Benha University
Benha Faculty of Engineering
January, 2017
Solution (Regular)
Examiner: Mohamed Awaad ; Ph.D.

Electrical Department
B. Sc. Course Exam

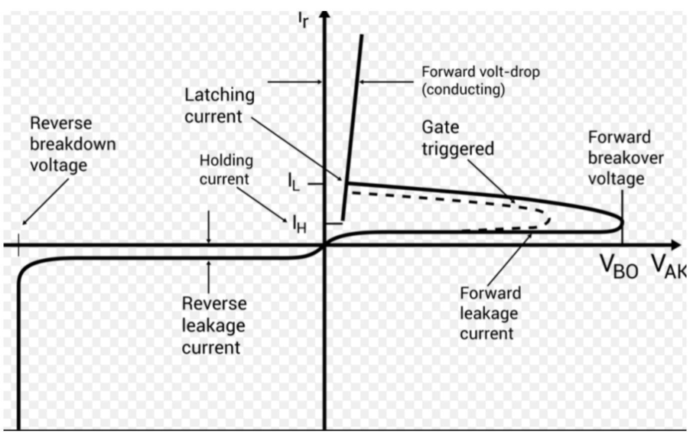
Power Electronics (A), E1335
Allowed Time: 3 Hours.

Question ❶ (*25 marks*)

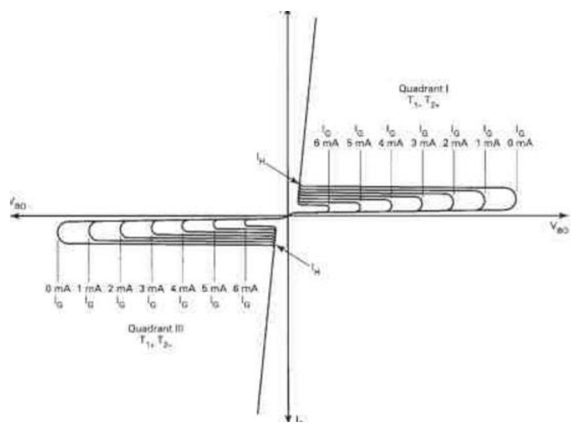
(a) Mention (Only) the suitable power converter in order to match the following I/O relationship.

a. Dc Chopper
b. Inverter
c. Ac Voltage Controller
d. Rectifier
e. Dc Chopper
f. Inverter

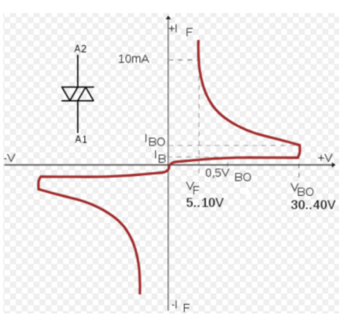
(b) Draw the characteristic Curves of: SCR – TRIAC – DIAC – BJT – Shokley Diode.



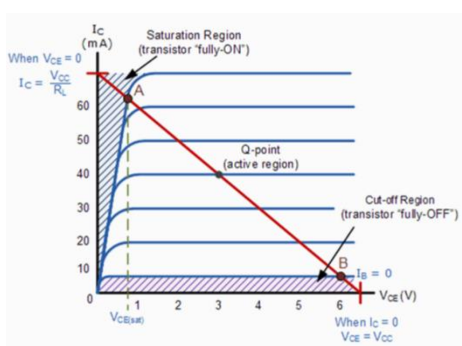
SCR



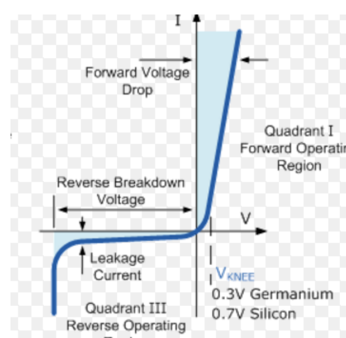
TRIAC



DIAC



BJT



Shokley Diode

(c) Draw the transistor model of the thyristor and state the theory of operation to pass current from anode to cathode. And state the turning ON conditions.

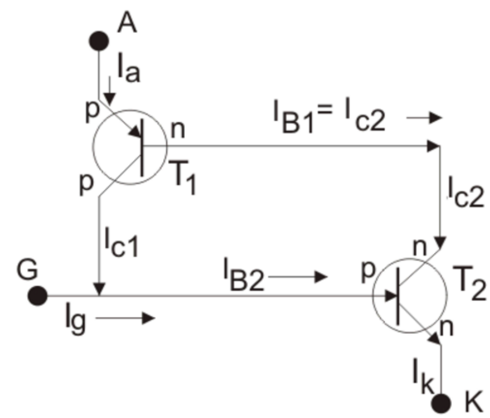
1- By applying positive voltage at gate between gate and cathode

Q2 will forward biased and turn on

2- When Q2 is saturated or On the current flow from collector 2 to emitter 2

3- Q1 starts to conduct V_{E1B1}greater than 0 forward biased and current flow from E1 to C1

4- When gate current interrupted thyristor still in on state



Turning ON conditions:

1- Positive anode cathode voltage
2- Gate pulse
3- Anode current greater than latching current

(d) The Power transistor is used as a switch and it has the following parameters V_{CC}=200 V, $V_{BE(sat)}$= 3 V, I_B = 8 A, $V_{CS(sat)}$= 2 V, I_C = 100 A, t_d= 0.5 µs, t_r = 1 µs, t_s= 5 µs, t_f = 3 µs and f_s = 10 KHz. The duty cycle is k = 50 %. The collector-to-emitter leakage current is I_{CEO}= 3 mA Determine the power loss due to collector current during (a) turn on $t_{on} = t_d + t_r$, (b) conduction period t_n, (c) turn off $t_{off} = t_s + t_f$. (d) off-time t_0, And (e) total average power losses p_T. (d) Plot the instantaneous power due to collector current $P_c(t)$.

Solution

$T = 1/f_s = 100\ \mu s$, $k = 0.5$. $kT = t_d + t_r + t_n = 50\ \mu s$, $t_n = 50 - 0.5 - 1 = 48.5\ \mu s$, $(1-k)T = t_s + t_f + t_o = 50\ \mu s$, and $t_o = 50 - 5 - 3 = 42\ \mu s$.

a. During delay time, $0 \le t \le t_d$:

$$i_c(t) = I_{CEO}$$
$$v_{CE}(t) = V_{CC}$$

The instantaneous power due to the collector current is

$$P_c(t) = i_c v_{CE} = I_{CEO}V_{CC} = 3 \times 10^{-3} \times 250 = 0.75\ \text{W}$$

The average power loss during the delay time is

$$P_d = \frac{1}{T}\int_0^{t_d} P_c(t)dt = I_{CEO}V_{CC}t_d f_s \quad (4.2$$
$$= 3 \times 10^{-3} \times 250 \times 0.5 \times 10^{-6} \times 10 \times 10^3 = 3.75\ \text{mW}$$

During rise time, $0 \le t \le t_r$:

$$i_c(t) = \frac{I_{CS}}{t_r}t$$
$$v_{CE}(t) = V_{CC} + (V_{CE(\text{sat})} - V_{CC})\frac{t}{t_r}$$

$$P_r = \frac{1}{T}\int_0^{t_r} P_c(t)dt = f_s I_{CS} t_r \left[\frac{V_{CC}}{2} + \frac{V_{CE(\text{sat})} - V_{CC}}{3}\right]$$
$$= 10 \times 10^3 \times 100 \times 1 \times 10^{-6}\left[\frac{250}{2} + \frac{2 - 250}{3}\right] = 42.33\ \text{W}$$

The total power loss during the turn-on is

$$P_{on} = P_d + P_r = 0.00375 + 42.33 = 42.33\ \text{W}$$

b. The conduction period, $0 \le t \le t_n$:

$$i_c(t) = I_{CS}$$
$$v_{CE}(t) = V_{CE(\text{sat})}$$
$$P_c(t) = i_c v_{CE} = V_{CE(\text{sat})}I_{CS} = 2 \times 100 = 200\ \text{W}$$
$$P_n = \frac{1}{T}\int_0^{t_n} P_c(t)dt = V_{CE(\text{sat})}I_{CS}t_n f_s = 2 \times 100 \times 48.5 \times 10^{-6} \times 10 \times 10^3 = 97\ \text{W}$$

c. The storage period, $0 \le t \le t_s$:

$$i_c(t) = I_{CS}$$
$$v_{CE}(t) = V_{CE(\text{sat})}$$
$$P_c(t) = i_c v_{CE} = V_{CE(\text{sat})}I_{CS} = 2 \times 100 = 200\ \text{W}$$
$$P_s = \frac{1}{T}\int_0^{t_s} P_c(t)dt = V_{CE(\text{sat})}I_{CS}t_s f_s = 2 \times 100 \times 5 \times 10^{-6} \times 10 \times 10^3 = 10\ \text{W}$$

The fall time, $0 \le t \le t_f$:

$$i_c(t) = I_{CS}\left(1 - \frac{t}{t_f}\right), \text{ neglecting } I_{CEO}$$
$$v_{CE}(t) = \frac{V_{CC}}{t_f}t, \text{ neglecting } I_{CEO}$$
$$P_c(t) = i_c v_{CE} = V_{CC}I_{CS}\left[\left(1 - \frac{t}{t_f}\right)\frac{t}{t_f}\right]$$

This power loss during fall time is maximum when $t = t_f/2 = 1.5\ \mu s$ gives the peak power.

$$P_m = \frac{V_{CC}I_{CS}}{4} = 250 \times \frac{100}{4} = 6250\ \text{W}$$

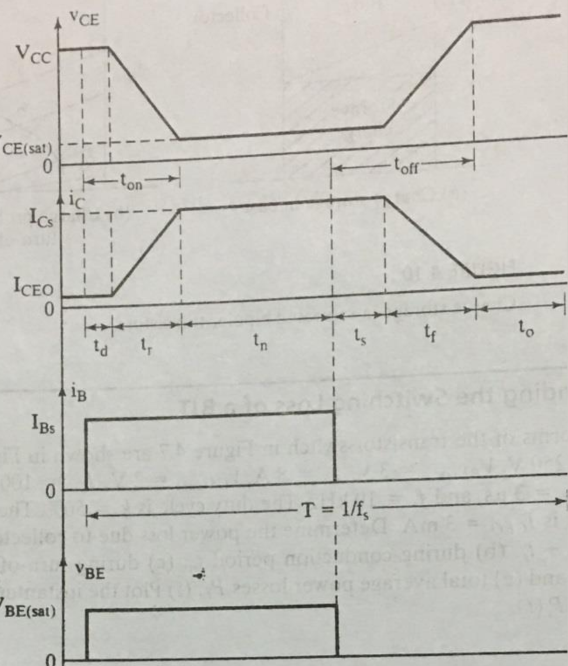


FIGURE 4.11
Waveforms of transistor switch.

$$P_c(t) = i_c v_{CE} = I_{CS}\frac{t}{t_r}\left[V_{CC} + (V_{CE\,(sat)} - V_{CC})\frac{t}{t_r}\right]$$

The power $P_c(t)$ is maximum when $t = t_m$, where

$$t_m = \frac{t_r V_{CC}}{2[V_{CC} - V_{CE\,(sat)}]}$$
$$= 1 \times \frac{250}{2(250 - 2)} = 0.504\ \mu s$$

and Eq. (4.22) yields the peak power

$$P_p = \frac{V_{CC}^2 I_{CS}}{4[V_{CC} - V_{CE(sat)}]}$$
$$= 250^2 \times \frac{100}{4(250 - 2)} = 6300\ W$$

$$P_f = \frac{1}{T}\int_0^{t_f} P_c(t)\,dt = \frac{V_{CC} I_{CS} t_f f_s}{6} \tag{4.31}$$
$$= \frac{250 \times 100 \times 3 \times 10^{-6} \times 10 \times 10^3}{6} = 125\ W$$

The power loss during turn-off is

$$P_{off} = P_s + P_f = I_{CS} f_s\left(t_s V_{CE(sat)} + \frac{V_{CC} t_f}{6}\right) \tag{4.32}$$
$$= 10 + 125 = 135\ W$$

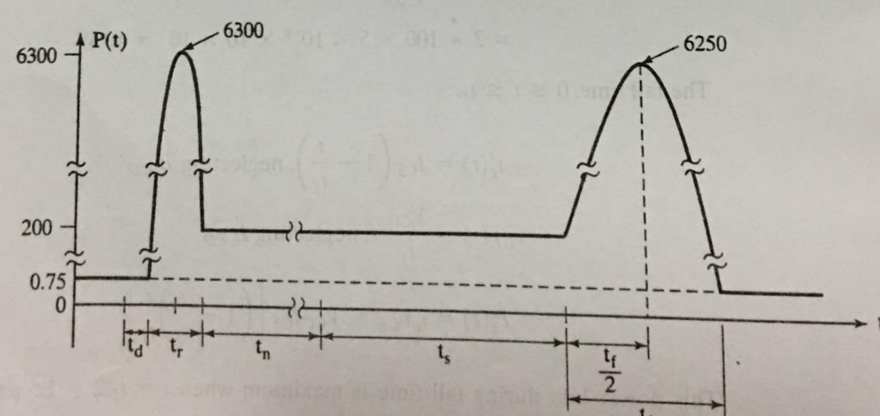
d. Off-period, $0 \le t \le t_o$:

$$i_c(t) = I_{CEO}$$
$$v_{CE}(t) = V_{CC}$$
$$P_c(t) = i_c v_{CE} = I_{CEO} V_{CC} \tag{4.33}$$
$$= 3 \times 10^{-3} \times 250 = 0.75\ W$$
$$P_0 = \frac{1}{T}\int_0^{t_o} P_c(t)\,dt = I_{CEO} V_{CC} t_o f_s$$
$$= 3 \times 10^{-3} \times 250 \times 42 \times 10^{-6} \times 10 \times 10^3 = 0.315\ W$$

e. The total power loss in the transistor due to collector current is

$$P_T = P_{on} + P_n + P_{off} + P_0 \tag{4.34}$$
$$= 42.33 + 97 + 135 + 0.315 = 274.65\ W$$

f. The plot of the instantaneous power is shown in Figure 4.12



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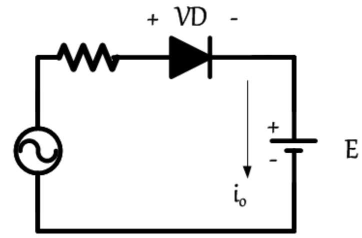
Question 2 (*20 marks*)



(a) The battery voltage in the Figure is E= 12 V and its capacity is 100Wh. The average charging current should be I_{dc}= 5 A. The primary input voltage is V_p= 120 V, 60 Hz. Calculate (a) the conduction angle δ Of the diode, (b) the current-limiting resistance R, (c) the power rating P_R of R, (d) the charging time h_o in hours, (e) the rectifier efficiency η, and (f) the PIV of the diode.

Solution

$E = 12$ V, $V_p = 120$ V, $V_s = V_p/n = 120/2 = 60$ V, and $V_m = \sqrt{2}\,V_s = \sqrt{2} \times 60 = 84.85$ V.

a. From Eq. (3.17), $\alpha = \sin^{-1}(12/84.85) = 8.13°$ or 0.1419 rad. $\beta = 180 - 8.13 = 171.87°$. The conduction angle is $\delta = \beta - \alpha = 171.87 - 8.13 = 163.74°$.

b. The average charging current I_{dc} is

$$I_{dc} = \frac{1}{2\pi}\int_{\alpha}^{\beta} \frac{V_m \sin \omega t - E}{R}\, d(\omega t)$$
$$= \frac{1}{2\pi R}(2V_m \cos \alpha + 2E\alpha - \pi E), \text{ for } \beta = \pi - \alpha \qquad (3.18)$$

which gives

$$R = \frac{1}{2\pi I_{dc}}(2V_m \cos \alpha + 2E\alpha - \pi E)$$
$$= \frac{1}{2\pi \times 5}(2 \times 84.85 \times \cos 8.13° + 2 \times 12 \times 0.1419 - \pi \times 12) = 4.26\ \Omega$$

c. The rms battery current I_{rms} is

$$I_{rms}^2 = \frac{1}{2\pi}\int_{\alpha}^{\beta} \frac{(V_m \sin \omega t - E)^2}{R^2}\, d(\omega t)$$
$$= \frac{1}{2\pi R^2}\left[\left(\frac{V_m^2}{2} + E^2\right)(\pi - 2\alpha) + \frac{V_m^2}{2}\sin 2\alpha - 4V_m E \cos \alpha\right]$$
$$= 67.4 \qquad (3.19)$$

or $I_{rms} = \sqrt{67.4} = 8.2$ A. The power rating of R is $P_R = 8.2^2 \times 4.26 = 286.4$ W.

d. The power delivered P_{dc} to the battery is

$$P_{dc} = EI_{dc} = 12 \times 5 = 60\ \text{W}$$

$$h_o P_{dc} = 100 \quad \text{or} \quad h_o = \frac{100}{P_{dc}} = \frac{100}{60} = 1.667\ \text{h}$$

e. The rectifier efficiency η is

$$\eta = \frac{\text{power delivered to the battery}}{\text{total input power}} = \frac{P_{dc}}{P_{dc} + P_R} = \frac{60}{60 + 286.4} = 17.32\%$$

f. The peak inverse voltage PIV of the diode is

$$\begin{aligned} \text{PIV} &= V_m + E \\ &= 84.85 + 12 = 96.85\ \text{V} \end{aligned}$$

(b) A Full-wave controlled bridge rectifier has an ac input voltage of 220 V rms at 50 Hz and a100 Ω load resistor. The firing angle is 600. Draw the power circuit and then calculate the following.

a) Average load voltage b) Average load current
c) Power absorbed by the load d) Converter power factor

e) Draw the wave form of the following items:

Ac supply, Firing angle, load voltage, load current, ac supply current, power devices voltage drop, and power devices currents

$V_{in} = 220 V_{rms}$ $\quad F = 50\,Hz$ $\quad R = 100\,\Omega$ $\quad \alpha = 60^\circ$

A *

$$V_{o\,avr} = \frac{V_m}{\pi}(1+\cos\alpha) = \frac{220*\sqrt{2}}{3.14}(1+\cos 60) = 148.55\,V$$

B *

$$i_{o\,avr} = \frac{V_{o\,avr}}{R} = \frac{148.55}{100} = 1.4855\ A$$

C *

$$V_{o\,rms} = \frac{V_m}{\sqrt{2}}\sqrt{1-\frac{\alpha}{\pi}+\frac{\sin 2\alpha}{2\pi}} = \frac{220*\sqrt{2}}{\sqrt{2}}\sqrt{1-\frac{60}{180}+\frac{\sin 120}{3.14}}$$

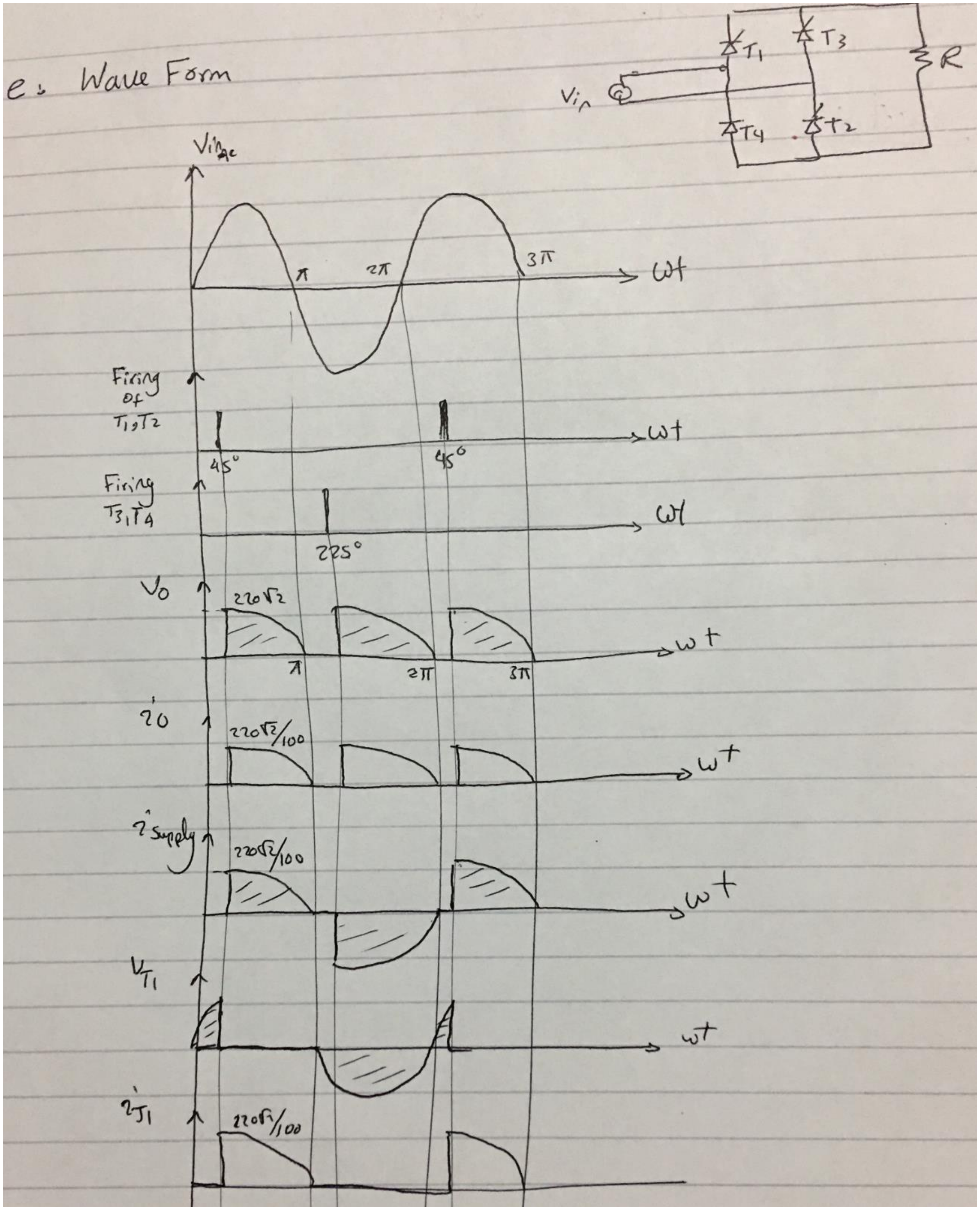
$$= 213.56\ V$$

$$i_{o\,rms} = 2.1356\ A$$

$$P_{absorbed} = i_{o\,rms}^{2} * R = (2.1356)^2 * 100 = 456.088\ W$$

D *

$$PF = \frac{P}{S} = \frac{V_{o\,R}\ i_{o\,rms}}{V_{in\,rms}\ i_{rms}} = 0.97$$


e: Wave Form
V_{in}
T1
T3
T4
T2
R
$V_{in\,ac}$
π
2π
3π
ωt
Firing of T1, T2
45°
45°
Firing T3, T4
225°
V_o
$220\sqrt{2}$
i_o
$220\sqrt{2}/100$
i_{supply}
$220\sqrt{2}/100$
V_{T1}
i_{T1}
$220\sqrt{2}/100$

(c) What the drawbacks of the single phase half-wave uncontrolled rectifier?

1- Average value of load voltage is low
2- High ripple in load voltage and load current
3- Need large filter and high cost
4- High weight

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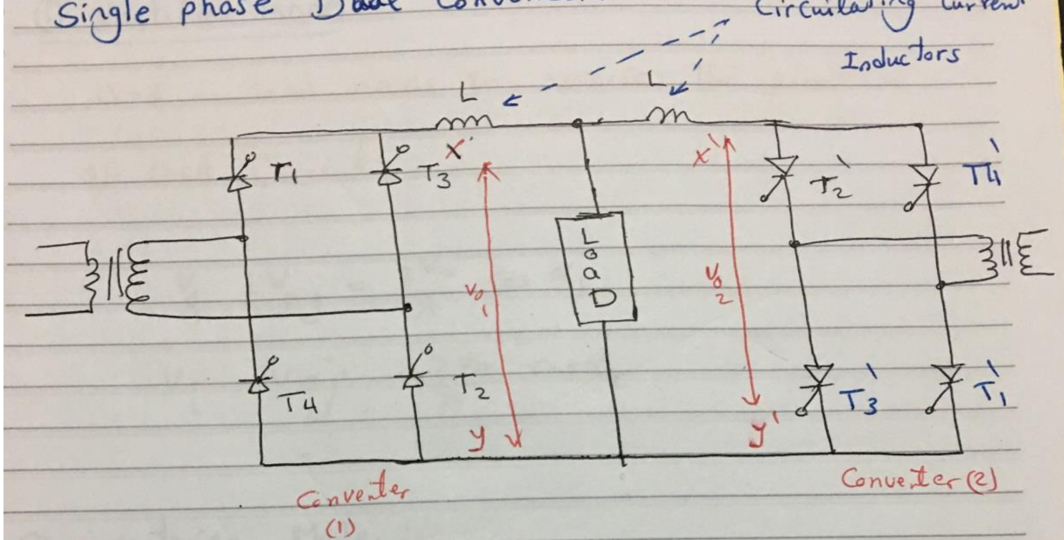
Question 3 (*15 marks*)

(a) Draw the power circuit of Dual Converter and mention (only) modes of operation.

Single phase Dual Converter.



Modes of operation.

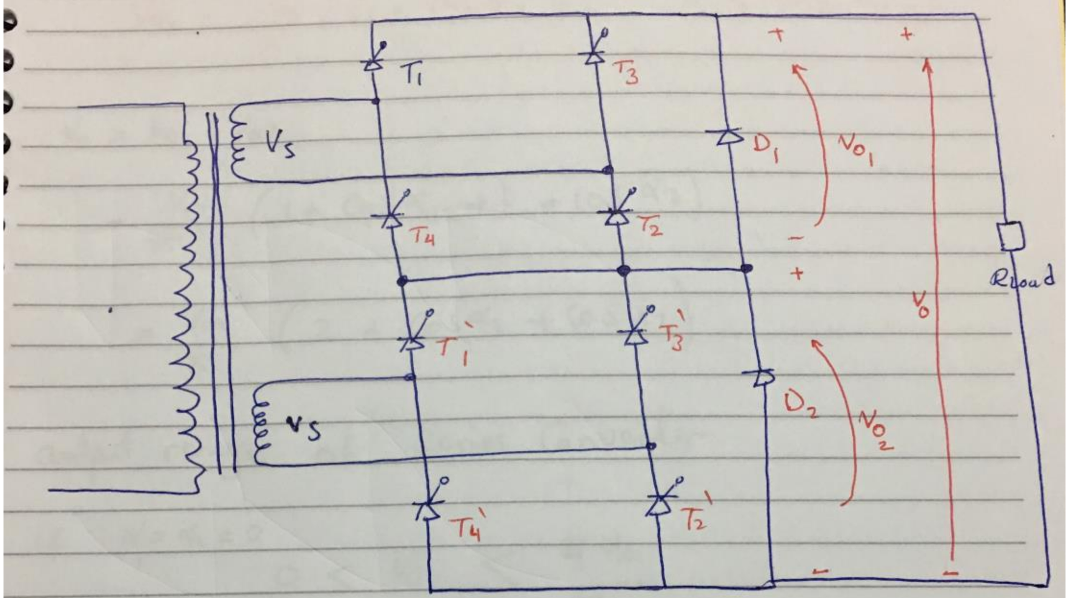
① Rectifier or Converter mode (one Converter only)

② Inverting Mode (converter as inverter & Converter as rectifier)

③ Circulating Current mode

(b) Draw the Power circuit of the series converter and explain its operation with waveform.

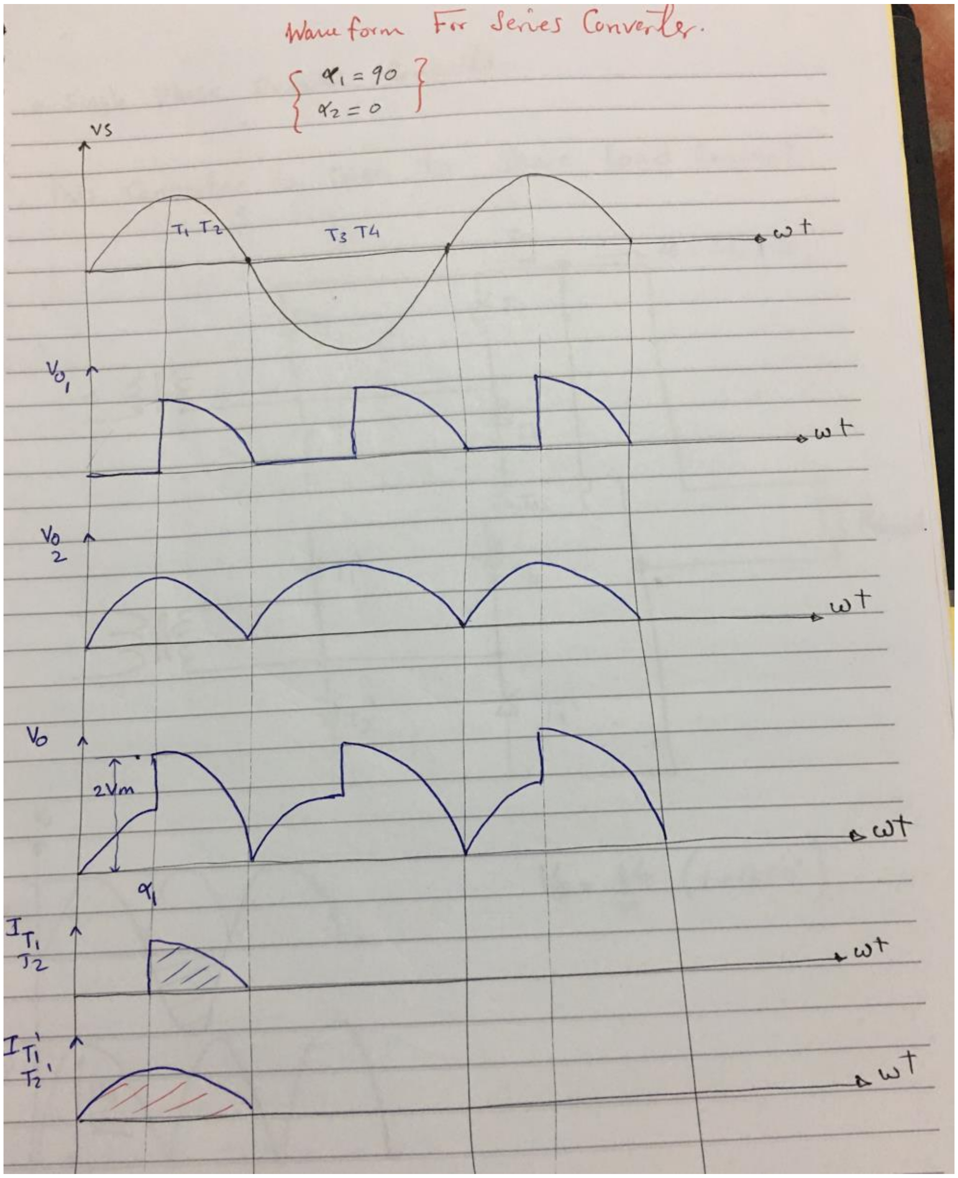
* Single phase series Converter.



Used To produce double value of voltage on The output.

$$V_o = V_{o_1} + V_{o_2}$$

all Thyristors in two Converters must be The same. in (Voltage rating and Current rating)


Wave form For Series Converter.
$\alpha_1 = 90$
$\alpha_2 = 0$
VS
ωt
$T_1\ T_2$
$T_3\ T_4$
V_{o_1}
V_{o_2}
V_o
2Vm
α_1
I_{T_1, T_2}
$I_{T_1', T_2'}$

$0 < \alpha < 180$

$V_{o_1} = \frac{V_m}{\pi}(1+\cos\alpha_1)$ $\qquad 0 < V_{o_1} < \frac{2V_m}{\pi}$

$V_{o_2} = \frac{V_m}{\pi}(1+\cos\alpha_2)$ $\qquad 0 < V_{o_2} < \frac{2V_m}{\pi}$

$V_o = V_{o1} + V_{o2}$

$= \frac{V_m}{\pi}(1+\cos\alpha_1 + 1 + \cos\alpha_2)$

$= \frac{V_m}{\pi}(2+\cos\alpha_1 + \cos\alpha_2)$

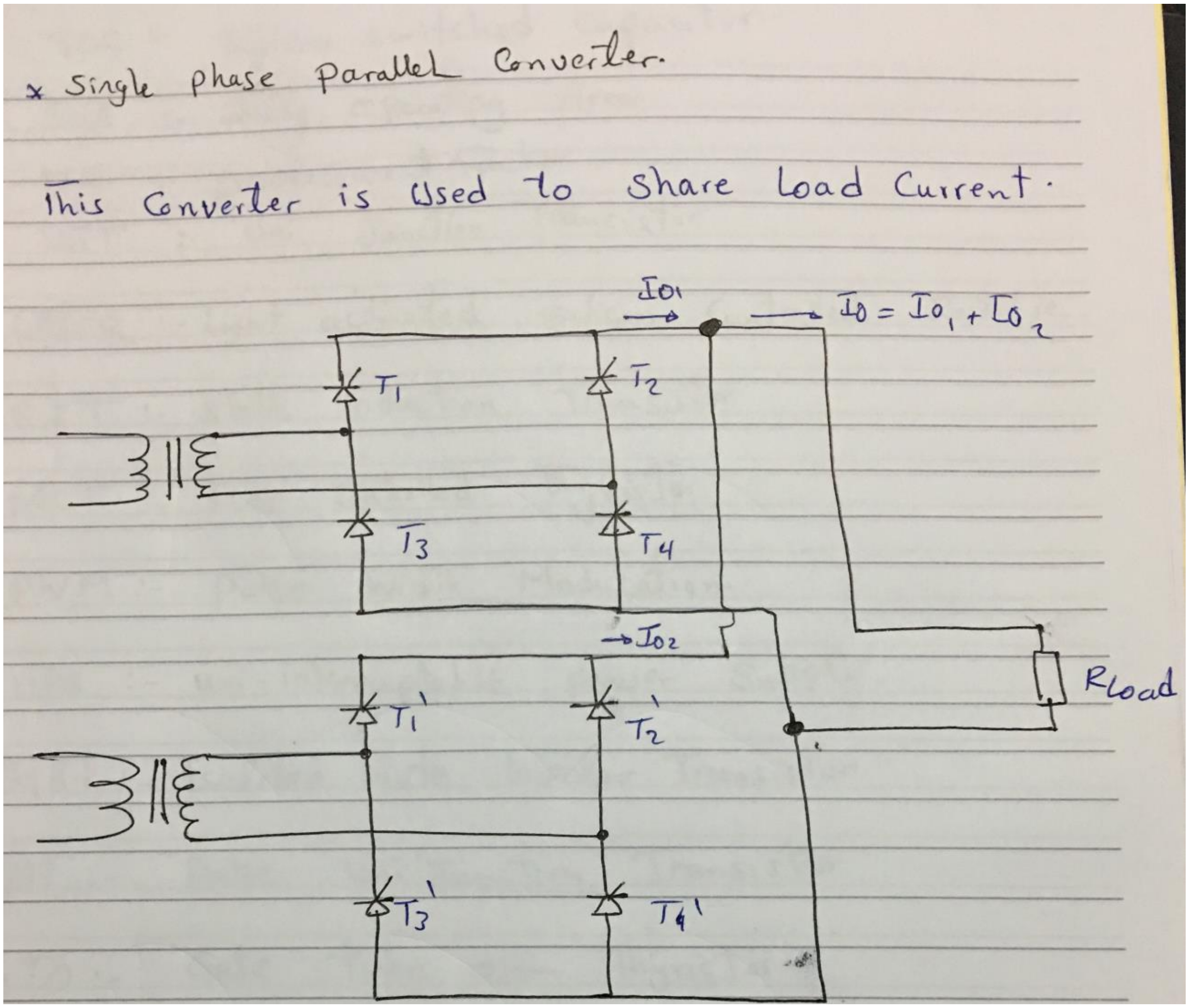
output range of Series Converter

if $\alpha_1 = \alpha_2 = 0$ $\qquad 0 < V_o < \frac{4V_m}{\pi}$

if $\alpha_1 = 0$ $\quad 0 < \alpha_2 < \pi$ $\qquad V_o = \frac{V_m}{\pi}(3+\cos\alpha_2)$

$\frac{2V_m}{\pi} < V_o < \frac{4V_m}{\pi}$

(c) Draw the Power circuit of the parallel Converter



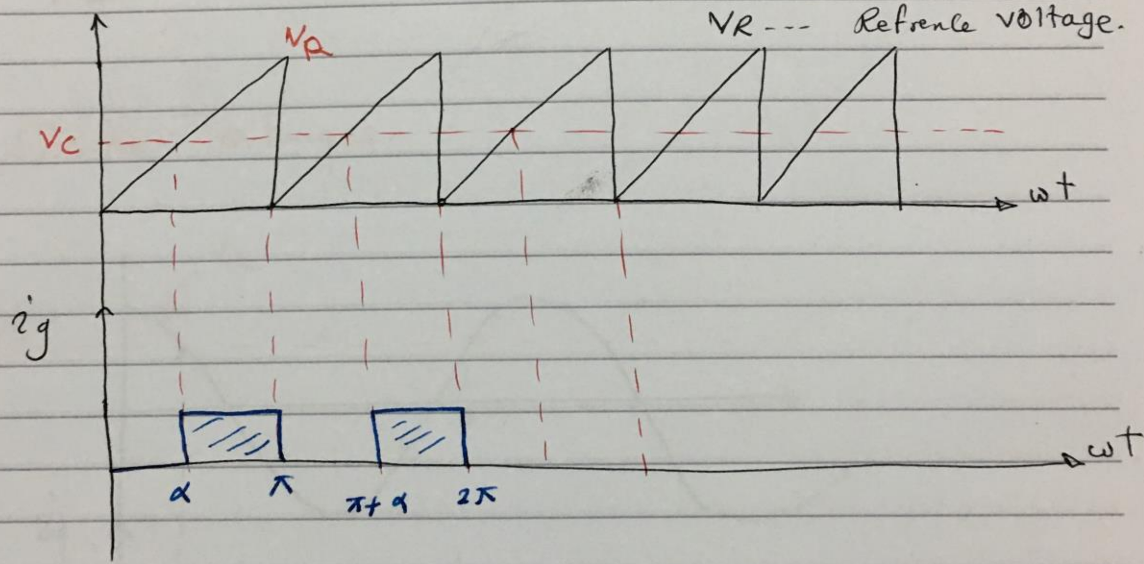
(d) Explain the two firing techniques for thyristor.

Thyristor Firing Techniques

1. Linear Firing Circuit
2. Cosine Firing Circuit.

1 Linear Firing Circuit.

V_C ---- Control voltage
V_R --- Refrence voltage.



$\because V_C \propto \alpha$

$\therefore \alpha = k_{\alpha} V_C \longrightarrow (1)$

$\therefore \alpha \uparrow$ when $V_C \uparrow$

$\alpha \downarrow$ when $V_C \downarrow$

$\rightsquigarrow \therefore$ propotional relation.

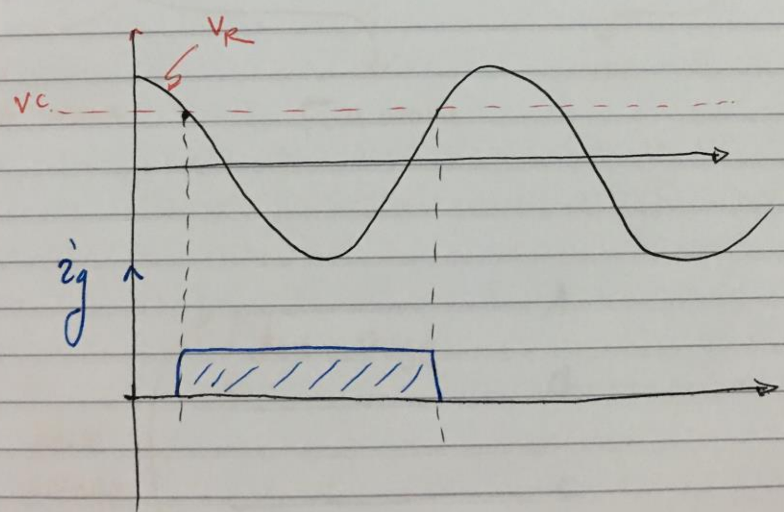
$$\therefore V_{dc} = \frac{2V_m}{\pi}\cos\alpha \longrightarrow (2)$$

From (1) in (2) $\longrightarrow \alpha = K V_c$

$$\boxed{\therefore V_{dc} = \frac{2V_m}{\pi}\cos(K V_c)} \longrightarrow \text{This eq}^{n}$$

relation Between Vdc and Vc Not linear.

[2] Cosine Technique.



$$V_{dc} \propto \cos\alpha$$

$$\cos\alpha = K V_c \longrightarrow \alpha = \cos^{-1}(K V_c)$$

$$\therefore V_{dc} = \frac{2V_m}{\pi}\cos(\cos^{-1} K V_c)$$

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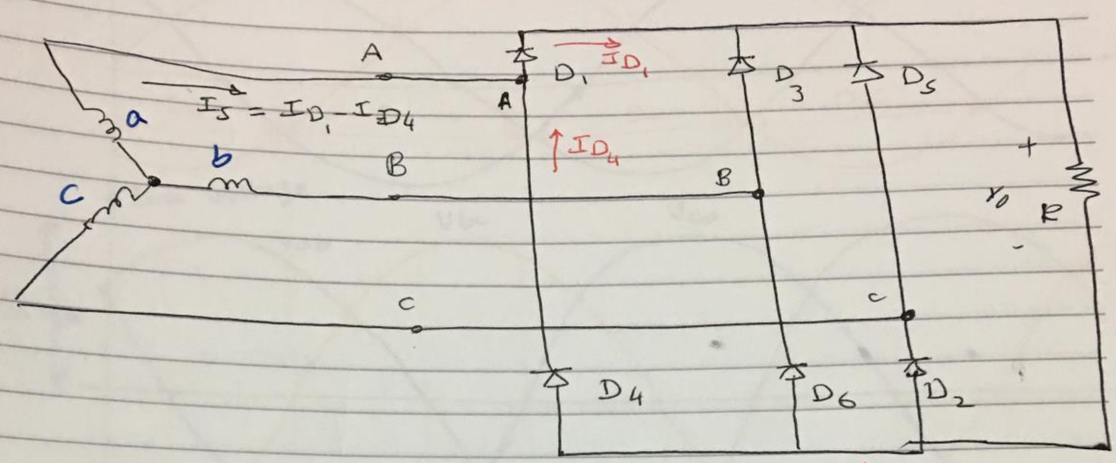
Question 4 (***15 marks***)

(a) Draw the Power Circuit and wave form of three phase Full wave Uncontrolled Rectifier.

* Three phase full wave Un Controlled bridge Rectifier.



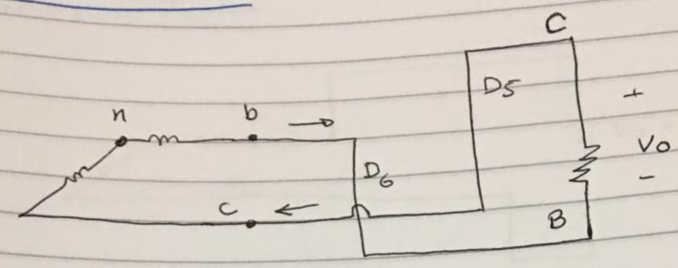
3-φ Converter.

For D_1 & D_3, D_5 will be Forward if its anode voltage is largest +ve voltage.

For D_2 D_4 D_6 will be Forward if its Cathode voltage is largest -ve voltage.

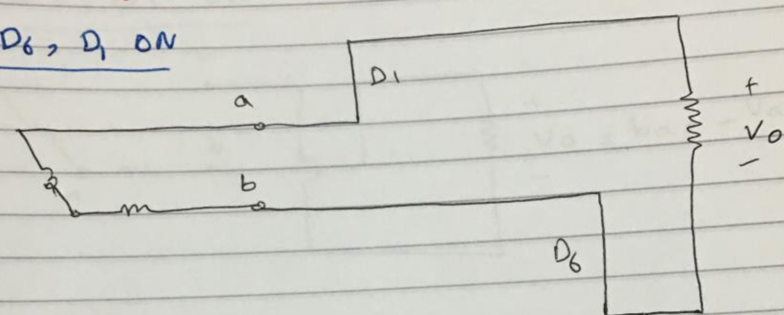
Only two diodes are ON

For $D_5 ; D_6$ ON



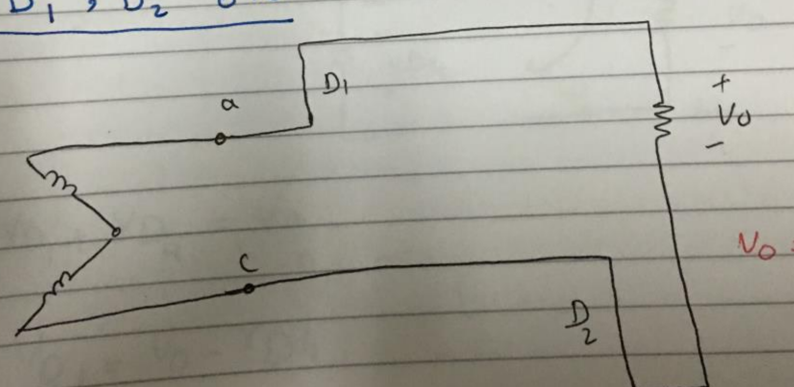
$V_o = V_{cn} - V_{bn} = V_{cb} = -V_{bc}$

For D_6 , D_1 ON



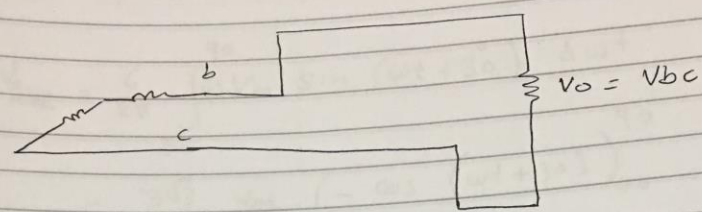
$V_o = V_{ab}$

For D_1 , D_2 ON



$V_o = V_{ac} = -V$

For D_1, D_3 ON



For D_3, D_4 ON

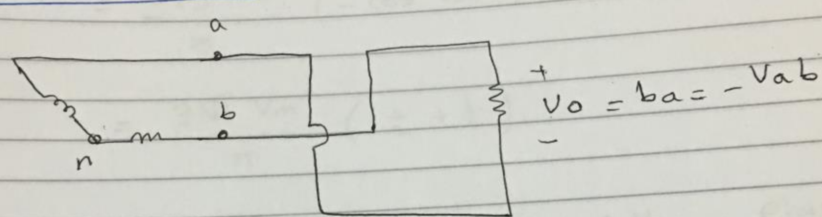
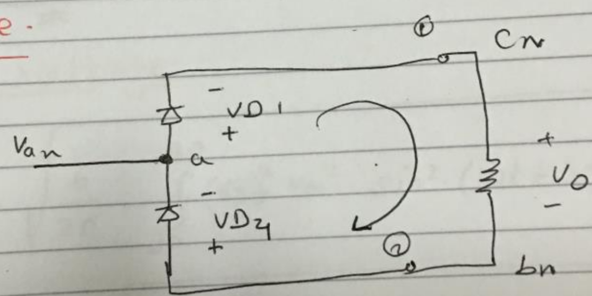
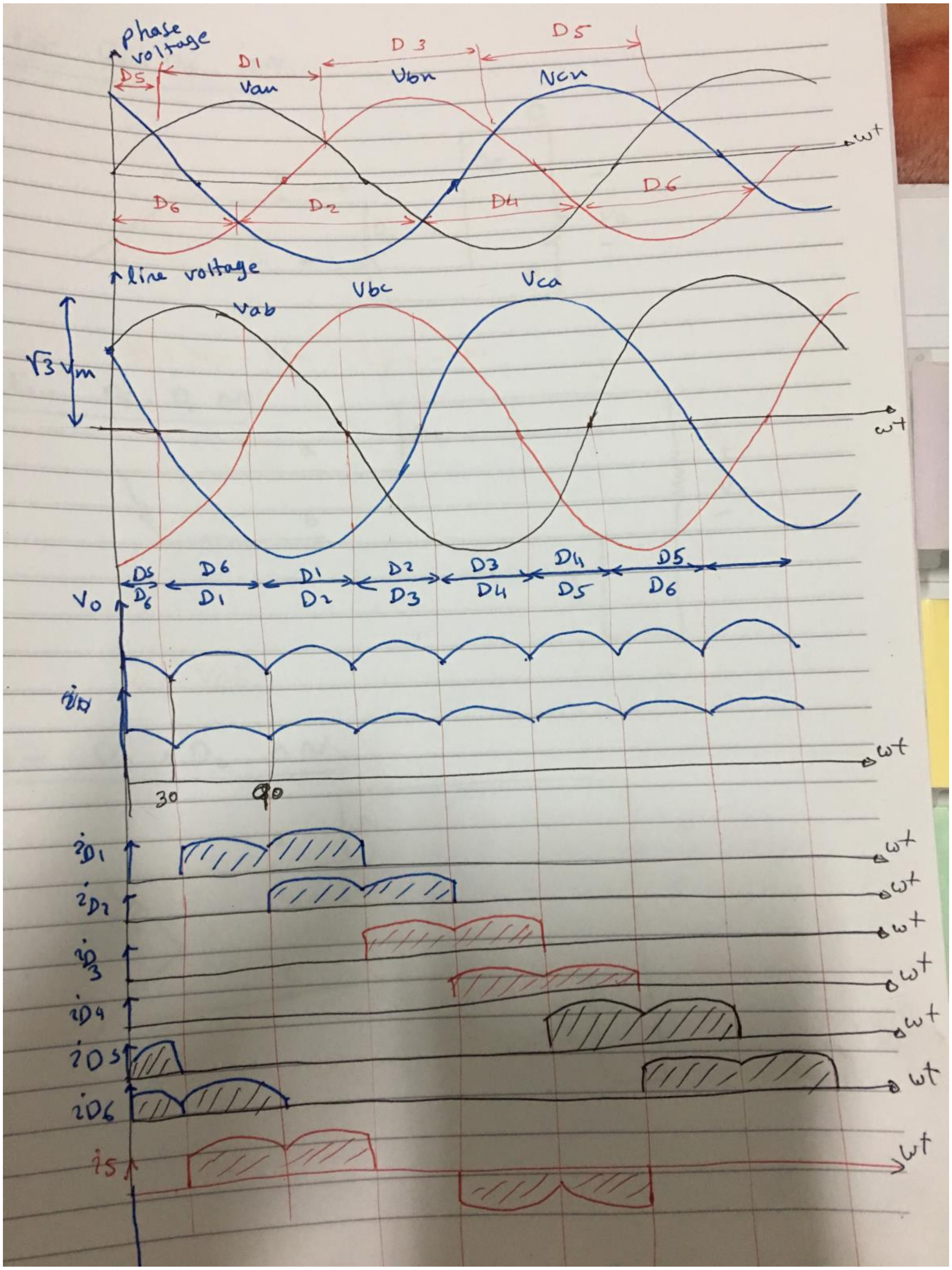


Diagram voltage.



$V_{D_1} + V_{D_4} = V_o$

$V_{D_1} = V_o - V_{D_4}$


phase voltage
D5
D1
Van
D3
Vbn
D5
Vcn
ωt
D6
D2
D4
D6
line voltage
Vab
Vbc
Vca
√3 Vm
ωt
D5 D6
D6 D1
D1 D2
D2 D3
D3 D4
D4 D5
D5 D6
Vo
ωt
30
90
iD1
iD2
iD3
iD4
iD5
iD6
is
ωt

Average output voltage

$$V_{o\,ave} = \frac{6}{2\pi}\int_{30}^{90} \sqrt{3}V_m \sin(\omega t + 30^\circ)\, d\omega t$$

$$= \frac{3\sqrt{3}}{\pi} V_m \left(-\cos(\omega t + 30)\right)_{30}^{90}$$

$$= \frac{3\sqrt{3}\, V_m}{\pi}\left(-\cos 120 + \cos 60\right)$$

$$= \frac{3\sqrt{3}\, V_m}{\pi}\left(\tfrac{1}{2} + \tfrac{1}{2}\right)$$

$$= \frac{3\sqrt{6}\, V_s}{\pi} = 2.34\, V_s \quad ; V_s \text{ --- phase voltage}$$

Rms output voltage

$$V_{o\,Rms} = \sqrt{\frac{6}{2\pi}\int_{30}^{90} (\sqrt{3})^2 V_m^2 \sin^2(\omega t + 30)\, d\omega t}$$

$$= 3V_m \sqrt{\frac{1}{2\pi}\int_{30}^{90} \left(1 - \cos 2(\omega t + 30)\right) d\omega t}$$

$$= \frac{3V_m}{\sqrt{2}}\sqrt{\frac{1}{\pi}\left(\omega t - \sin 2(\omega t + 30)\right)_{30}^{90}}$$

$$= 1.655\, V_m = 2.341\, V_s \text{ ---- } V_s \text{ phase volta}$$

(b) A three pulse uncontrolled rectifier is connected to a 3-ϕ , 4-wire, 220 V AC source. If the load resistive is 20 Ω, find

a. The maximum load voltage.
b. The average load voltage.
c. The average load current.
d. The maximum load current.
e. The maximum diode current.
f. The PIV of the diode.
g. The average diode current.
h. The form factor.
i. The pulse number.
J. The conduction angle.

Solution a) The maximum value of line voltage is

$$V_{L(m)} = \sqrt{2}\,(220) = 311 \text{ V}$$

The maximum value of the phase voltage is

$$V_m = 311 / \sqrt{3} = 179.6 \text{ V}$$

b) $V_{o(avg.)} = 0.827 \cdot 179.6 = 148.5$ V

c) $I_{o(avg.)} = V_{o(avg.)}/R = 148.5/5.20 = 7.4$ A

d) $I_{o(m)} = V_m/R = 179.6/20 = 9$ A

e) $I_{D(m)} = I_{o(max)} = 9$ A

f) PIV $\geq V_{L(m)} = 311$ V

g) $I_{D(avg.)} = \dfrac{I_{o(avg.)}}{3} = 7.4/3 = 2.5$ A

h) $FF = \sqrt{n} = \sqrt{3} = 1.732$

i) $P = 3$

j) $\theta = 120°$

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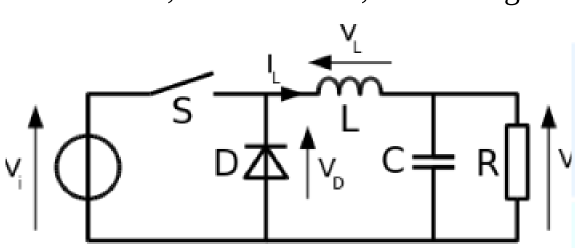
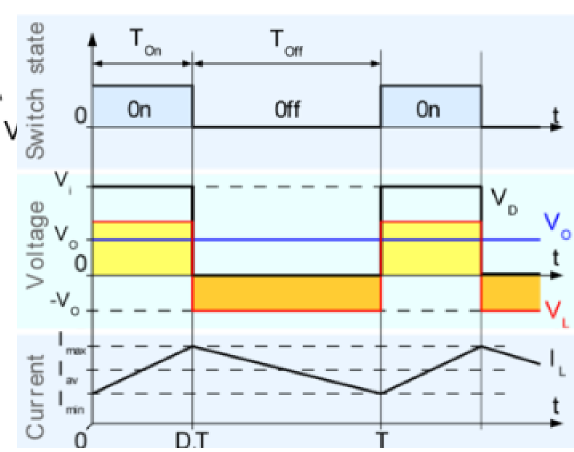
Question 5 (***15 marks***)

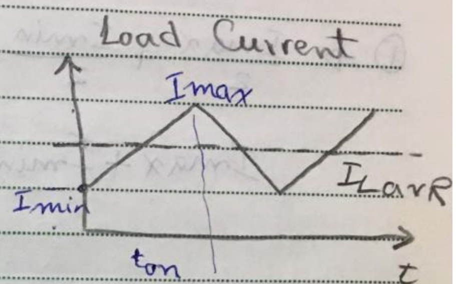
(a) Draw the power circuit of Buck Converter and Waveform of inductor current , load current , diode current , load voltage and capacitor current





(b) Prove that, $L_{\min} = \dfrac{R(1-D)}{2F_{swt.}}$, The boundary of continuous condition is when I_{min}=0. If the value of I_{min}<0, the converter enters in the discontinuous conduction mode.

Baundry Condition Between Continaus and dis Continaus



$$I_{L_{avR}} = \frac{V_{oavR}}{R} = \frac{I_{max}+I_{min}}{2} \longrightarrow ①$$

$$\Delta I_{L_o} = I_{max} - I_{min}$$

$$\therefore V_L = L \frac{\Delta I_L}{\Delta t}$$

during oFF time

$$-V_L = -V_o = L\left[I_{min} - I_{max}\right]\frac{1}{t_{off}}$$

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$$\Delta I_L = I_{max} - I_{min} = V_{o_{avR}} \frac{t_{off}}{L} \longrightarrow ②$$

① + ②

① $\Rightarrow \dfrac{I_{max}}{2} + \dfrac{I_{min}}{2} = \dfrac{V_{oavR}}{R}$

$$I_{max} + I_{min} = \frac{2V_{oavR}}{R}$$

② $\Rightarrow I_{max} - I_{min} = \dfrac{V_{oavR}\, t_{off}}{L}$

$$2I_{max} = V_{oavR}\left[\frac{2}{R} + \frac{t_{off}}{L}\right]$$

$$\Rightarrow \therefore I_{max} = V_{oavR}\left[\frac{1}{R} + \frac{t_{off}}{2L}\right] \rightarrow ①$$

①−②

① $I_{max} + I_{min} = \dfrac{2V_{oavR}}{R}$

② $I_{max} - I_{min} = \dfrac{V_{oavR}\, t_{off}}{L}$

NOTES

$$2I_{min} = \frac{2V_{oavR}}{R} - V_{oavR}\, t_{off}/L$$

$$I_{min} = V_{oavR}\left[\frac{1}{R} - \frac{t_{off}}{2L}\right] \rightarrow ②$$

$$\therefore D = \frac{T_{on}}{T} = \frac{T - T_{off}}{T}$$

$$TD = T - T_{off}$$

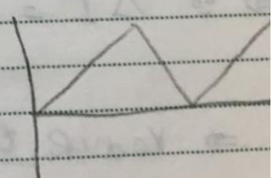
$$T_{off} = T - TD = T(1-D) \longrightarrow ③$$

From ③ in ①

$$I_{max} = V_{oav} R \left[\frac{1}{R} + \frac{T(1-D)}{2L} \right]$$

The Controller in max Current D, L, F

⇒ at Baundry Condition



$$I_{min} = 0$$

$$I_{min} = V_{oav} R \left[\frac{1}{R} - \frac{T(1-D)}{2L} \right)$$

$$0 = \frac{1}{R} - \frac{T(1-D)}{2L}$$

$$\frac{1}{R} = \frac{T(1-D)}{2L}$$

$$L_{min} = \frac{T(1-D)R}{2}$$

$$L_{min} = \frac{R(1-D)}{2F_{swt}}$$ Critical

$L >> L_{min}$ Continaus

$L << L_{min}$ dis Continaus

(c) For Buck Converter , Drive ripple voltage Relation $\frac{\Delta v_o}{v_o} = \frac{1}{8CLF_{swt.}^2}(1-D)$

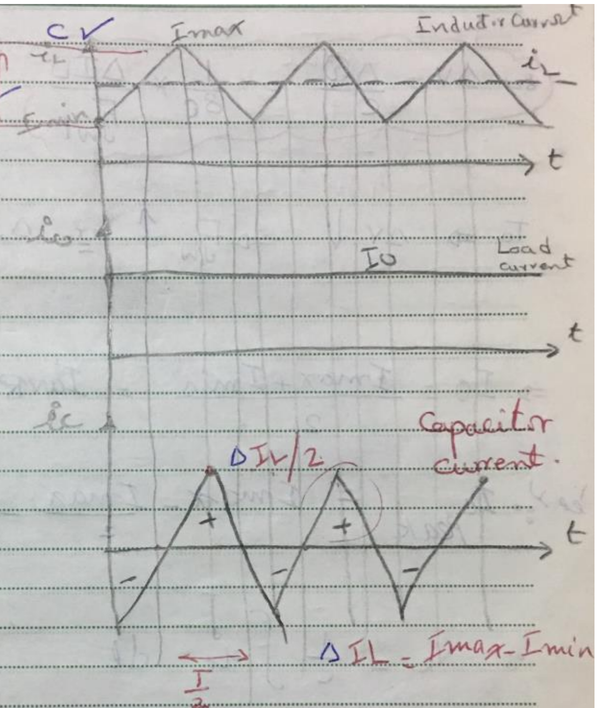
iF ΔQ ✓ and C ✓

$\therefore \Delta V_o$ ✓

$\Rightarrow$ how find C

$\therefore \frac{\Delta Q}{\Delta t} = i_c$

$Q = \int i_c \, dt$



$\therefore Q =$ Area under the Curve

$\Delta Q = \frac{1}{2} * \frac{T}{2} * \frac{\Delta I_L}{2}$

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$= \frac{1}{8} * T * \Delta I_L$

$\Delta Q = \frac{1}{8} * \frac{\Delta I_L}{F_{swt}}$

$$\therefore \Delta V = \frac{\Delta Q}{C} = \frac{1}{8C} * \frac{\Delta I_L}{F_{sw}}$$

To $\Rightarrow \Delta V \downarrow \Rightarrow F_{sw} \uparrow$ or $\Delta I_L \downarrow$ or $C \uparrow$

$$\Rightarrow I_o = \frac{I_{max} + I_{min}}{2} = I_{avR}.$$

$$\therefore I_{c_{peak}} = I_{max} - \frac{I_{max}}{2} - \frac{I_{min}}{2}$$

$$\therefore V_c = \frac{1}{C} \int i_c \, dt$$

I $-ve$ $\therefore \Rightarrow C$ يفرغ

I $+ve$ $\therefore \Rightarrow C$ يشحن

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Good Luck,
Mohamed Awaad