



Examination Answer Books

12 Pages

Instructions to Candidates

1. Please give the information requested in the boxes below.
2. Enter your name in the space provided to the right, fold over and seal down (using the label provided) to hide your name.
3. The answers must be legibly written. The Examiners can either ignore illegible script or have it typed and the expense of typing charged to the candidate.
4. Write your answers in ink.
5. Begin each answer on a fresh page. Do all rough work in the answer book and cross it through.
6. No part of this book is to be torn out; it must be handed in complete.
7. If more books than one are used, fasten them together using the tags available from the invigilator(s).
8. Every book must be handed in. In no circumstances may answer books, used or unused, be taken out of the examination venue.

Complete, fold and seal
(see note 2 below)

SURNAME: Grennan

FORENAME(S): Thomas Sean

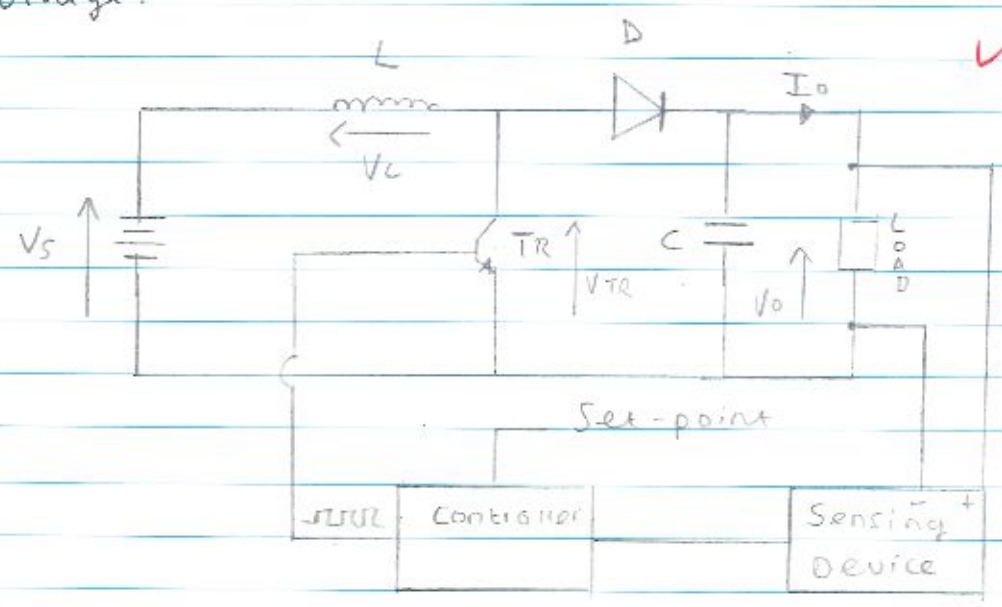
1	Student Number	1809799
2	Title of Examination Paper	PE + D
3	Module Code	SGEE6001
4	Date and Time of Examination	20/05/2022 9:30
5	Examination Venue	Gym
6	Seat Number	10
7	Number of Answer Books handed in	2 (1 OF 2)

List the numbers of the questions you have attempted	Office Use
Q3	25
Q4	24
Q5	22
Q1	15
Total	86

3a) The converter circuit seen in Figure Q3 is a DC-DC converter known as the Boost Converter, the purpose of this circuit is to increase the input voltage on it's output, making $V_o > V_s$.
When the transistor is on, the inductor is shorted to ground, thus dropping V_s across itself, this primes the inductor building up it's magnetic field. When the transistor turns OFF current is driven from the inductor, through the diode, charging the capacitor to V_s , after the transient period the duty cycle of the transistor can be controlled to increase the output voltage to the desired value.
* 1

3

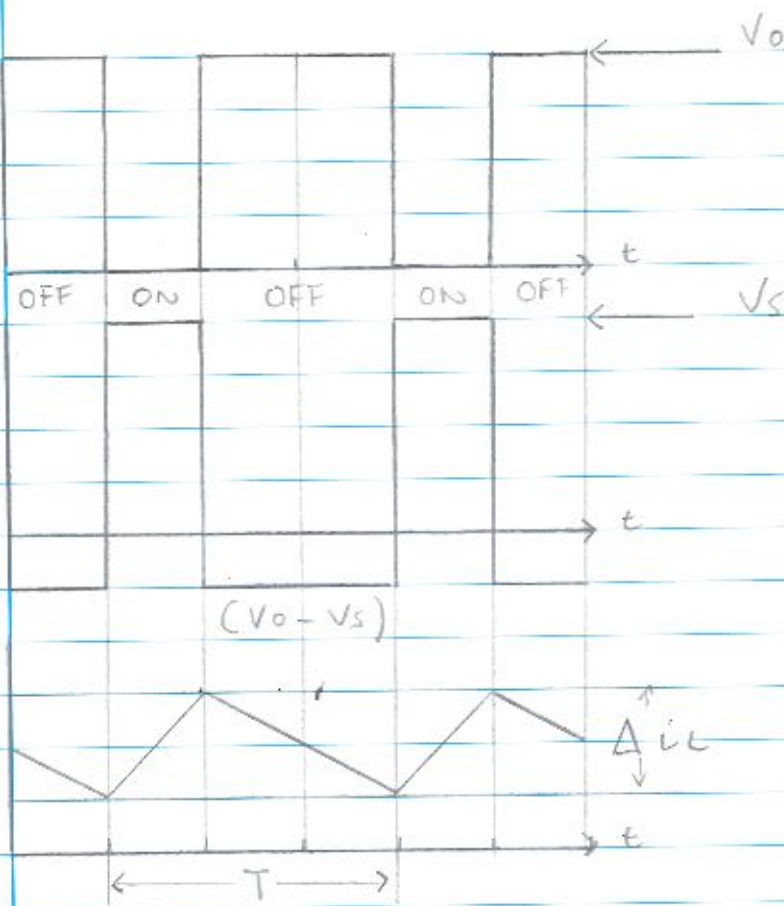
A control method to maintain voltage output under load uses a voltage sensing device like a shunt to measure the output voltage. this value is fed into a ~~gear~~ controller which compares the actual voltage to the desired set-point, the error between these values determines the transistors switching frequency to achieve the desired output voltage.



3

* The diode prevents the capacitor discharging into the battery.

6)

 V_{Te} V_L I_L 

$$(1) i) \quad V_s t_{on} - (V_o - V_s) t_{off} = 0$$

$$t_{on} = DT, \quad t_{off} = (1-D)T$$

$$\therefore V_s DT - (V_o - V_s)(1-D)T = 0$$

$$\text{and, } \frac{1}{1-D} = \frac{V_o}{V_s}$$

$$\therefore D = 1 - \frac{V_s}{V_o}$$

$$D = 1 - \frac{12}{20} = 0.4$$

✓



(ii)
$$\Delta I_L = \frac{V_s t_{on}}{L} = \frac{V_s D T}{L}$$

Where $T = \frac{1}{f} = \frac{1}{20,000} = 50 \times 10^{-6}$

$$\therefore \Delta I_L = \frac{12 \times 0.4 \times 50 \times 10^{-6}}{150 \times 10^{-6}} = 1.6 \text{ A}$$
 ✓

3

(iii) Assuming no losses, $V_s \times I_L(\text{AVG}) = V_o \times I_o$

$$\therefore I_L(\text{AVG}) = \frac{V_o \times I_o}{V_s} = \frac{20 \times 1.5}{12}$$

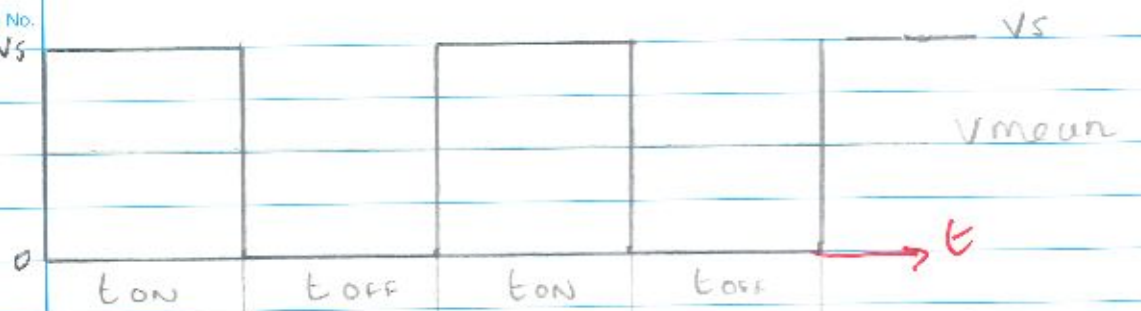
$$I_L(\text{AVG}) = 2.5 \text{ A}$$

$$I_L(\text{PK}) = I_L(\text{AVG}) + \frac{\Delta I_L}{2}$$

$$I_L(\text{PK}) = 2.5 + \frac{1.6}{2} = 3.3 \text{ A}$$
 ✓

5

4 a)

 v_a  i_a

$I_a(max)$
 $I_a(mean)$
 $I_a(min)$

 i_d  i_s 

$$D = \frac{t_{on}}{t_{on} + t_{off}} = \frac{t_{on}}{T}$$

$$V_{mean} = \frac{1}{T} \int_0^{t_{on}} V_s dt + \frac{1}{T} \int_{t_{on}}^{t_{on}+t_{off}} 0 dt$$

$$V_{mean} = \frac{1}{T} \int_0^{t_{on}} V_s dt$$

$$V_{mean} = \frac{1}{T} \int_0^{t_{on}} V_s dt$$

$$V_{\text{mean}} = \frac{1}{T} \left[V_s t \right]_0^{t_{\text{on}}}$$

$$= \frac{V_s t_{\text{on}}}{T}$$

Combined with duty cycle equation:

$$V_{\text{mean}} = D V_s$$

b)

(i) Since the armature resistance is negligible,

$$E = k_b \times \omega = 0.6 \times 100 = 60 \text{ V}$$

$$D = \frac{E}{V_s} = \frac{60}{96} = 0.625$$

$$T = \frac{1}{f} = \frac{1}{1000} = 1 \times 10^{-3}$$

$$\text{On time} = DT$$

$$\text{On time} = 0.625 \times 1 \times 10^{-3} = 0.625 \times 10^{-3}$$

$$\text{On time} = 0.625 \text{ ms}$$

$$\text{OFF time} = (1 - D)T$$

$$\text{OFF time} = (1 - 0.625) \times 1 \times 10^{-3} = 0.375 \times 10^{-3}$$

$$\therefore \text{On time} = 0.625 \text{ ms}$$

$$\text{OFF time} = 0.375 \text{ ms}$$

$$b) ii) T_L = K_b \times I_{a(\text{mean})}$$

$$I_{a(\text{mean})} = \frac{T_L}{K_b} = \frac{6}{0.6} = 10 \text{ A} \quad \checkmark$$

At on time :

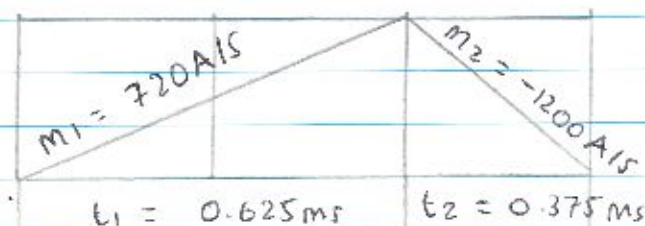
$$V_s - E = L_a \frac{dia}{dt}$$

$$\therefore \frac{dia}{dt} = \frac{V_s - E}{L_a} = \frac{96 - 60}{0.05} = 720 \text{ A/s} \quad \checkmark$$

At OFF time :

$$-E = L_a \frac{dia}{dt}$$

$$\therefore \frac{dia}{dt} = \frac{-E}{L_a} = \frac{-60}{0.05} = -1200 \text{ A/s} \quad \checkmark$$



$$I_{\text{max}} = I_{\text{min}} + (m_1 \times t_1)$$

$$I_{\text{max}} = I_{\text{min}} + (720 \times 0.625 \times 10^{-3})$$

$$I_{\text{max}} = I_{\text{min}} + 0.45 \text{ A} \quad \text{--- (1)}$$

$$I_{\text{mean}} = \frac{I_{\text{max}} + I_{\text{min}}}{2} = 10 \text{ A}$$

$$\therefore I_{\text{max}} + I_{\text{min}} = 20 \text{ A}$$

$$I_{\text{max}} = 20 \text{ A} - I_{\text{min}} \quad \text{--- (2)}$$

Combine equations (1) and (2) :

$$2I_{\max} = 20 + 0.45 = 20.45 \text{ A}$$

$$I_{\max} = 20.45 / 2 = 10.225 \text{ A}$$

$$I_{\min} = 20 - I_{\max} = 20 - 10.225 \text{ A} = 9.775 \text{ A}$$

$$I_a(\max) = 10.225 \text{ A}$$

$$I_a(\min) = 9.775 \text{ A}$$

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(iii) At on time :

$$I_a = I_a(\min) + m_1 t$$

$$I_a = 9.775 + 720 t \text{ A}$$

1

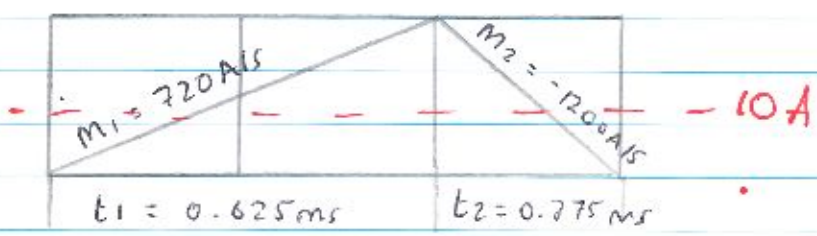
At off time :

$$I_a = I_a(\max) - m_2 t \text{ A}$$

$$I_a = 10.225 - 1200 t \text{ A}$$

1

Refer to diagram 1 on previous page. or below :



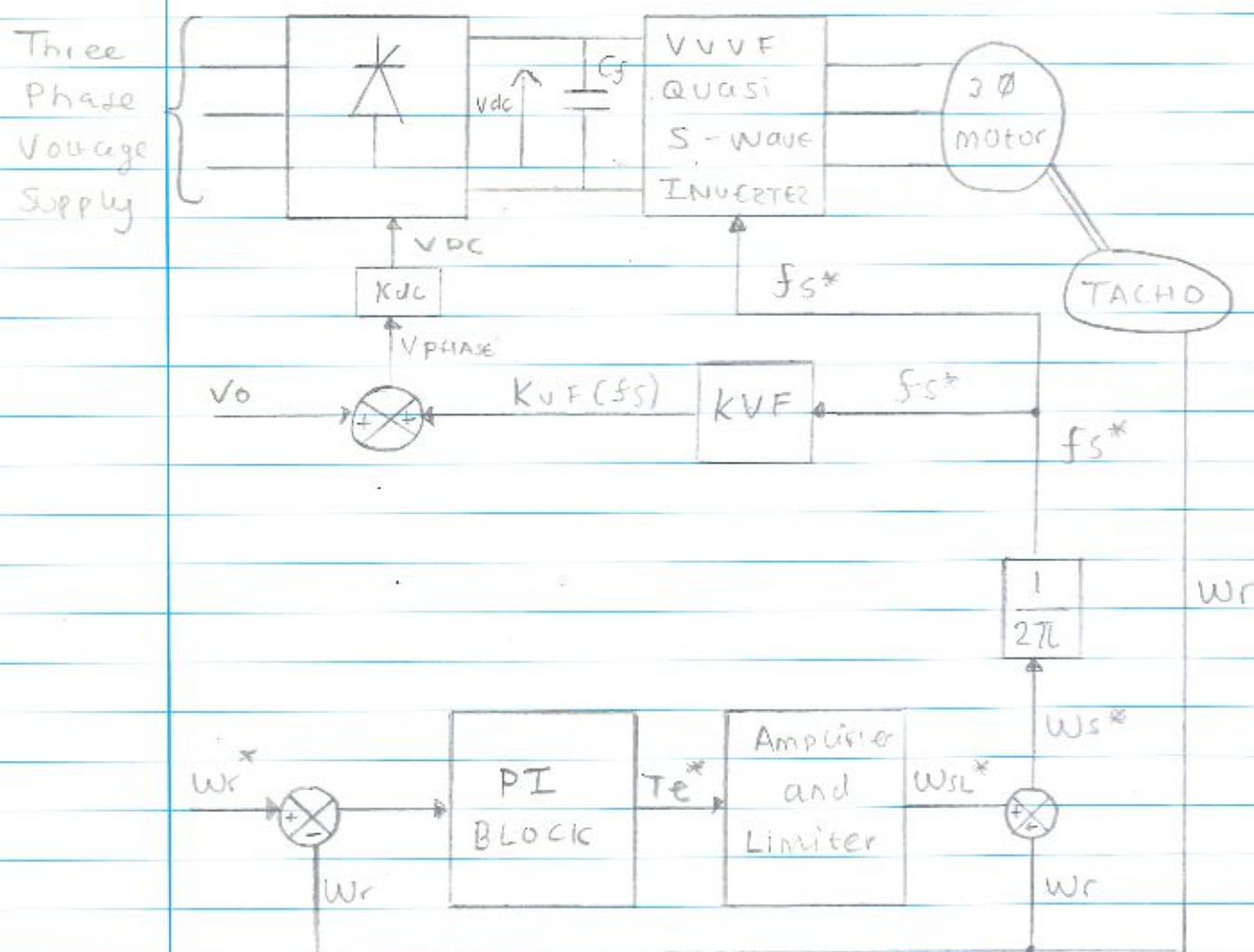
1

Q5)

Question No.

Examiner Only

- 5 a) The air gap flux in an induction motor must be kept at a constant value to prevent magnetic saturation, since the flux in an induction motor is proportional to the stator voltage divided by the supply frequency, both voltage and frequency must be controlled. A method of controlling these is implemented in the VVVF quasi square wave inverter with a closed speed control loop, this is suited to low demand applications like pumps and fans to keep a constant V/Hz ratio.



16) The actual rotor speed (ω_r) is measured by a tachogenerator coupled to the motor rotor, this is compared to the required rotor speed (ω_r^*) at a summing point, the error between these is fed into a PI block which produces the torque set-point (T_e^*).

T_e^* is fed into an amplifier and limiter to produce the slip speed demand signal (ω_{sl}^*), the limiter ensures that the motor does not exceed its rated maximum slip allowance, preventing it from entering an unstable region of operation. ω_{sl}^* is added to the actual rotor speed (ω_r) to produce the stator field speed demand (ω_s^*), this is divided by 2π to obtain the stator frequency demand (f_s^*) which is fed into the inverter. f_s^* is also then scaled by the K_{VF} constant to produce ($K_{VF} \times f_s$) the voltage-frequency constant. $K_{VF} \times f_s$ is added to the voltage offset to produce the phase voltage, which is then scaled by K_{VC} to produce the DC voltage required for the rectifier to maintain the V/Hz ratio.

(5)

The offset voltage is significant as it is required to overcome the stator resistance at 0 Hz. This strategy is implemented to control the required V/Hz ratio required for the air gap flux.

Equation missing

$$\begin{aligned} V_{PH} &= ? \\ V_o &= ? \\ V_{DC} &= ? \end{aligned}$$

6)

$$V_{\text{line}} = 220 \text{ V}$$

$$V_{\text{phase}} = V_{\text{line}} / \sqrt{3} = 220 / \sqrt{3} = 127.017 \text{ V}$$

$$\text{HP} = 6 \text{ HP}$$

$$\eta = 0.83$$

$$P_M = \text{HP} \times 745.7 = 6 \times 745.7 = 4474.2$$

$$P_e = P_M / \eta = 4474.2 / 0.83 = 5390.6024$$

$$\text{P.F.} = 0.87$$

$$f = 50 \text{ Hz}$$

$$R_r = 0.185 \Omega$$

$$R_s = 0.281 \Omega$$

$$X_s = 0.56 \Omega$$

$$X_r = 0.853 \Omega$$

(i)

$$W_{SL} = \frac{R_r}{L_s + L_r}$$

$$L_s = \frac{X_s}{2\pi f} = \frac{0.56}{2\pi \times 50} = 0.001782535$$

$$L_r = \frac{X_r}{2\pi f} = \frac{0.853}{2\pi \times 50} = 0.002715183$$

$$W_{SL} = \frac{0.185}{0.001782535 + 0.002715183} \quad \checkmark$$

$$W_{SL} = 41.41.132 \text{ rad/s} \quad \checkmark$$

(ii)

$$P_e = 3 V_{\text{PH}} \times I_s \times \cos \phi$$

$$\therefore I_s = \frac{P_e}{3 \times V_{\text{PH}} \times \cos \phi}$$

$$I_s = \frac{5390.6024}{3 \times 127.017 \times 0.87} = 16.26 \text{ A} \quad \checkmark$$



(iii) $V_o = I_s \times R_s$
 $V_o = 16.26 \times 0.281 = 4.57 \text{ V}$ ✓

(1)

(iv) $K_{VF} = \frac{V_{PM} - V_o}{f} = \frac{127.017 - 4.57}{50}$

$K_{VF} = 2.45 \text{ V/Hz}$ ✓

(1)

(v) $V_{DC} = 2.22 (V_o + K_{VF}(f_s))$
 $V_{DC} = 2.22 (4.57 + 2.45(50))$ ✓
 $V_{DC} = 2.22 (127.07)$
 $V_{DC} = 282.1 \text{ V}$

(2)

c) The advantages of using a PWM inverter drive is that more control over the rectified and ~~switched~~ chopped up output is available, thus producing a waveform that closely represents a sine-wave when compared to a Quasquare wave inverter which has a Step-waveform.

(2)

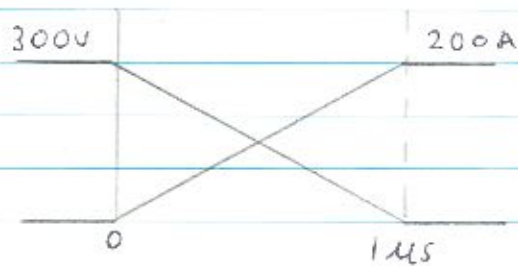
Q 1)

Question No.

Examiner Only

1)

b) i)



Instantaneous values
between 0 and T .

$$V = -\frac{V}{T} \times t + V = V \left(1 - \frac{t}{T} \right)$$

$$I = \frac{I}{T} \times t$$

Instantaneous Power = VI

$$VI = V \left(1 - \frac{t}{T} \right) \times \frac{I}{T} \times t$$

$$= VI \left(1 - \frac{t}{T} \right) \frac{t}{T}$$

$$= VI \left(\frac{t}{T} - \frac{t^2}{T^2} \right)$$

$$\text{Energy Loss} = \int_0^T \overset{vi}{VI} dt$$

$$VI \int_0^T \frac{t}{T} - \frac{t^2}{T^2} dt$$

$$VI \left[\frac{t^2}{2T} - \frac{t^3}{3T^2} \right]_0^T$$

③

$$\therefore VI \left[\frac{t^2}{2T} - \frac{t^2}{3T^2} \right]_0^T$$

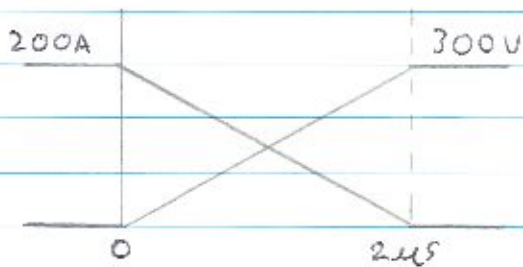
you can not cancel yet until the limits are put in.

$$\therefore VI \left[\frac{t}{2} - \frac{t}{3} \right]_0^T$$

$$\therefore VI \left[\frac{T}{2} - \frac{T}{3} \right] = \frac{VIT}{6} \text{ Joules}$$

2

At OFF time:



Instantaneous values between 0 and T.

$$V = \frac{V}{T} \times t$$

$$I = -\frac{I}{T} \times t + I = I \left(1 - \frac{t}{T} \right)$$

Instantaneous power = VI (or IV)

$$VI = I \left(1 - \frac{t}{T} \right) \times \frac{V}{T} \times t$$

$$= VI \left(1 - \frac{t}{T} \right) \times \frac{t}{T}$$

$$= VI \left(\frac{t}{T} - \frac{t^2}{T^2} \right)$$

The instantaneous Power equations are identical for turn-on and turn-off, therefore it is determined that the switching energy loss is :

$$\frac{VIT}{6} \text{ Joules}$$

(ii) Switching Loss = (On Loss + Off Loss) * Switching freq

$$\text{On loss} = \frac{VIT}{6} = \frac{300 \times 200 \times 1 \times 10^{-6}}{6} = 0.01 \text{ J}$$

$$\text{Off loss} = \frac{VIT}{6} = \frac{300 \times 200 \times 2 \times 10^{-6}}{6} = 0.02 \text{ J}$$

$$\text{Mean Switching loss} = (0.01 + 0.02) \times 10 \times 10^3$$

$$\text{Mean Switching loss} = 300 \text{ W}$$

(iii) Conduction Loss = $V_{CE} \times I_C \times D$
 $= 2.1 \times 200 \times 0.5 = 210 \text{ W}$

(iv) Total Loss = Conduction Loss + Switching Loss
 Total Loss = $210 + 300 = 510 \text{ W}$