) - 2 \left(0 - \cos\left(\frac{n\pi}{3}\right) \right) \right] \quad [1 \text{ mark}]$$

$$= \frac{2V_b}{3n\pi} \left[2 \cos\left(\frac{n\pi}{3}\right) + 1 - \cos\left(\frac{n\pi}{3}\right) - \cos\left(\frac{n\pi}{3}\right) + 1 + 2 \cos\left(\frac{n\pi}{3}\right) \right] \quad [1 \text{ mark}]$$

$$a_n = \frac{2V_b}{3n\pi} \left[2 \cos\left(\frac{n\pi}{3}\right) + 2 \right] = \frac{4V_b}{3n\pi} \left[\cos\left(\frac{n\pi}{3}\right) + 1 \right] \quad [1 \text{ mark}]$$

$$\begin{aligned} \therefore a_1 &= \frac{4 \times V_b}{3 \times \pi} \left[\cos\left(\frac{\pi}{3}\right) + 1 \right] = 0.637 V_b \\ a_3 &= \frac{4 V_b}{3 \times 3\pi} \left[\cos\left(\frac{3\pi}{3}\right) + 1 \right] = 0 \\ a_5 &= \frac{4 V_b}{3 \times 5\pi} \left[\cos\left(\frac{5\pi}{3}\right) + 1 \right] = 0.127 V_b \\ a_7 &= \frac{4 V_b}{3 \times 7\pi} \left[\cos\left(\frac{7\pi}{3}\right) + 1 \right] = 0.091 V_b \end{aligned} \quad [4 \text{ marks}]$$

$$\begin{aligned} \therefore v(t) &= \frac{6V_b}{3\pi} \left[\sin(\omega t) + \frac{1}{5} \sin(5\omega t) + \frac{1}{7} \sin(7\omega t) \right] \\ v(t) &= \frac{2V_b}{\pi} \left[\sin(\omega t) + \frac{1}{5} \sin(5\omega t) + \frac{1}{7} \sin(7\omega t) \right] \end{aligned} \quad [1 \text{ mark}]$$

QUESTION 3 (continued)

(b)

$$V_b = 420 \text{ V}$$

$$\omega = 2\pi \times 35 = 219.91 \text{ rad/s}$$

$$\therefore V(t) = \frac{2 \times 420}{\pi} \left[\sin(\omega t) + \frac{1}{5} \sin(5\omega t) + \frac{1}{7} \sin(7\omega t) \right]$$

RMS values of voltages are

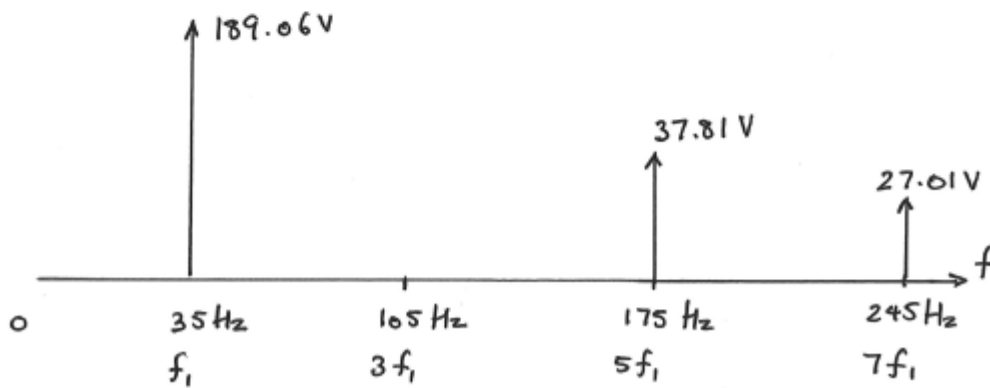
$$V_1 = \frac{2 \times 420}{\pi} \times \frac{1}{\sqrt{2}} = 189.06 \text{ V}$$

$$V_3 = 0$$

$$V_5 = \frac{189.06}{5} = 37.81 \text{ V}$$

$$V_7 = \frac{189.06}{7} = 27.01 \text{ V}$$

[3 marks]



[2 marks]

QUESTION 3 (continued)

$$X_L = 2\pi f L$$

$$\textcircled{a} \ 35 \text{ Hz}, \quad X_L = 2 \times \pi \times 35 \times 0.004 \\ = 0.88 \ \Omega$$

$$\textcircled{a} \ 175 \text{ Hz}, \quad X_L = 2 \times \pi \times 175 \times 0.004 \\ = 4.398 \ \Omega$$

$$\textcircled{a} \ 245 \text{ Hz}, \quad X_L = 6.158 \ \Omega$$

[3 marks]

$$i = i_1 + i_3 + i_5 + i_7$$

$$= \frac{V_1}{Z_1} + 0 + \frac{V_5}{Z_5} + \frac{V_7}{Z_7}$$

[1 mark]

$$Z_1 = 0.3 + j 0.88$$

$$= 0.9297 \angle 71.18^\circ$$

[1 mark]

$$Z_5 = 0.3 + j 4.398$$

$$= 4.408 \angle 86.098^\circ$$

[1 mark]

$$Z_7 = 0.3 + j 6.158$$

$$= 6.165 \angle 87.21^\circ$$

[1 mark]

QUESTION 3 (continued)

$$\begin{aligned} i_1 &= \frac{189.06}{0.9297 \angle 71.18^\circ} \\ &= 203.36 \angle -71.18^\circ \text{ Amps.} \end{aligned}$$

[1 mark]

$$\begin{aligned} i_5 &= \frac{37.81}{4.408 \angle 86.098^\circ} \\ &= 8.58 \angle -86.098^\circ \text{ Amps} \end{aligned}$$

[1 mark]

$$\begin{aligned} i_7 &= \frac{27.01}{6.165 \angle 87.21^\circ} \\ &= 4.38 \angle -87.21^\circ \text{ Amps} \end{aligned}$$

[1 mark]

$$\begin{aligned} I_{RMS} &= \sqrt{203.36^2 + 8.58^2 + 4.38^2} \\ &= 203.59 \text{ A.} \end{aligned}$$

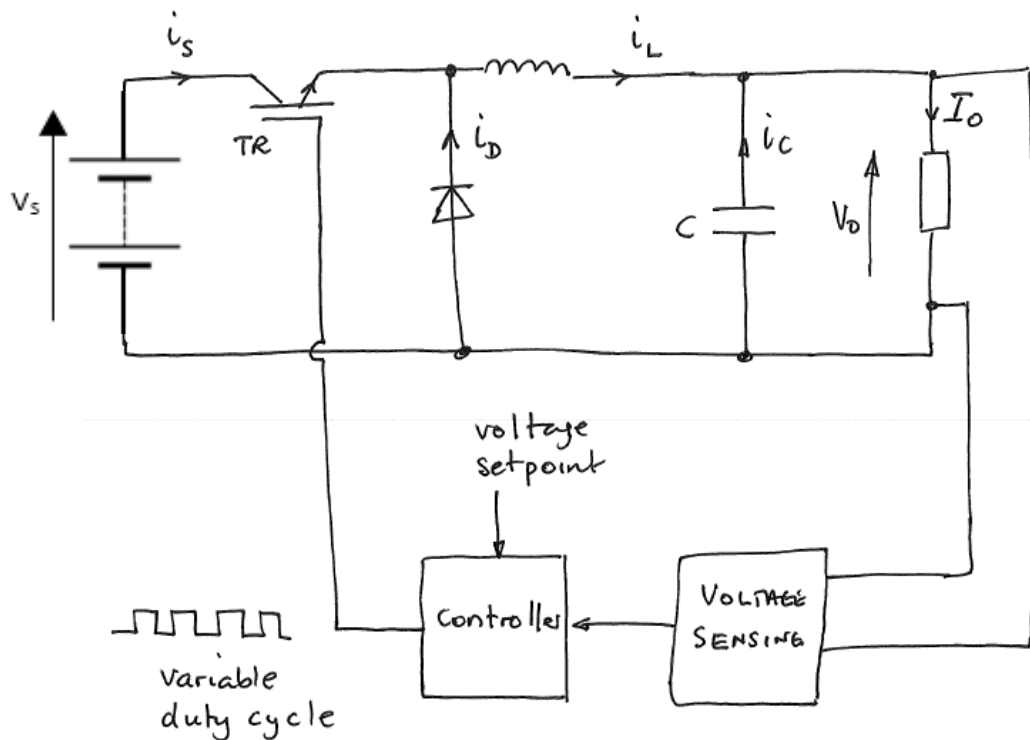
[1 mark]

Total marks for this question = 34

QUESTION 4

- (a) The circuit is called a buck converter because it decreases voltage making $V_o < V_s$. The inductor act as a filter providing constant voltage and current to the load. The diode allows the current in the inductor to continue to flow when the transistor is off. After a transient period, the output voltage is determined by the duty cycle of the transistor switching.

[2 marks]



[2 marks]

The above diagram shows that the output voltage is fed back to a controller which compares it with the set-point voltage. The duty cycled is controlled so as to maintain output voltage at the set-point.

[1 mark]

QUESTION 4 (continued)

(b)

- (i) The current waveforms for an inductor current that is just continuous are shown below. The cycle time at 125KHz = 8us. [1 mark]

$$\text{The duty cycle} = V_o/V_s = 15/40$$

$$= 0.375 \quad [1 \text{ mark}]$$

$$\text{Hence the on-time} = 0.375 \times 8\mu\text{s}$$

$$= 3\mu\text{s} \quad [1 \text{ mark}]$$

$$\text{And the off-time} = 5\mu\text{s} \quad [1 \text{ mark}]$$

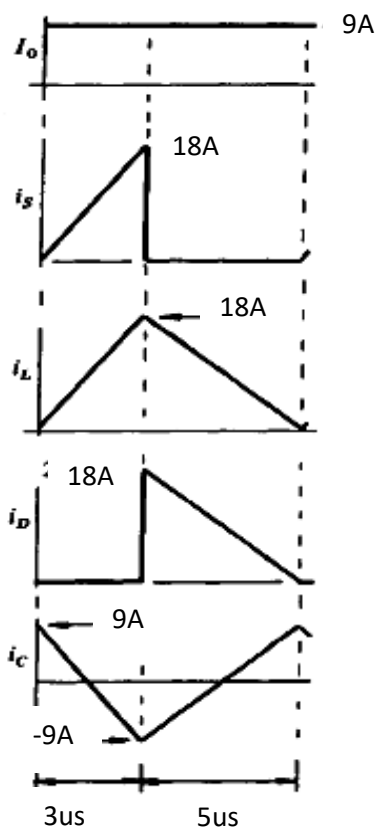
- (ii) The charge into the capacitor must equal the charge out in each cycle, hence:

$$\text{The mean value of } i_c = 0 \quad [1 \text{ mark}]$$

$$\begin{aligned} \text{And mean value of } i_L &= I_o \\ &= 9\text{A} \end{aligned} \quad [1 \text{ mark}]$$

Because the current changes are linear, the source and inductor currents must peak at 18A [1 mark]

- (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. [1 mark]



[2 marks]

[2 marks]

[2 marks]

[2 marks]

[2 marks]

QUESTION 4 (continued)

(d)

$$\begin{aligned}
 \text{During the ON time, the voltage across the inductor} &= 40 - 15 \\
 &= 25\text{V}
 \end{aligned}$$

[1 mark]

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

$$\begin{aligned}
 \text{And the gradient } di/dt &= 15/(3 \times 10^{-6}) \\
 &= 5 \times 10^6 \text{ A/s}
 \end{aligned}$$

[2 marks]

$$\begin{aligned}
 \text{Therefore, the inductor value } L &= 25 / 5 \times 10^6 \\
 &= 5 \mu\text{H}
 \end{aligned}$$

[1 mark]

(e)

The ripple load voltage is the capacitor voltage, using

[1 mark]

$$q = CV$$

$$\text{and } i = dq/dt$$

[1 mark]

$$\text{The change in output voltage} = \Delta q / C$$

[1 mark]

From the waveforms, Δq is the area under the graph corresponding to half the cycle time

[1 mark]

$$\begin{aligned}
 \Delta q &= \frac{1}{2} \times 4 \times 10^{-6} \times 9 \\
 &= 18 \times 10^{-6} \text{ coulombs}
 \end{aligned}$$

[1 mark]

$$\Delta v_o = \Delta q / C$$

[1 mark]

$$= 18 \times 10^{-6} / 150 \times 10^{-6}$$

$$= 0.12\text{V}$$

[1 mark]

Total marks for this question = 34