KARPAGAM COLLEGE OF ENGINEERING, COIMBATORE-32

B.E - EEE CIA - II SEMESTER - VI

12E605 - POWER ELECTRONICS (ANSWER KEY)

PART - A

A1.

UnControlled rectifier	Controlled rectifier
A rectifier employing diodes is called an uncontrolled rectifier, because its average output voltage is a fixed dc voltage. Varg is High compared to fully controlled Rectifier	A rectifier employing thyristor is called as controlled rectifier, so that the average output voltage is a variable dc voltage. Varg is less compared to uncontrolled Rectifier

(2)

A2. Expression of average DC load voltage of 1ϕ fully controlled converter with R load.

$$V_{dc} \text{ (or) } V_0 = \frac{V_m}{\pi}(1+\cos\alpha)$$ (2)

A3. Condition to make fully controlled rectifier to operate in inversion mode.

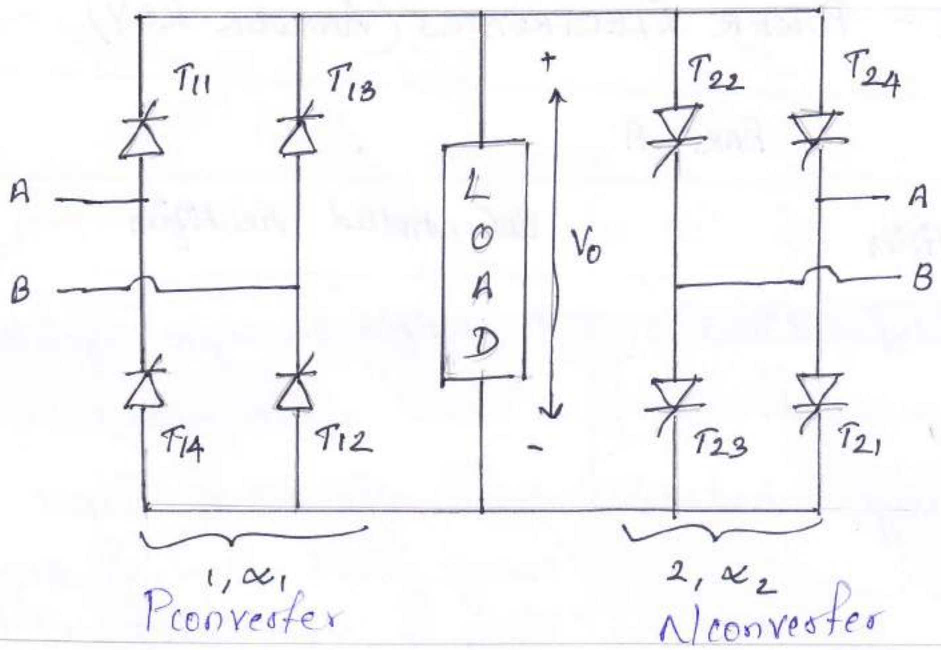
For $\alpha > 90°$, the fully controlled rectifier operates in inversion mode and during the inversion operation the DC power at the output is converted to AC power at the source (or) i/p (2)

A4. Range of firing angle and extinction angle in fully controlled converter.

For fully controlled converter, the range of firing angle is (0 - 180°) & the range of extinction angle is (180° to 360°).

(or) $\alpha < 180°$ and $\beta > 180°$

A5. Circuit diagram of Single phase dual converter.



A6. Constant frequency control and Variable frequency control.

Constant frequency control	Variable frequency control
In this control technique, the frequency of the chopper remains constant, but ON period is changed to vary the output. It should be noted that as 'ON' pulse width varies, 'OFF' pulse width also varies.	In this control technique, either on time (T_{on}) or off time (T_{off}) is kept constant. And frequency is varied to change the o/p voltage.

A7. Expression of average o/p voltage for step up and step down chopper.

For step up chopper $\rightarrow$ $V_{0(av)}$ (or) $V_{dc} = \dfrac{V_s}{1-\delta}$

For stepdown chopper $\rightarrow$ $V_{0(av)}$ (or) $V_{dc} = \delta V_s$

$\delta \rightarrow$ duty cycle $= \dfrac{T_{on}}{T}$ $\quad V_s \rightarrow$ i/p source voltage.

A8. Current Limit control.

In this control technique, ~~the~~ Output current is continuously sensed and is maintained within minium & maximum limit.

If the output current falls below certain minimum level, then chopper turns-on. This increases the output aswell as output current. When reaches maximum Switch is turned-OFF.

A9.

Given :

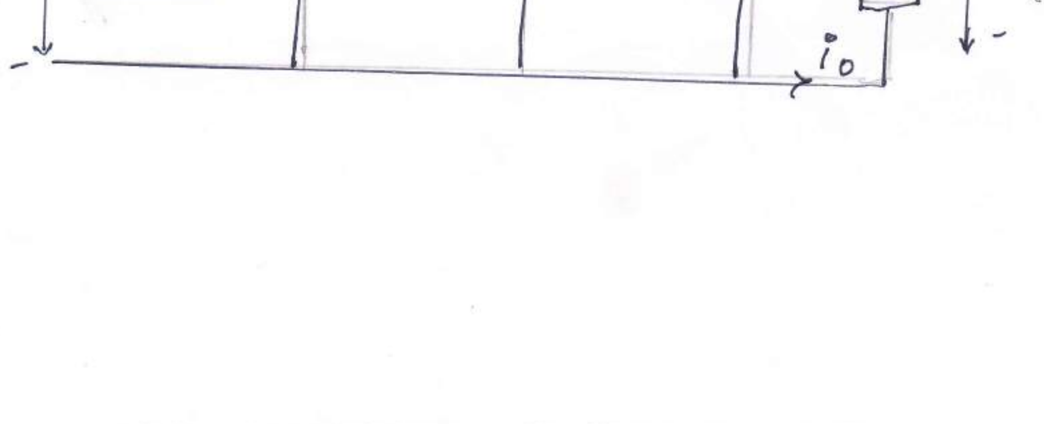
$V_s = 80V$. δ(duty cycle) = 20% = 0.2

To find : o/p voltage of boost converter $V_0 = \frac{V_s}{1-\delta}$

$$= \frac{80}{1-0.2} = \frac{80}{0.8} = 100 V$$

$$V_0 = 100V$$

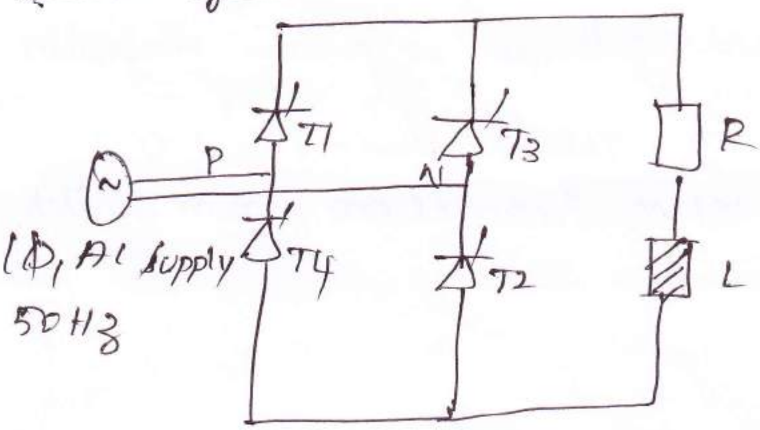
A10. Circuit diagram of Cuk converter.



Part-B (30 marks)

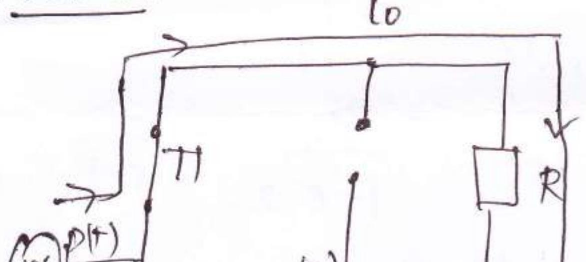
B1.a.i) Single phase fully controlled thyristor bridge Rectifier with RL Load:-

Circuit diagram: (1 mark)



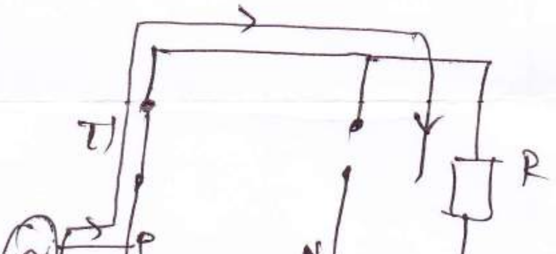
Operation: (2 mark).

α to π:



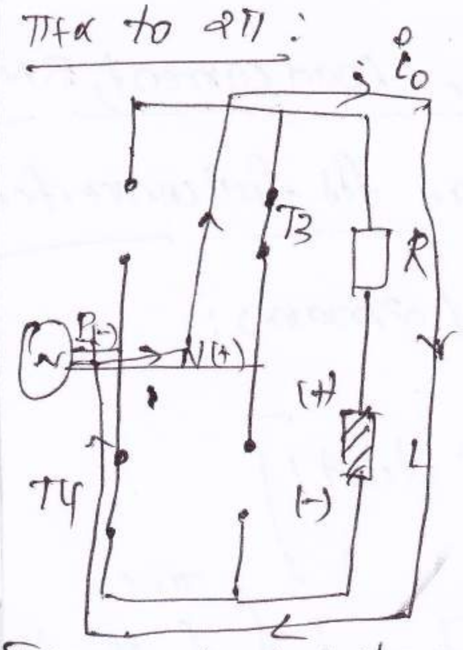
T_1T_2 conducts; L charges.
V_0 is +ve and i_0 is +ve.
i_0 is increased as L charges

π to π+α:



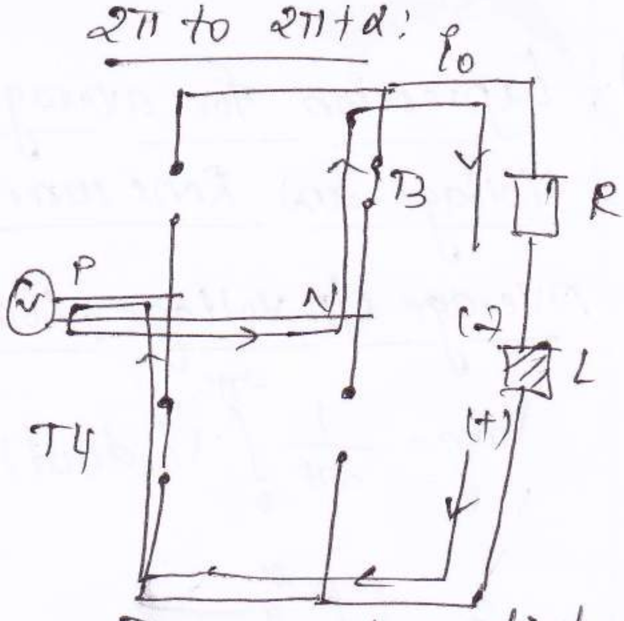
T_1T_2 conducts; L discharges
V_0 is −ve and i_0 is +ve
But i_0 decreases as L discharges.

$\pi+\alpha$ to 2π:



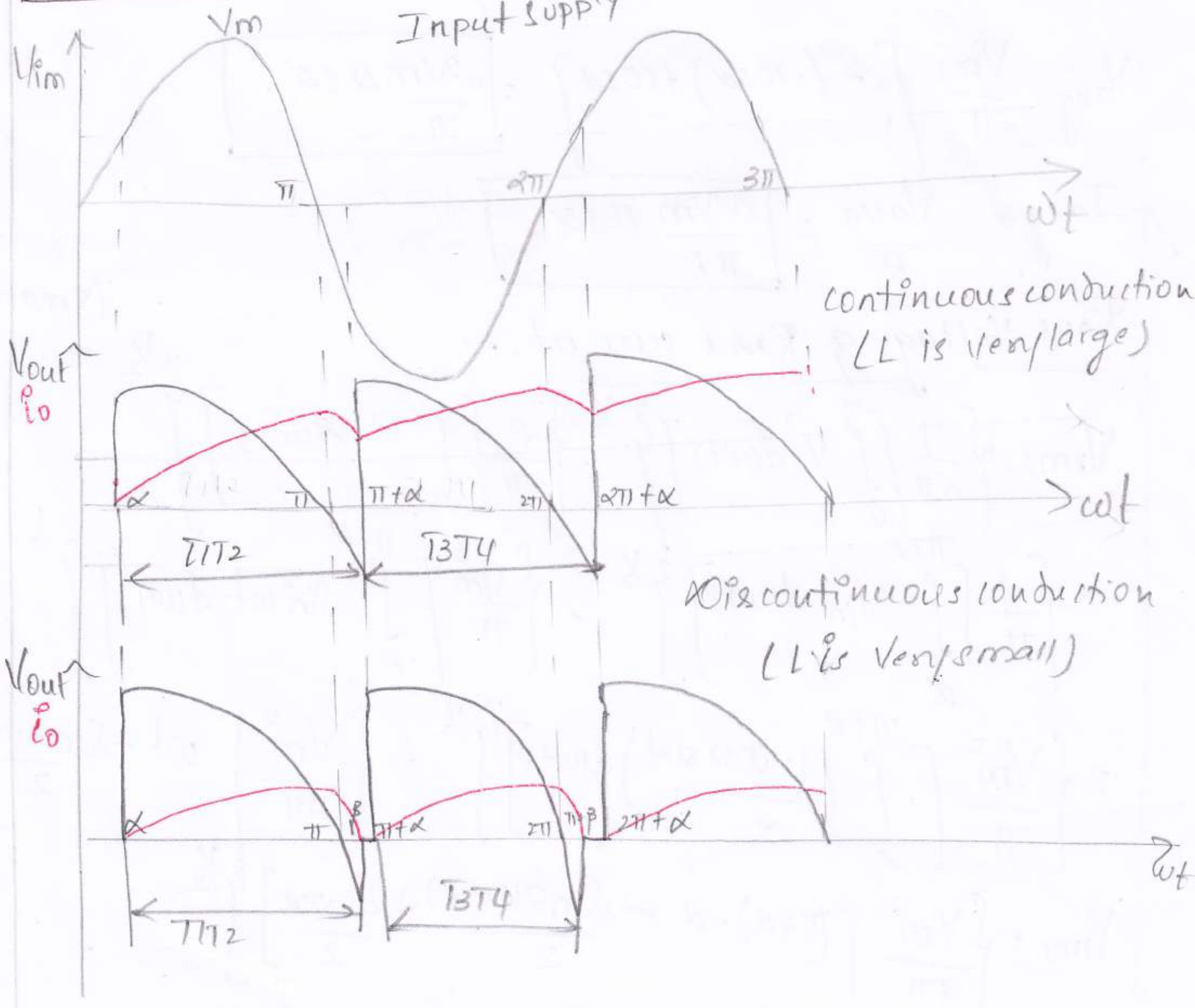
T3T4 conducts, L charges
V_0 is +ve and i_0 is +ve
i_0 increases as L charges

2π to $2\pi+\alpha$:



T3T4 conducts, L discharges
V_0 is -Ve and i_0 is +ve
i_0 decreases as L discharges

Waveform: (3 marks)



ii) Expression for average o/p voltage, Load current, Rms Voltage and Rms current for RL Load fed full converter:

Average o/p Voltage, Load current: (2 marks):

$$V_{avg} = \frac{1}{2\pi}\int_0^{2\pi} V\, d(\omega t) = \frac{2}{2\pi}\left[\int_0^{\pi} V\, d(\omega t)\right]$$

$$= \frac{1}{\pi}\left[\int_0^{\alpha} 0\, d(\omega t) + \int_{\alpha}^{\pi+\alpha} V_{in}\, d(\omega t)\right] = \frac{1}{\pi}\left[\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t\, d(\omega t)\right]$$

$$= \frac{V_m}{\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi+\alpha} = \frac{V_m}{\pi}\left[-\cos(\pi+\alpha) + \cos\alpha\right].$$

$$V_{avg} = \frac{V_m}{\pi}\left[-(-\cos\alpha) + \cos\alpha\right] = \boxed{\frac{2V_m \cos\alpha}{\pi}.}$$

$$I_{avg} = \frac{V_{avg}}{R} = \boxed{\frac{2V_m}{\pi R}\cos\alpha.}$$

Rms Voltage & Rms current:- (3 mark)

$$V_{rms} = \left\{\frac{1}{2\pi}\left[\int_0^{2\pi} V^2\, d(\omega t)\right]\right\}^{1/2} = \left\{\frac{2}{2\pi}\left[\int_0^{\pi} V^2\, d(\omega t)\right]\right\}^{1/2}$$

$$= \left\{\frac{1}{\pi}\left[\int_{\alpha}^{\pi+\alpha} V_{in}^2\, d(\omega t)\right]\right\}^{1/2} = \left\{\frac{V_m^2}{\pi}\left[\int_{\alpha}^{\pi+\alpha} \sin^2\omega t\, d(\omega t)\right]\right\}^{1/2}$$

$$= \left\{\frac{V_m^2}{\pi}\left[\int_{\alpha}^{\pi+\alpha}\left(\frac{1-\cos 2\omega t}{2}\right) d(\omega t)\right]\right\}^{1/2} = \left\{\frac{V_m^2}{2\pi}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_{\alpha}^{\pi+\alpha}\right\}^{1/2}$$

$$V_{rms} = \left\{\frac{V_m^2}{2\pi}\left[(\pi+\alpha) - \alpha - \frac{\sin 2(\pi+\alpha)}{2} + \frac{\sin 2\alpha}{2}\right]\right\}^{1/2}$$

$$= \left\{ \frac{V_m^2}{2\pi} \left[\pi + \frac{\sin 2\alpha}{2} \right] \right\}^{1/2}$$

$$V_{rms} = \frac{V_m}{\sqrt{2\pi}} \left[\pi + \frac{\sin 2\alpha}{2} \right]^{1/2}$$

$$I_{rms} = \frac{V_{rms}}{R} = \frac{V_m}{R\sqrt{2\pi}} \left[\pi + \frac{\sin 2\alpha}{2} \right]^{1/2}$$

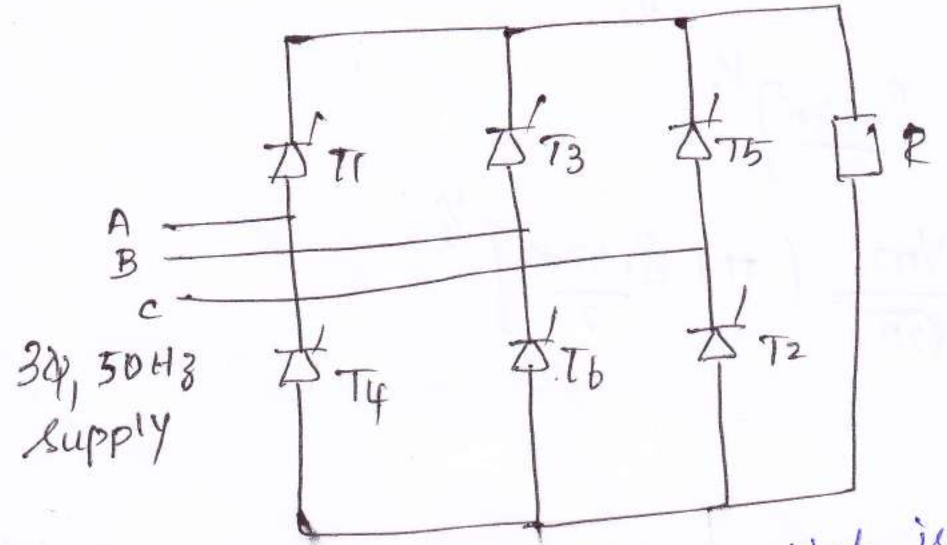
iii) Fullycontrolled Rectifier	Halfcontrolled Rectifier
i) All the devices or switches used are of controllable type	Half of the devices (or) switches are controllable and other are uncontrollable type
ii) Output Voltage crosses zero and goes negative	ii) Output voltage is only positive
iii) Regeneration is possible	iii) Regeneration is not possible

~~(iv)~~

B) b.i) Three-Phase fully controlled converter with R Load:

It has six switches and two devices conduct simultaneously.

Circuit diagram: (1 mark)



Commutating Voltages of each switch is given bellow.

$T_1 \Rightarrow V_{AC}$ $\quad$ $T_4 \Rightarrow V_{CA}$

$T_3 \Rightarrow V_{BA}$ $\quad$ $T_6 \Rightarrow V_{AB}$

$T_5 \Rightarrow V_{CB}$ $\quad$ $T_2 \Rightarrow V_{BC}$

Switching table: (2 marks).

Degree of conduction Interval	Devices in conduction	output Voltage	Incoming device
$30+\alpha$ to $90+\alpha$	$T_6\ T_1$	V_{AB}	T_1
$90+\alpha$ to $150+\alpha$	$T_1\ T_2$	V_{AC}	T_2
$150+\alpha$ to $210+\alpha$	$T_2\ T_3$	V_{BC}	T_3
$210+\alpha$ to $270+\alpha$	$T_3\ T_4$	V_{BA}	T_4
$270+\alpha$ to $330+\alpha$	$T_4\ T_5$	V_{CA}	T_5
$330+\alpha$ to $30+\alpha$	$T_5\ T_6$	V_{CB}	T_6

where $\alpha \Rightarrow$ firing angle

$V_{AN} = V_m \sin \omega t$ Equations of input supply: (3 marks)

$V_{BN} = V_m \sin(\omega t - 120^\circ)$

$V_{CN} = V_m \sin(\omega t + 120^\circ)$

$V_{AB} = V_{AN} - V_{BN} = \sqrt{3}\, V_m \sin(\omega t + 30^\circ)$

$V_{AC} = V_{AN} - V_{CN} = \sqrt{3}\, V_m \sin(\omega t - 30^\circ)$

$V_{BC} = V_{BN} - V_{CN} = \sqrt{3}\, V_m \sin(\omega t - 90^\circ)$

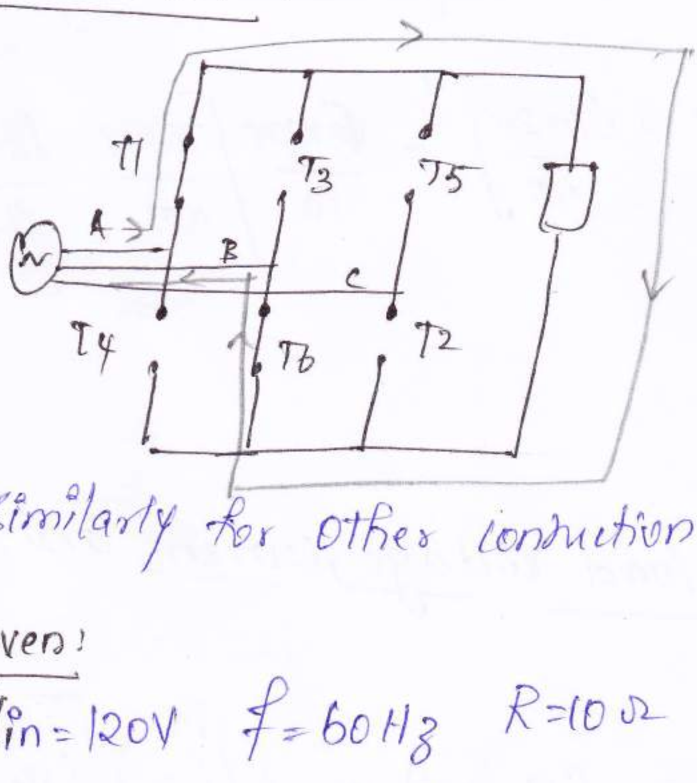
$V_{BA} = V_{BN} - V_{AN} = \sqrt{3}\, V_m \sin(\omega t - 150^\circ)$

$V_{CA} = V_{CN} - V_{AN} = \sqrt{3}\, V_m \sin(\omega t + 150^\circ)$

$V_{CB} = V_{CN} - V_{BN} = \sqrt{3}\, V_m \sin(\omega t + 90^\circ)$

Operation:-

$30+\alpha$ to $90+\alpha$:-



$V_0 = V_{AB}$.

Similarly for other conduction interval.

(ii) Given:

$V_{in} = 120V$ $f = 60Hz$ $R = 10\,\Omega$

$V_{avg} = 25\%$ of $V_{avg(max)}$

To find:

(i) Delay angle (α) (ii) Rms and average output current

At $\alpha=0$, $V_{avg(max)} = \frac{2V_m}{\pi}\cos(0) = \frac{2V_m}{\pi}$

$$= \frac{2\times\sqrt{2}\times 120}{\pi} = \frac{2\times 169.68}{\pi}$$

$$\boxed{V_{avg(max)} = 108\,V}$$

$V_{avg} = 25\%$ of $V_{avg(max)} = 0.25\times 108 = 27V$

$27 = \frac{120\times\sqrt{2}}{\pi}(1+\cos\alpha) \Rightarrow \boxed{\alpha = 120^\circ}$ (2 mark)

$I_{avg} = \frac{V_{avg}}{R} = \frac{27}{10} = 2.7A$; $\boxed{I_{avg} = 2.7A}$ (1 mark)

$I_{rms} = \frac{V_{rms}}{R} = \frac{V_m}{R}\left[\frac{\pi-\alpha}{2\pi} + \frac{\sin 2\alpha}{4\pi}\right]^{1/2} = \frac{\sqrt{2}\times 120}{10}\left[\frac{\pi-120^\circ}{2\pi} + \frac{\sin 240^\circ}{4\pi}\right]^{1/2}$

$I_{rms} = \frac{53V}{10} = 5.3A$

$\boxed{I_{rms} = 5.3A}$ (2 mark)

(iii) Expression for Average load voltage, current and Rms voltage, current:

$V_{avg} = \frac{1}{2\pi}\int_0^{2\pi} V\,d(\omega t) = \frac{2}{2\pi}\int_0^{\pi} V\,d(\omega t) = \frac{1}{\pi}\left[\int_0^{\alpha} 0 + \int_{\alpha}^{\pi} V_{in}\,d(\omega t)\right]$

$= \frac{1}{\pi}\left[\int_{\alpha}^{\pi} V_m \sin\omega t\,d(\omega t)\right] = \frac{V_m}{\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi} = \frac{V_m}{\pi}\left[-\cos\pi + \cos\alpha\right]$

$$\boxed{V_{avg} = \frac{V_m}{\pi}(1+\cos\alpha)}$$

$$I_{avg} = \frac{V_{avg}}{R} = \frac{V_m}{\pi R}(1+\cos\alpha)$$ (2marks)

$$V_{rms} = \left\{\frac{1}{2\pi}\left[\int_0^{2\pi} v^2\, d(\omega t)\right]\right\}^{1/2} = \left\{\frac{2}{2\pi}\left[\int_0^{\pi} v^2\, d(\omega t)\right]\right\}^{1/2} = \left\{\frac{1}{\pi}\left[\int_\alpha^{\pi} V_{in}^2\, d(\omega t)\right]\right\}^{1/2}$$

$$= \left\{\frac{V_m^2}{\pi}\left[\int_\alpha^{\pi} \sin^2\omega t\, d(\omega t)\right]\right\}^{1/2} = \left\{\frac{V_m^2}{\pi}\left[\int_\alpha^{\pi} \frac{1-\cos 2\omega t}{2}\right]\right\}^{1/2}$$

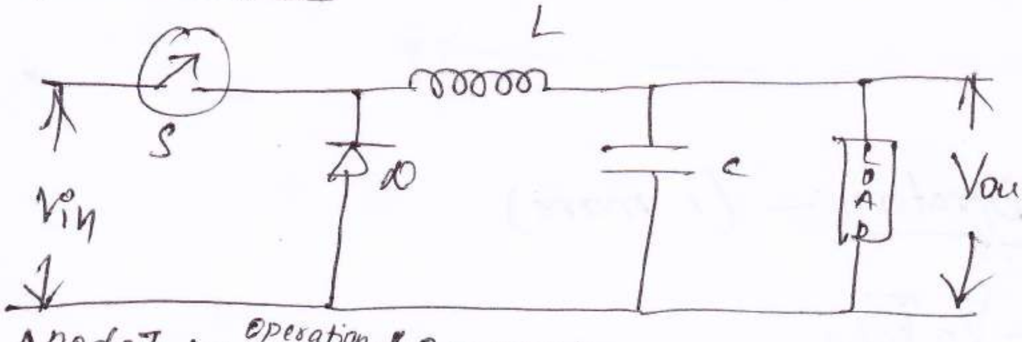
$$= \left\{\frac{V_m^2}{2\pi}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_\alpha^{\pi}\right\}^{1/2} = \left\{\frac{V_m^2}{2\pi}\left[\pi-\alpha - \frac{\sin 2\pi}{2} + \frac{\sin 2\alpha}{2}\right]\right\}^{1/2}$$

$$\boxed{V_{rms} = V_m\left[\frac{\pi-\alpha}{2\pi} + \frac{\sin 2\alpha}{4\pi}\right]^{1/2}}$$

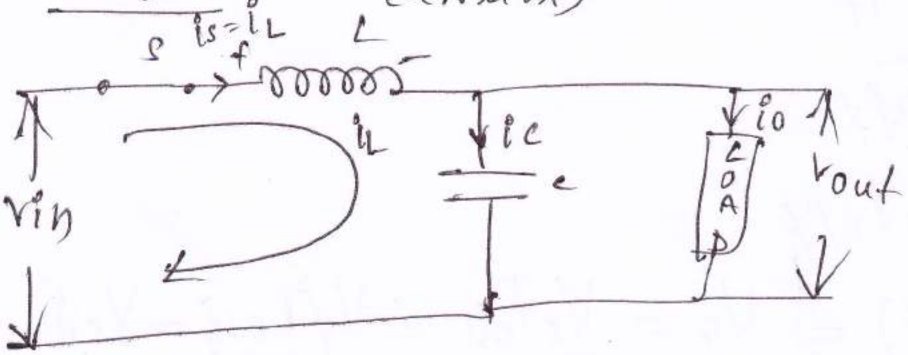
$$I_{rms} = \frac{V_{rms}}{R} = \frac{V_m}{R}\left[\frac{\pi-\alpha}{2\pi} + \frac{\sin 2\alpha}{4\pi}\right]^{1/2}$$ (2marx)

B2.9.i) Buck converter:

Circuit diagram: (1 marx)

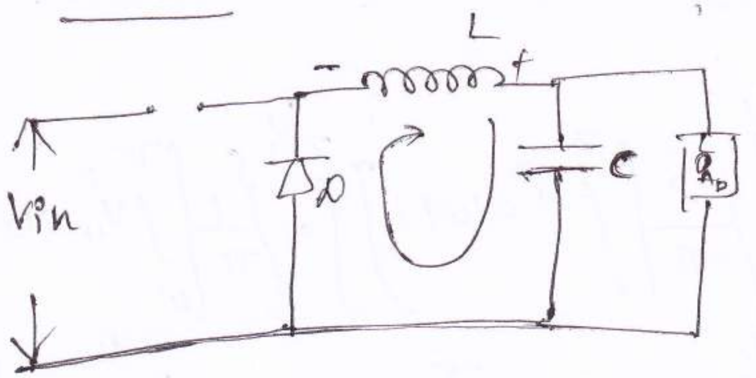


ModeI :- Operation - (2marx)



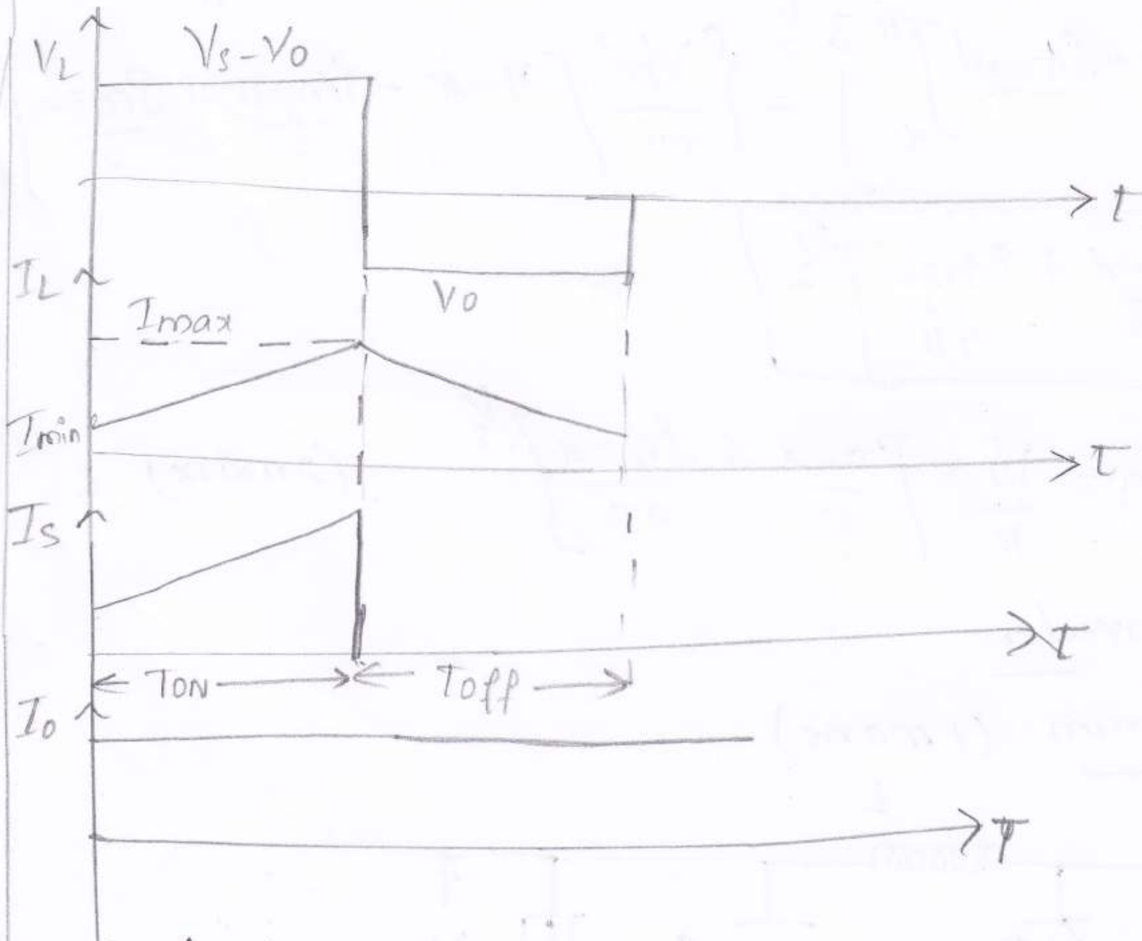
$$V_L = V_s - V_0$$

Mode II :-



$V_L = V_o$.

waveform: (2 mark)



Output voltage Equation:- (1 mark)

$$(V_s - V_o) T_{on} = V_o T_{off}$$

$$V_s T_{on} - V_o T_{on} = V_o T_{off}$$

$$V_s T_{on} = V_o T_{on} + V_o T_{off}$$

$$V_s T_{on} = V_o (T_{on} + T_{off}) \Rightarrow V_o = \frac{V_s T_{on}}{T_{off} + T_{on}} = V_s \left(\frac{T_{on}}{T}\right) = V_s \delta$$

$$\boxed{V_o = \delta V_s}$$

ii) Output Voltage, Peak to Peak ripple current of Inductor and Peak to Peak ripple voltage of capacitor:-

$$V_L = L \frac{di}{dt}$$

Turn-on:

$$V_L = V_s - V_o \rightarrow (i)$$

$$V_L = L \frac{(i_2 - i_1)}{(t_2 - t_1)} = L \frac{(i_{max} - i_{min})}{T_{on}} \rightarrow (ii)$$

Equating (i) & (ii)

$$V_s - V_o = L \frac{\Delta I}{t_{on}} \Rightarrow \Delta I = \frac{(V_s - V_o) T_{on}}{L} \rightarrow (A)$$

Turn-off:-

$$V_L = -V_o \rightarrow (iii)$$

$$V_L = L \frac{(i_1 - i_2)}{(t_3 - t_2)} = L \frac{(I_{min} - I_{max})}{T_{off}} \rightarrow (iv)$$

Equating (iii) & (iv)

$$-V_o = L \frac{-\Delta I}{T_{off}} \Rightarrow \Delta I = \frac{V_o T_{off}}{L} \rightarrow (B)$$

Equating (A) & (B).

$$\frac{(V_s - V_o) T_{on}}{\cancel{L}} = \frac{V_o T_{off}}{\cancel{L}}$$

$$V_s T_{on} - V_o T_{on} = V_o T_{off}$$

$$V_s T_{on} = V_o [T_{on} + T_{off}] = V_o T$$

$$V_o = \frac{V_s T_{on}}{T} = V_s \delta ; \boxed{V_o = V_s \delta}$$

$$\Delta I = \frac{(V_s - V_o) T_{on}}{L} \rightarrow (A)$$

$\div$ (A) by T

$$\Delta I = \frac{(V_s - \delta V_s) T_{on}/T}{L/T} = \frac{V_s (1-\delta)\delta}{Lf}$$

$$\boxed{\Delta I = \frac{\delta V_s (1-\delta)}{Lf}}$$

$$V_c = \frac{\Delta I}{8Cf} = \frac{\delta V_s (1-\delta)}{8LCf^2}$$

iii) Given:

$V_s = V_{in} = 10V$; $V_{avg} = 15V$; $I_{avg} = 0.4A$; $f = 20KHz$

$L = 100H$.

To find:

(i) Dutycycle ratio, ii) Ripplecurrent

Solution:

$$V_{avg} = \frac{V_s}{1-\delta}$$

$$1-\delta = \frac{V_s}{V_{ag}} \Rightarrow \delta = 1 - \frac{V_s}{V_{avg}} = 1 - \frac{10}{15} = 0.334$$

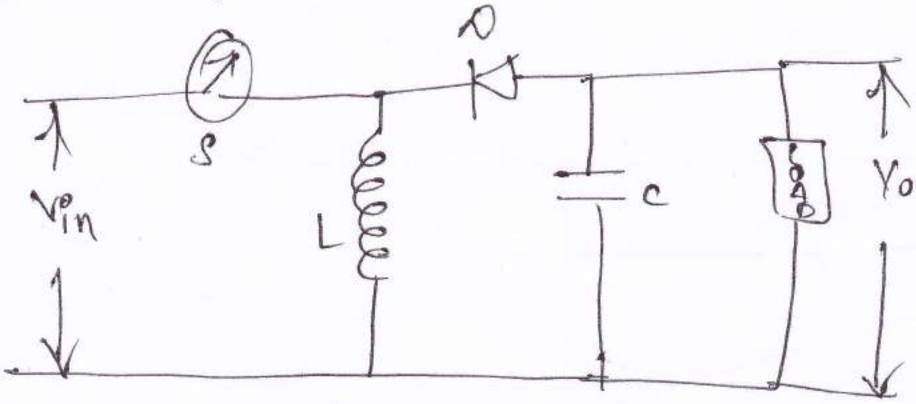
$$\boxed{\delta = 0.334}$$ (2mark)

$$\Delta I = \frac{V_s \delta}{Lf} = \frac{10 \times 0.334}{100 \times 20 \times 10^3} = 1.67 \mu A$$

(2mark)

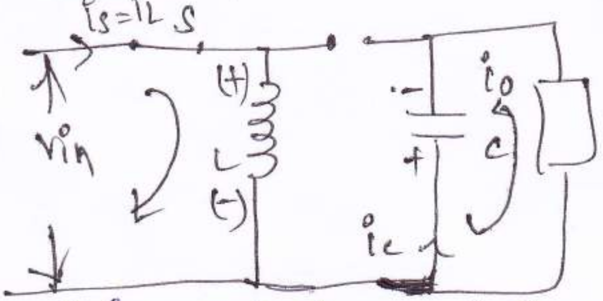
b) i) Buck - Boost converter:

Circuit diagram:- (1mark)



Operation! (2 marks)

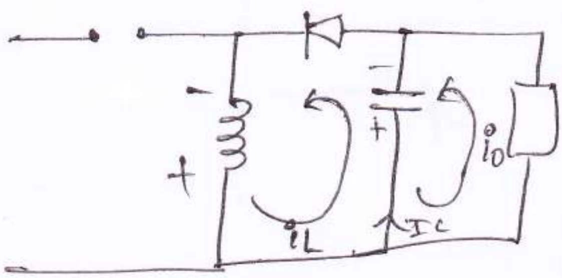
Mode I: S is on



S is on, L charges & i_L increases

$I_c = -I_o$; $V_L = V_s$

Mode II! S is OFF



S is off, L discharges & decreases

$I_c = i_L - i_o = i_2 - i_o$.

$V_L = V_o$

Output Voltage, Ripplecurrent & voltage:

$$V_L = L\frac{di}{dt}$$

Turn-on:

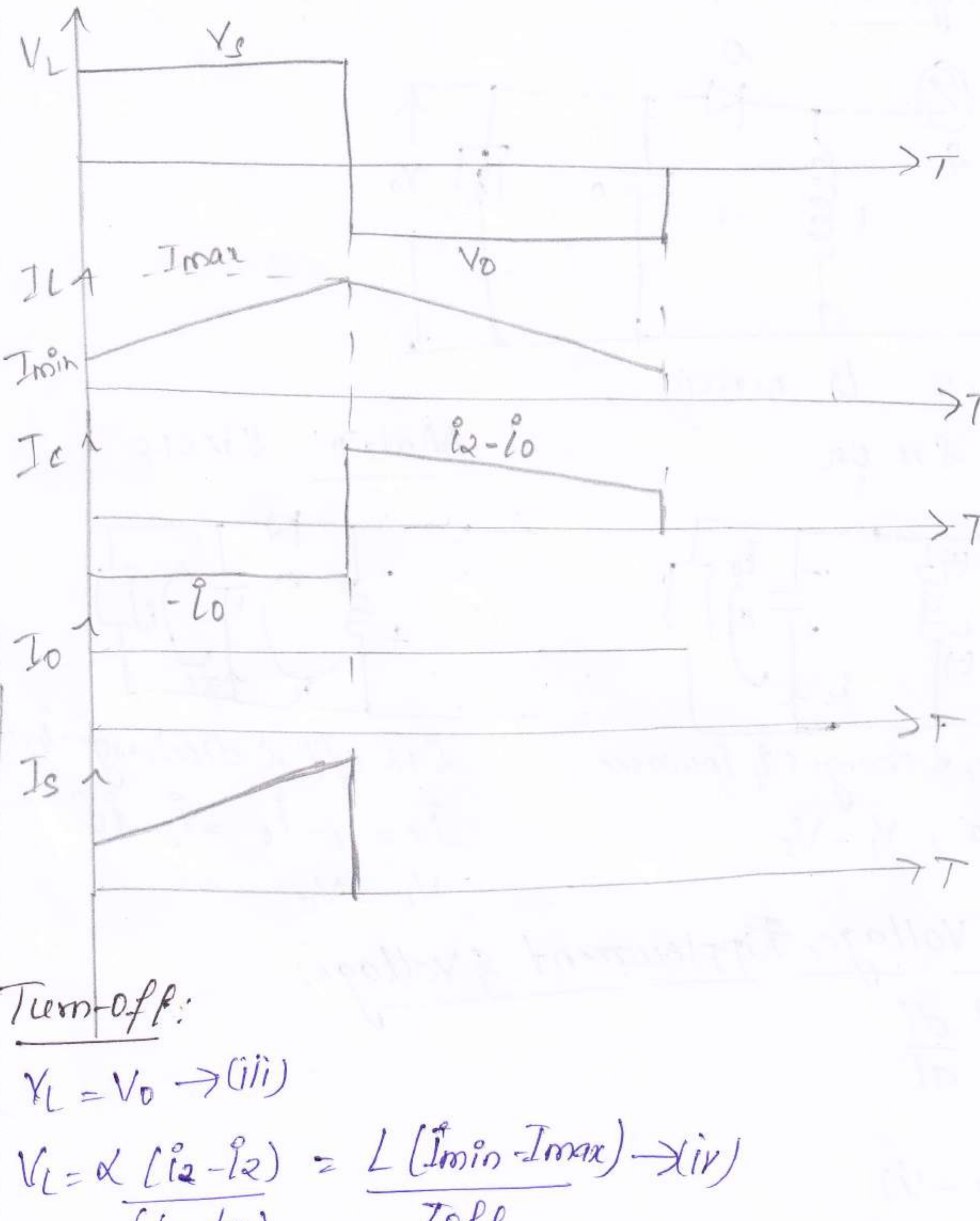
$$V_L = V_s \quad -(i)$$

$$V_L = L\frac{(i_2 - i_1)}{(t_2 - t_1)} = L\frac{(I_{max} - I_{min})}{T_{on}} \rightarrow (ii)$$

Equating (i) & (ii)

$$V_s = \frac{L(\Delta I)}{T_{on}} \Rightarrow \boxed{\Delta I = \frac{V_s T_{on}}{L}} \rightarrow (A)$$

Waveform: (3Marks)



Turn-off:

$V_L = V_0 \rightarrow$ (iii)

$V_L = L \dfrac{(i_2 - i_2)}{(t_4 - t_3)} = \dfrac{L(I_{min} - I_{max})}{T_{off}} \rightarrow$ (iv)

Equating (iii) & (iv)

$V_0 = \dfrac{L(-\Delta I)}{T_{off}} \Rightarrow \boxed{\Delta I = \dfrac{-V_0 T_{off}}{L}} \rightarrow$ (B)

Equating (A) & (B)

$$\frac{-V_0 T_{off}}{\cancel{L}} = \frac{V_s T_{on}}{\cancel{L}}$$

$$V_0 = \frac{-V_s T_{on}}{T_{off}} = \frac{-V_s T_{on}}{T - T_{on}}$$

$$= \frac{-V_s}{\frac{T - T_{on}}{T_{on}}} = \frac{-V_s}{\frac{T}{T_{on}} - 1} = \frac{-V_s}{\frac{1}{\delta} - 1} = \frac{-V_s}{\frac{1-\delta}{\delta}} = \frac{-\delta V_s}{1-\delta}$$

$$\boxed{V_0 = \frac{-\delta V_s}{1-\delta}} \Rightarrow \delta =$$

$$\Delta I = \frac{V_s T_{on}}{L} \rightarrow (A)$$

$\div$ (A) by T $\quad \Delta I = \frac{V_s \frac{T_{on}}{T}}{\frac{L}{T}} = \frac{V_s \delta}{Lf}$

$$V_c = \frac{1}{C}\int_0^{t_{on}} i_c dt + V_{c(t=0)}$$

$$V_c - V_{c(t=0)} = \frac{1}{C}\int_0^{t_{on}} i_c dt$$

$$\Delta V_c = \frac{I_c}{C}[t_{on}] = \frac{I_c}{C}\left[\frac{L\Delta I}{V_s}\right] = \frac{I_c}{C}\left[\frac{L}{V_s}\left[\frac{V_s\delta}{Lf}\right]\right]$$

$$\Delta V_c = \frac{I_c \delta}{Cf} = \frac{-I_0 \delta}{Cf}$$

$$\boxed{\Delta V_c = \frac{-I_0 \delta}{Cf}}$$

iii) Expression of output Voltage, Ripple current & Voltage of boost converter.

$$V_L = L\frac{di}{dt}$$

Turn-on:

$V_L = V_s \rightarrow (i)$

$V_L = L\frac{(i_2 - i_1)}{t_2 - t_1} = L\frac{(I_{max} - I_{min})}{T_{on}} \rightarrow (ii)$

Equating (i) & (ii); $V_s = \frac{L\Delta I}{T_{on}} \Rightarrow \Delta I = \frac{V_s T_{on}}{L} \rightarrow (A)$

Turn-off:

$V_L = V_s - V_o \rightarrow (iii)$

$V_L = L\frac{(i_4 - i_2)}{t_4 - t_3} = \frac{L(I_{min} - I_{max})}{T_{off}} \rightarrow (iv)$

Equating (iii) & (iv); $V_s - V_o = \frac{-L\Delta I}{T_{off}} \Rightarrow \Delta I = \frac{-(V_s - V_o)T_{off}}{L} \rightarrow (B)$

Equating (A) & (B) $\frac{V_s T_{on}}{\cancel{L}} = -\frac{(V_s - V_o)T_{off}}{\cancel{L}}$

$V_s T_{on} = -V_s T_{off} + V_o T_{off}$

$V_o = \frac{V_s T}{T_{off}} = \frac{V_s T}{T - T_{on}} = \frac{V_s}{\frac{T}{T} - \frac{T_{on}}{T}} \quad \cancel{\frac{V_s}{1/\delta - 1}} = \frac{V_s}{1-}$

$V_o = \frac{V_s}{-\delta + 1} = \frac{V_s}{1-\delta} \Rightarrow \boxed{V_o = \frac{V_s}{1-\delta}}$ (2 mark)

$\Delta I = \frac{V_s T_{on}}{L} \div$ by T

(1 mark)

$\Delta I = \frac{V_s T_{on}/T}{L/T} = \frac{V_s \delta}{Lf} \quad \boxed{\Delta I = \frac{V_s \delta}{Lf}}$

$$\Delta V_c = \frac{I_0}{c}\left[\frac{L\Delta I}{V_s}\right]$$

$$= \frac{I_0}{c}\left(\frac{L}{V_s}\left[\frac{V_s\delta}{Lf}\right]\right]$$

$$\boxed{\Delta V_c = \frac{I_0\delta}{Cf}}$$ (1 mark)

ii) $V_{in} = 12V$ $L = 150H$ $C = 220F$ $I_{avg} = 1.25A$ $\delta = 0.25$
$f = 25kHz$

$$V_0 = \frac{-V_s\delta}{1-\delta} = \frac{-12 \times 0.25}{1-0.25} = -4V.$$ (1 mark)

$$V_c = \frac{I_0\delta}{fc} = \frac{1.25 \times 0.25}{25 \times 10^3 \times 220} = 5.68 \times 10^{-8} V$$

$$\boxed{V_c = 0.0568 \mu V}$$ (2 marks)

$$\Delta I = \frac{V_s\delta}{fL} = \frac{12 \times 0.25}{25 \times 10^3 \times 150} = 8 \times 10^{-7} A$$

$$\boxed{\Delta I = 0.8 \mu A}$$ (2 mark).