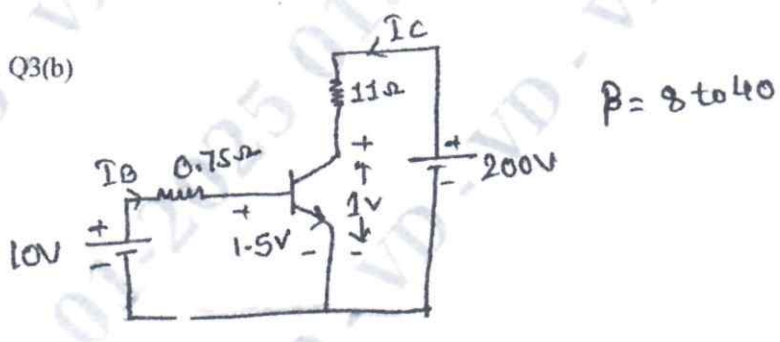
CBCS SCHEME

BEE503

ifth Semester B.E./B.Tech. Degree Examination, Dec.2024/Jan.2025
Power Electronics

Time: 3 hrs. Max. Marks: 100

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. M : Marks , L: Bloom's level , C: Course outcomes.

		Module – 1	M	L	C
Q.1	a.	Explain control characteristics of power devices with neat circuit and wave form.	8	L1	CO1
	b.	With neat diagram, explain different types of power electronic converters.	8	L1	CO1
	c.	The forward voltage drop of power diode is $V_D = 1.2V$ at $I_D = 300A$, $n = 2$ and $V_T = 25.7mV$, find the reverse saturation current I_S.	4	L3	CO1
		OR			
Q.2	a.	Explain Full wave Rectifier with central tapped transformer with R load. Derive the expression for $V_{o(rms)}$, $V_{o(av)}$, RF , FF, TUF.	10	L2	CO1
	b.	With neat waveform and equation, explain Reverse Recovery characteristics.	10	L2	CO1
		Module – 2			
Q.3	a.	Explain Steady State characteristics and switching characteristics of BJT with neat circuit and waveforms.	10	L2	CO2
	b.	For the transistor switch of Fig. Q3(b), calculate forced beta, β_f of transistor, ODF and power loss P_T of transistor. Fig. Q3(b) 	10	L3	CO2
		OR			
Q.4	a.	Explain different methods of providing gate and base drive isolation.	10	L1	CO2
	b.	The collector clamping of Antisaturation control has $V_{CC} = 100V$, $R_C = 1.5\Omega$, $Vd_1 = 2.1V$, $Vd_2 = 0.9V$, $V_{BE} = 0.7V$, $V_B = 15V$ and $R_B = 2.5\Omega$ and B = 16. Calculate i) The Collector current without clamping ii) The Collector – Emitter clamping voltage and iii) The Collector current with clamping.	10	L3	CO2

		Module – 3			
Q.5	**a.**	Derive an expression for the anode current of thyristor with the help of two transistor analogy.			
	b.	The latching current for SCR inserted in between adc voltage source of 200V and load is 100 mA. Calculate the minimum width gate pulse current required to turn on SCR in case load consist of i) L = 0.2H ii) R = 20Ω in series with L = 0.2H.	**10**		
		OR			
Q.6	**a.**	With the help of neat diagram and waveform, explain RC firing circuit used with half controlled rectifier.	**10**	**L2**	**C**
	b.	Design the UJT triggering circuit for SCR. Given $V_{BB} = 20V$, $\eta = 0.6$, $I_P = 10\mu A$, $V_V = 2V$, $I_V = 10mA$. The frequency of oscillation is 100Hz. The triggering pulse width should be 50μS.	**10**	**L3**	**CO3**
		Module – 4			
Q.7	**a.**	With neat diagram and waveform explain single phase dual converter.	**10**	**L2**	**CO4**
	b.	A single phase half wave converter is operated from a 120V, 50Hz supply and the load resistance of 10Ω. If average output is 25% of the maximum possible average output voltage calculate: i) Delay angle ii) The rms and average output current iii) The rms and average thyristor current. iv) The Input power factor.	**10**	**L3**	**C)4**
		OR			
Q.8	**a.**	With neat circuit and waveform, explain the operation of single phase bidirectional AC voltage controller with resistive load. Obtain the equation for output voltage.	**10**	**L2**	**CO4**
	b.	The single phase full wave AC voltage controller operates on single phase supply voltage of 230V rms at 50Hz. If the triac is triggered at a delay angle of 45°, during each half cycle of Input supply. Calculate i) RMS value of output voltage. ii) RMS value of current through heater. iii) Average value of triac current and RMS. iv) Input power factor.	**10**	**L3**	**CO4**
		Module – 5			
Q.9	**a.**	Explain the principle of operation of a step – up chopper with suitable circuit diagram and waveform. Derive the expression for average output voltage.	**10**	**L1**	**CO5**

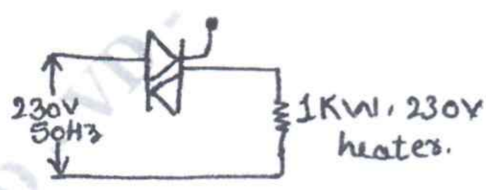


Fig. Q8(b)

		A step up input chopper is 200 V. The output required is 600 V. If the conducting time of thyristor is 200 μs, compute i) Chopping frequency ii) If pulse width is halved for constant frequency of operation, find the new output voltage.	10	L3	CO5
		OR			
.10	**a.**	With circuit diagram, explain the operation of 1 ϕ full bridge inverter with R load.	10	L1	CO5
	b.	The single phase full bridge inverter has a resistive load of 24Ω and DC input voltage of 48 V. Determine i) rms output voltage at fundamental frequency. ii) The output supply. iii) The peak and average currents of each transistor.	10	L3	CO5

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Question Paper Solution of Power Electronics (BEE503)

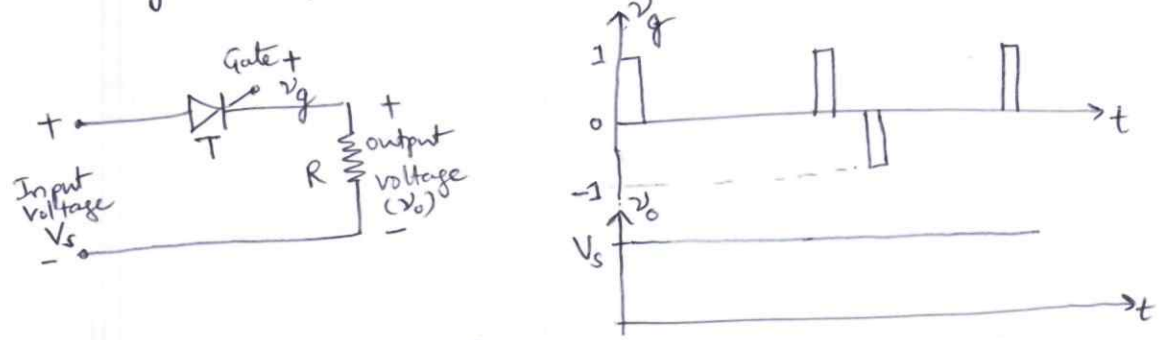
(Dec 2024/ Jan 2025)

Prepared by: Prof. Kirankumar H.
Dept. of E E Engg.

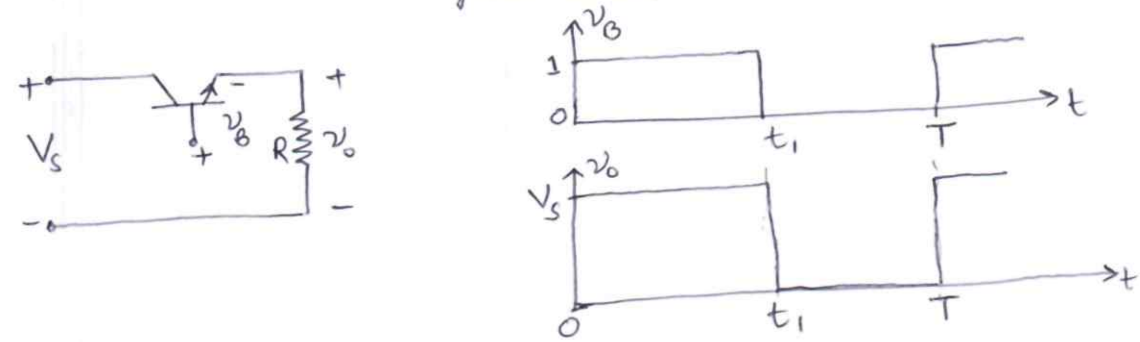
Q1) a) Explain control characteristics of power devices with neat circuit diagram & waveform. (08 Marks)

Ans:

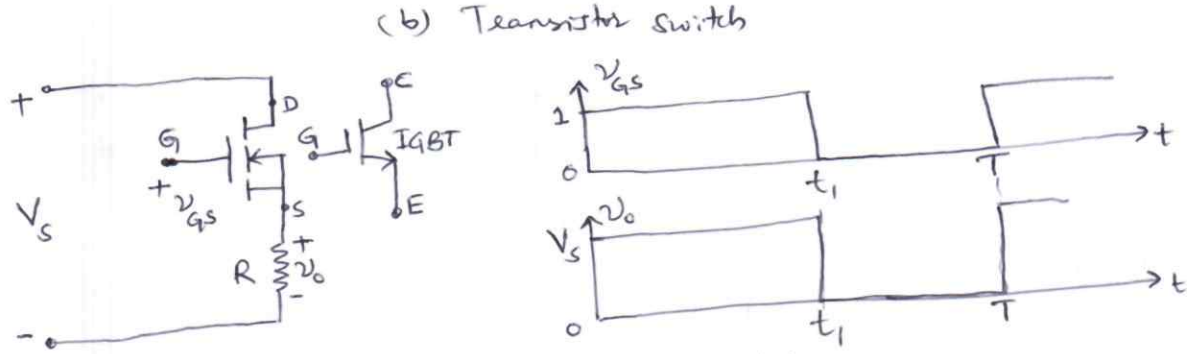
- The power semiconductor devices can be operated as switches by applying control signals to the gate terminal of thyristors and to the base of bipolar transistors. The required output is obtained by varying the conduction time (or firing angle) of these switching devices.
- The fig. 1(A) shown below has output voltages and control characteristics of commonly used power semiconductor devices.



(a) Thyristor switch



(b) Transistor switch



(c) MOSFET/IGBT Switch

Fig. 1(A): Control characteristics of power switching devices

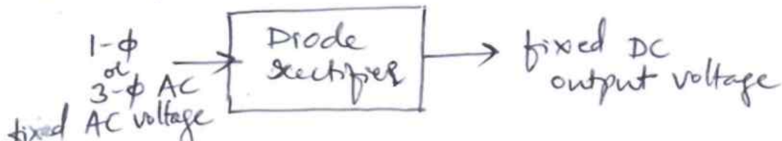
- Once a thyristor is in a conduction mode, the gate signal of either positive or negative magnitude has no effect and this is shown in above fig. 1(A)(a).

Q1) b) With neat diagram, explain different types of power electronic converters (08 Marks)

- The power electronic circuits can be classified into six types

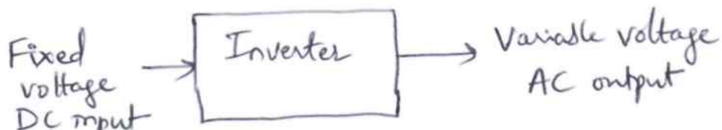
1) Diode rectifiers
2) DC - DC converters (DC choppers)
3) DC - AC converters (inverters)
4) AC - DC converters (Controlled rectifiers)
5) AC - AC converters (controllers of AC voltage)

- 1) <u>Diode rectifiers</u>:



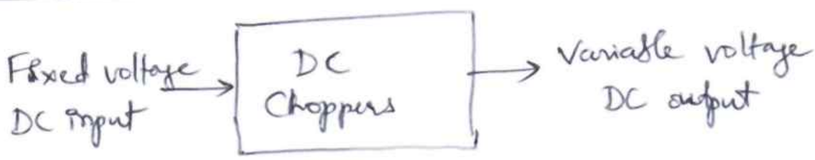
It is a uncontrolled rectifier which converts AC voltage into a fixed DC voltage.

2) <u>DC - AC converters</u>:



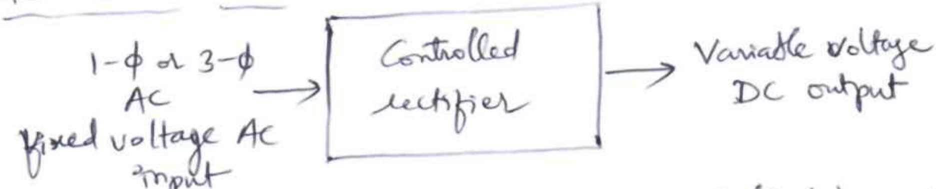
A DC-AC converter is also known as an inverter. The o/p voltage contains harmonics which could be filtered out before supplying to the load.

3) <u>DC - DC converters</u>:



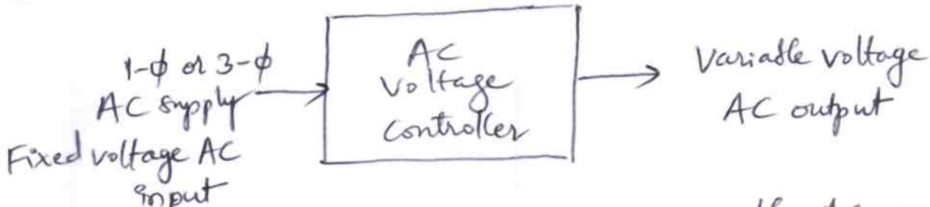
A DC-DC converter is also known as a chopper or switching regulator. By varying the duty cycle of the switch the output voltage can be controlled.

4) <u>AC - DC converters</u>



The average value of output voltage can be controlled by varying the conduction time of thyristors. The input could be a single or three phase source. These converters are also known as controlled rectifiers.

5) AC-AC Converters :



These converters are used to obtain a variable AC output voltage V₀ from a fixed AC source and these types of converters use TRIAC and are also known as AC voltage controllers.

Q1) c) The forward voltage drop of power diode is $V_D = 1.2$ V at $I_D = 300$ A, $n = 2$ and $V_T = 25.7$ mV, find the reverse saturation current I_S. (04 Marks)

Ans: Reverse saturation current is given by

$$I_S = \frac{I_D}{\left(e^{\frac{V_D}{n V_T}}\right)}$$

where $I_D = 300$ A, $V_D = 1.2$ V
$n = 2$ & $V_T = 25.7$ mV

Substituting the values we get

$$I_S = 2.16 \times 10^{-8} \text{ A} = 0.0216\ \mu\text{A}$$

Q2) a) Explain full wave rectifier with centre tapped transformer with R load. Derive the expression for $V_{o(rms)}$, $V_{o(av)}$, RF, FF & TUF. (10 Marks)

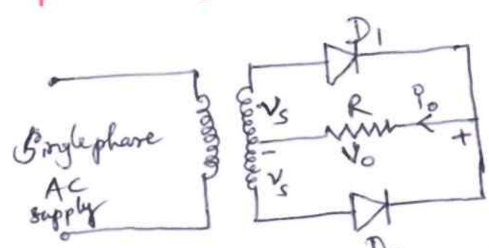


Fig. 2(a)(i): Single phase full wave rectifier with centre tapped transformer with R-load

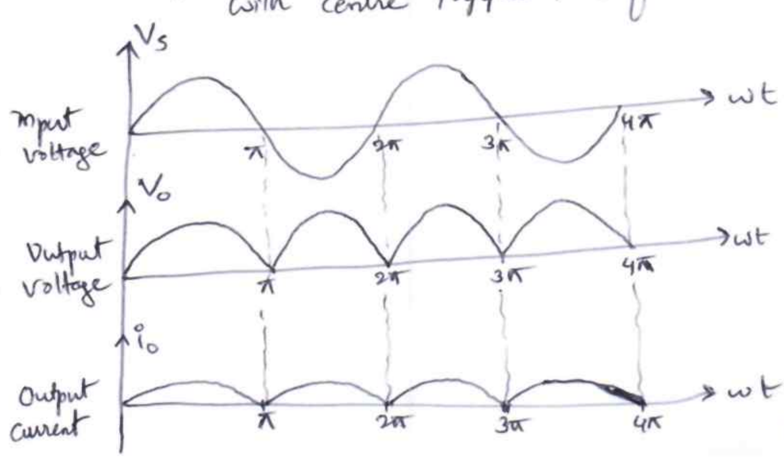


Fig 2(a)(ii): Waveforms

- Derivation of expression:

i) Output average voltage $V_{o(av)}$:

$$V_{o(av)} = \frac{1}{T}\int_0^T V_o(\omega t)\cdot dt$$

$$= \frac{1}{\pi}\int_0^\pi V_m \sin\omega t \cdot dt$$

$$= \frac{V_m}{\pi}\left[\cos\omega t\right]_0^\pi = \frac{2V_m}{\pi}$$

$$\therefore V_{o(av)} = 0.637\, V_m$$

ii) Output rms voltage $V_{o(rms)}$:

$$V_{o(rms)} = \left[\frac{1}{T}\int_0^T v_o^2(\omega t)\cdot d\omega t\right]^{1/2}$$

$$= \left[\frac{1}{\pi}\int_0^\pi V_m^2 \sin^2\omega t\cdot d\omega t\right]^{1/2}$$

$$= \left\{\frac{V_m^2}{2\pi}\left[(\omega t)_0^\pi - \left(\frac{\sin 2\omega t}{2}\right)_0^\pi\right]\right\}^{1/2}$$

$$V_{o(rms)} = \frac{V_m}{\sqrt{2}} = 0.707\, V_m$$

iii) Form factor (FF):

$$FF = \frac{V_{o(rms)}}{V_{o(av)}} = \frac{0.707\, V_m}{0.637\, V_m} = 1.11$$

iv) Ripple Factor (RF):

$$RF = \sqrt{FF^2 - 1} = \sqrt{1.11^2 - 1} = 0.4817$$

v) Transformer Utilization Factor (TUF):

$$TUF = \frac{P_{o(av)}}{V_{s(rms)}\cdot I_{s(rms)}}$$

$$P_{o(av)} = \frac{(0.637\,V_m)^2}{R}, \quad V_{s(rms)} = \frac{V_m}{\sqrt{2}} = 0.707\, V_m$$

$$I_{s(rms)} = \frac{I_{o(rms)}}{\sqrt{2}} = \frac{V_{o(rms)}/R}{\sqrt{2}} = \frac{V_m}{2R}$$

$$\therefore TUF = \frac{(0.637\,V_m)^2/R}{2\,V_{s(rms)}\cdot I_{s(rms)}} = \frac{(0.637\,V_m)^2/R}{2\times 0.707\,V_m\cdot V_m/2R} = 0.574$$

57.4%

Q)2) b) With neat waveform & equation, explain Reverse Recovery Characteristics. (10 Marks)

- The current in forward biased junction diode is due to the net effect of majority and minority carriers.
- Once a diode is in forward conduction mode and then if its forward current is reduced to zero (due to application of a reverse voltage), the diode continues to conduct due to minority charge carriers that remain stored in the pn-junction and the bulk semiconductor material.
- The minority charge carriers require a certain time to recombine with opposite charge carriers and to be neutralized. This time is called the reverse recovery time of the diode.

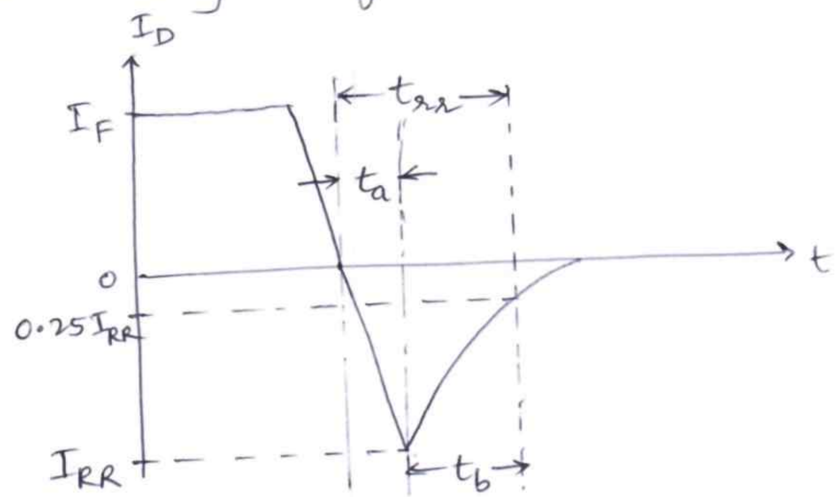


Fig.2(b): Reverse recovery characteristics (Soft recovery)

- In the above fig.1 reverse recovery time (t_{rr}) is denoted by t_{rr} and is measured from the initial zero crossing of the diode current to 25% of maximum (or peak) reverse current I_{RR}.
- The t_{rr} has two components, t_a & t_b

  t_a → it is due to charge storage in depletion region of the junction & represents the time between the zero crossing and the peak reverse current I_{RR}.

  t_b → it is due to charge storage in bulk semiconductor material.

Softness factor (SF) → The ratio of t_b / t_a is known as the softness factor (SF)

The reverse recovery time (t_{rr}) is given by

$$t_{rr} = t_a + t_b$$

the peak reverse recovery current can be express in reverse $\frac{di}{dt}$

$$\therefore I_{RR} = t_a \cdot \frac{di}{dt}$$

Also,

$$t_{rr} \cong \sqrt{\frac{2 Q_{RR}}{(di/dt)}} \quad \& \quad I_{RR} = \sqrt{2 \cdot Q_{RR} \left(\frac{di}{dt}\right)}$$

where Q_{RR} — reverse recovery charge in coloumbs

Q>3>a> Explain steady state characteristics and switching characteristics of BJT with neat circuit & waveforms. (10 Marks)

* Steady state characteristics:

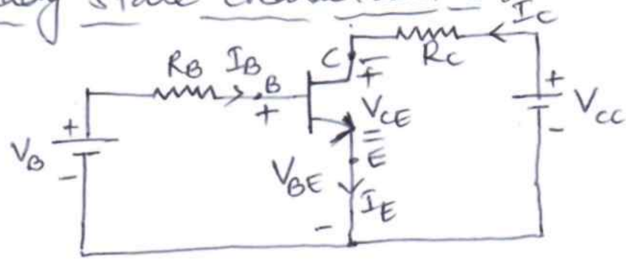


Fig. 3)a)(i): Circuit diagram

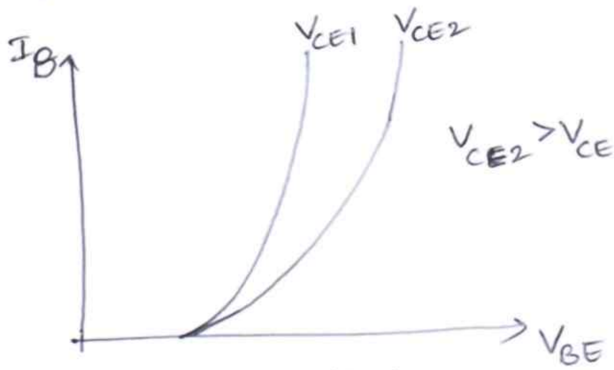
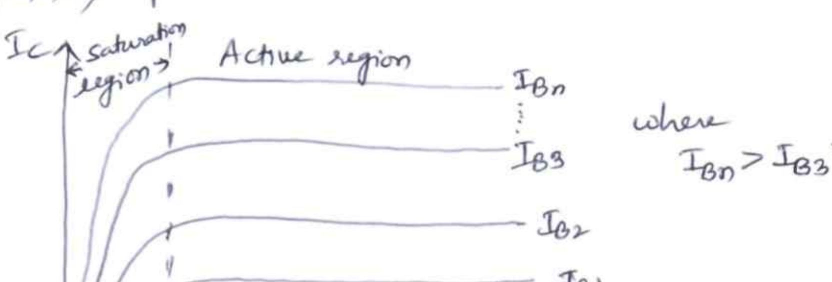


Fig. 3)a)(ii): Input characteristics



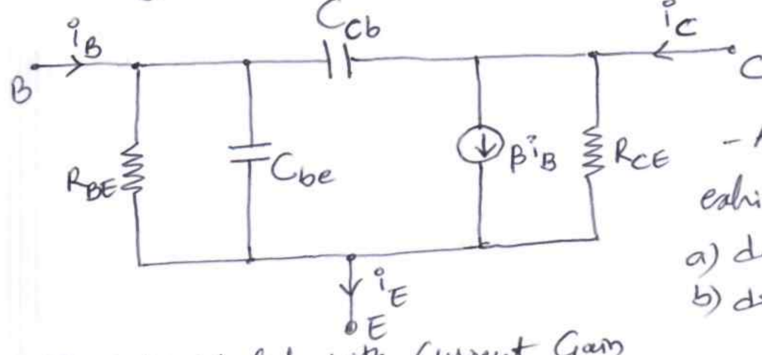
where $I_{Bn} > I_{B3} > I_{B2} > I_{B1}$

Fig. 3(a) (iii): Output characteristics

- Common emitter configuration is shown in figures, which is a NPN transistor, is generally used in switching applications.
- The typical input characteristics of base current I_B, against base-emitter voltage V_{BE} is shown in fig. Typical output characteristics of collector current I_C against collector-emitter voltage V_{CE}.

- There are three operating regions of a transistor:
  Cut off, active & saturation region.
  In the cut off region, the transistor is Off
  In the active region, the transistor acts as amplifier
  In the saturation region, the transistor acts as a switch.
- Hence the transistor is operated in cut off & saturation region for switching applications.

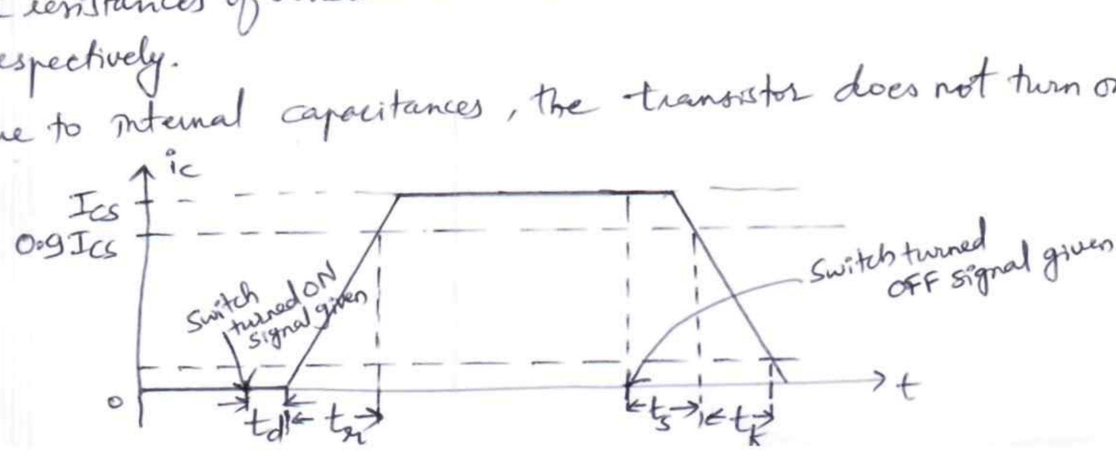
* Switching Characteristics:



Transistor Model with Current Gain

- A forward biased pn junction exhibits two parallel capacitance
  a) depletion layer capacitance &
  b) diffusion capacitance

- Under steady state conditions these capacitances do not play any role But under transient conditions, they influence the turn-on & turn-off, behaviour of the transistor.
- C_{cb} & C_{be} are the effective capacitances of the CBJ & BEJ respectively The resistances of collector to emitter and base to emitter are r_{ce} & r_{be} respectively.
- Due to internal capacitances, the transistor does not turn on instantl

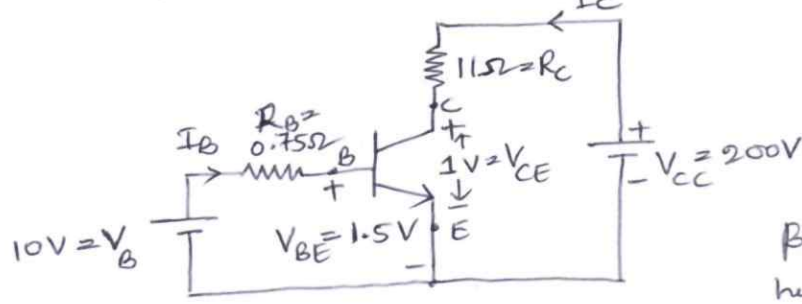


Here, t_d = delay time
t_r = rise time
t_s = storage time
t_f = fall time

∴ on-time of switch, $t_{on} = t_d + t_r$

& off-time of switch, $t_{off} = t_s + t_f$

Q3) b) For the transistor switch of fig Q3(b) calculate β_{forced}, β_f of transistor, ODF and power loss P_T of transistor. (10 Marks)



β = 8 to 40

here $\beta_{min} = \beta = 8$

here $I_{C(sat)} = \dfrac{V_{CC} - V_{CE(sat)}}{R_C} = \dfrac{200-1}{11} = 18.09$ A

$I_{B(sat)} = \dfrac{I_{C(sat)}}{\beta_{min}} = \dfrac{18.09}{8} = 2.26$ A

W.K.T Over drive factor, $ODF = \dfrac{I_B}{I_{B(sat)}}$

where $I_B = \dfrac{V_B - V_{BE}}{R_B} = \dfrac{10-1.5}{0.75} = 11.33$ A

∴ $ODF = \dfrac{11.33}{2.26} = 5.01 \simeq 5$

W.K.T $\beta_{forced} = \dfrac{I_{C(sat)}}{I_B} = \dfrac{18.09}{11.33} = 1.597 \simeq 1.6$

Now power loss of transistor is given by

$P_T = V_{BE} I_B + V_{CE} I_C$

$P_T = (1.5 \times 11.33) + (1 \times 18.09)$

$P_T = 35.085$ W

Q> 4> a> Explain different methods of providing gate and base drive isolation (10 marks)

- There are two methods of providing isolation to gate or base drives.
  i) Isolation using Pulse Transformers
  ii) Isolation using Optocouplers

* Isolation using Pulse Transformers

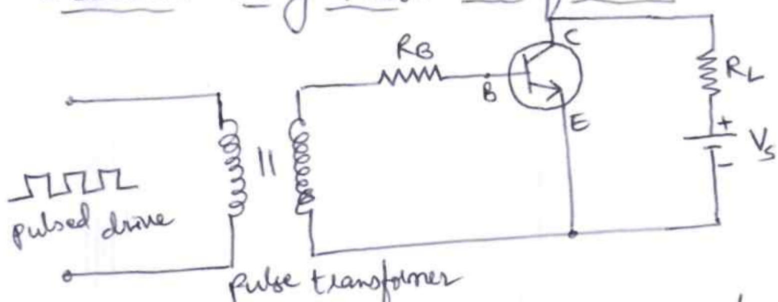


Fig. 4> a> i> Electric isolation using pulse transformer

- Pulse transformer has one primary and one or more secondary windings. It is normally used for pulsed mode of triggering.
- In the above circuit, observe that the triggering circuit is electrically isolated from BJT. Hence if there is any electric damage to BJT, there will be no effect on triggering circuit.
- Advantages: 1> Does not need electrical power externally for its operation
  2> Its very simple to use
- Disadvantages: 1> It saturates at low frequencies hence it can be used only for high frequencies
  2> Due to magnetic coupling, the signal is distorted.

* Isolation using Optocoupler

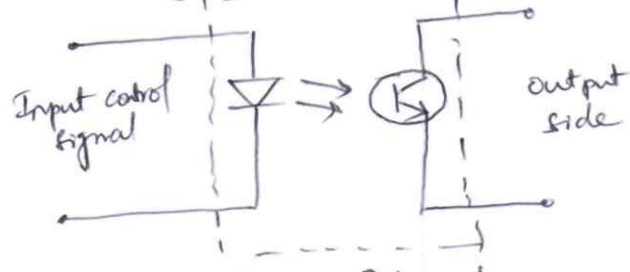


Fig. 4> a> ii> Optocoupler

- It consists of pair of infrared LED & ~~opto~~ photo transistor as shown in above fig. When the signal is given to the IR LED, it turns ON. Its light falls on phototransistor. Therefore phototransistor also starts conducting.

- Advantages: 1) Very good response at low frequencies
  2) Compact & cheaper optocoupler devices are available
- Disadvantages: 1) It needs external biasing voltage for their operation
  2) High frequency response is poor.

Q) 4) b) The collector clamping of Antisaturation control has $V_{CC} = 100V$, $R_C = 1.5\,\Omega$, $V_{d1} = 2.1\,V$, $V_{d2} = 0.9\,V$, $V_{BE} = 0.7\,V$, $V_B = 15\,V$ & $R_B = 2.5\,\Omega$ & $\beta = 16$. Calculate
i) The collector current without clamping
ii) The collector-emitter clamping voltage
iii) The collector current with clamping (10 Marks)

Ans: i) Collector current without clamping

from fig. base current can be expressed as

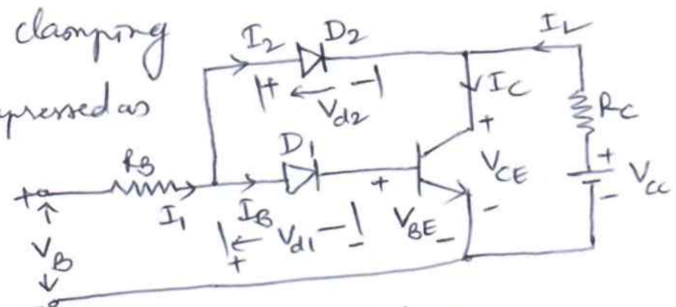


Fig. 4) b): Circuit diagram

$$I_B = \frac{V_B - V_{d1} - V_{BE}}{R_B}$$

$$I_B = \frac{15 - 2.1 - 0.7}{2.5} = 4.88\,A$$

$$I_C = \beta I_B = 16 \times 4.88 = 78.08\,A$$

ii) Collector emitter clamping voltage V_{CE}

From the circuit, the collector emitter clamping voltage is,

$$V_{CE} = V_{BE} + V_{d1} - V_{d2}$$

$$V_{CE} = 0.7 + 2.1 - 0.9 = 1.9\,V$$

iii) Collector current with clamping

load current is, $I_L = \dfrac{V_{CC} - V_{CE}}{R_C}$

$$I_L = \frac{100 - 1.9}{1.5} = 65.4\,A$$

Collector current with clamping is given from the circuit as,

$$I_C = \beta I_B = \beta(I_1 - I_2)$$

here, $I_2 = I_C - I_L$

hence $I_1 = \beta(I_1 - I_C + I_L)$

$$I_C = \beta I_1 - \beta I_C + \beta I_L$$

$$(1+\beta) I_C = \beta (I_1 + I_L)$$

$$I_C = \frac{\beta}{1+\beta} (I_1 + I_L)$$

here I_1 is base current without clamping, i.e 4.88 A. Hence above equation becomes,

$$I_C = \frac{16}{16+1} (4.88 + 65.4) = 66.15 \text{ A}$$

Q>5>a> Derive an expression for the anode current of thyristor with the help of two transistor analogy. (10 Marks)

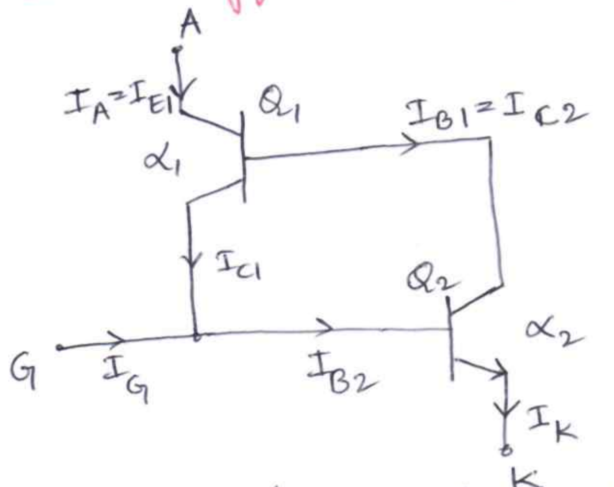


Fig.5>a> : Equivalent circuit of two transistor model of thyristor

- A thyristor can be considered as two complementary transistors, one PNP-transistor Q_1 & other NPN-transistor Q_2 as shown in fig.

- The collector current I_C of a thyristor is related in general to the emitter current I_E & the leakage current of the collector-base junction, I_{CBO} as

$$I_C = \alpha I_E + I_{CBO} \quad \text{——— (1)}$$

and the common base current gain is defined as $\alpha = \frac{I_C}{I_E}$.

- For transistor Q_1, the emitter current is the anode current I_A & the collector current I_{C1} can be found from eq. (1)

$$I_{C1} = \alpha_1 I_{E1} + I_{CBO1}$$

$$I_{C1} = \alpha_1 I_A + I_{CBO1} \quad \text{——— (2)}$$

where α_1 - current gain & I_{CBO1} → leakage current of Q_1

- Similarly for transistor Q_2, the transistor Q_2, the collector current I_{C2} is

$$I_{C2} = \alpha_2 I_K + I_{CBO2} \quad \text{—— (3)}$$

where α_2 is the current gain & I_{CBO2} — leakage current of Q_2

- By combining I_{C1} & I_{C2}, we get

$$I_A = I_{C1} + I_{C2}$$

$$I_A = \alpha_1 I_A + I_{CBO1} + \alpha_2 I_K + I_{CBO2} \quad \text{—— (4)}$$

For gating current of I_G, $I_K = I_A + I_G$ & solving eqn. (4) for I_A gives

Anode Current,
$$I_A = \frac{\alpha_2 I_G + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$

Q5) b) The latching current for SCR inserted in between a DC voltage source of 200 V and load is 100 mA. Calculate the minimum width gate pulse current required to turn on SCR in case load consist of i) L = 0.2 H & ii) R = 20 Ω in series with L = 0.2 H. (10 Marks)

Ans: W.K.T

thyristor current, $i(t) = \frac{V_s}{R}\left[1 - e^{-tR/L}\right]$

i) In case (1) where R = 0, it becomes a pure inductive load

$$\therefore i(t) = \frac{V_s}{L}(t)$$

$$\therefore 100 \times 10^{-3} = \frac{200}{0.2} \times t$$

$$\therefore t = 100 \mu s$$

This means minimum pulse width is 100 μs for successful turn ON of SCR.

ii) Load is $R = 20\Omega$ in series with $L = 0.2\,H$

here $i(t) = \frac{V_s}{R}\left(1 - e^{-t \times \frac{R}{L}}\right)$

$$100 \times 10^{-3} = \frac{200}{20}\left(1 - e^{-t \times \frac{20}{0.2}}\right)$$

solving for t, we get

$t = 100.5\ \mu S$

∴ The minimum width of pulse to turn on SCR successfully is 100.5 μS.

Q6) a) With a help of neat diagram and waveform, explain RC firing circuit used with half controlled rectifier. (10 Marks)

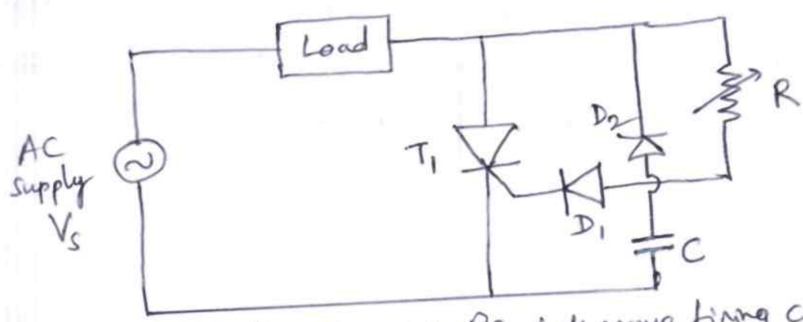


Fig. 6)a)(i) : RC half wave firing circuit

- The above fig. shows the RC firing circuit. In the negative half cycle, the capacitor charges through diode D_2 to negative supply voltage. The capacitor charges to $-V_m$.
- The capacitor then discharges through the resistance R during the positive half cycle of the supply. The thyristor triggers when capacitor charges to value greater than $V_{g(min)}$.
- The diode D_1 prevents the negative capacitor voltage appearing to gate of the thyristor. The triggering angle can be controlled from 0° to 180°.
- For zero output the following relation holds:

$$RC \geq \frac{1.3}{2f}$$

- Here 'f' is supply frequency. Since triggering is controlled only in half cycle of the supply, this circuit is also called half wave RC firing circuit.

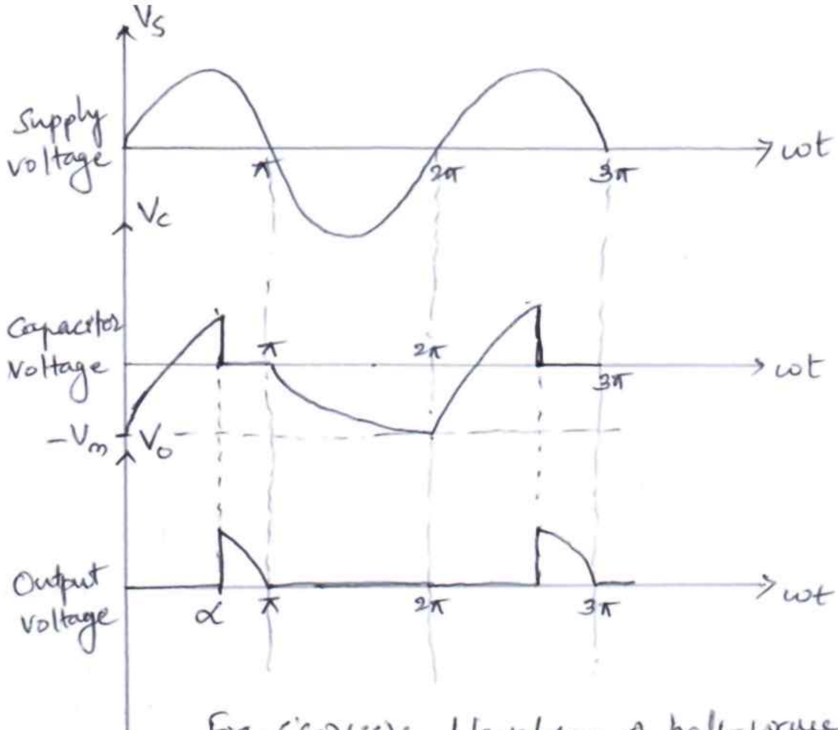


Fig. 6(a)(ii): Waveforms of half wave RC firing circuit

Q>6> b> Design the UJT triggering circuit for SCR. Given $V_{BB} = 20V$, $\eta = 0.6$, $I_p = 10\mu A$, $V_v = 2V$, $I_v = 10mA$. The frequency of oscillation is 100 Hz. The triggering pulse width should be 50 μS. (10 Marks)

Ans: here $f = 100$ Hz

$$\therefore T = \frac{1}{f} = \frac{1}{100}$$

W.K.T $T = R_C C \ln\left(\frac{1}{1-\eta}\right)$

Substituting values in above equation

$$\frac{1}{100} = R_C C \ln\left(\frac{1}{1-0.6}\right)$$

$$\therefore R_C C = 0.0109135$$

Let us select $C = 1\mu F$, then R_C will be

$$R_C = \frac{0.0109135}{1 \times 10^{-6}} = 10.91\,k\Omega$$

The peak voltage is given as, $V_p = \eta V_{BB} + V_D$

Let $V_D = 0.8$ & substituting other values

$$V_p = 0.6 \times 20 + 0.8 = 12.8\,V$$

The min. value of R_C can be calculated from eqn.

$$R_{C(min)} = \frac{V_{BB} - V_v}{I_v} = \frac{20-2}{10 \times 10^{-3}} = 1.8\,k\Omega$$

Value of R_2 can be calculated from eqn.

$$R_2 = \frac{10^4}{\eta V_{BB}} = \frac{10^4}{0.6 \times 20} = 833.33\,\Omega$$

Here the pulse width is given, i.e 50 μS.

Hence, value of R_1 will be,

$$\tau_2 = R_1 C$$

The width $\tau_2 = 50\,\mu S$ and $C = 1\,\mu F$, hence above eq^n becomes

$$50 \times 10^{-6} = R_1 \times 1 \times 10^{-6}$$

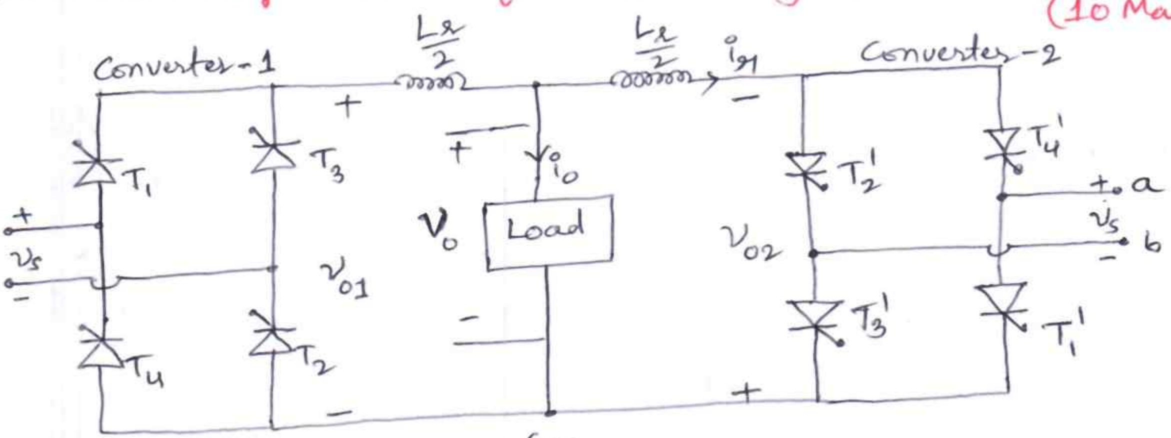
$$\therefore R_1 = 50\,\Omega$$

Thus we obtained the values of components of UJT triggering circuit as

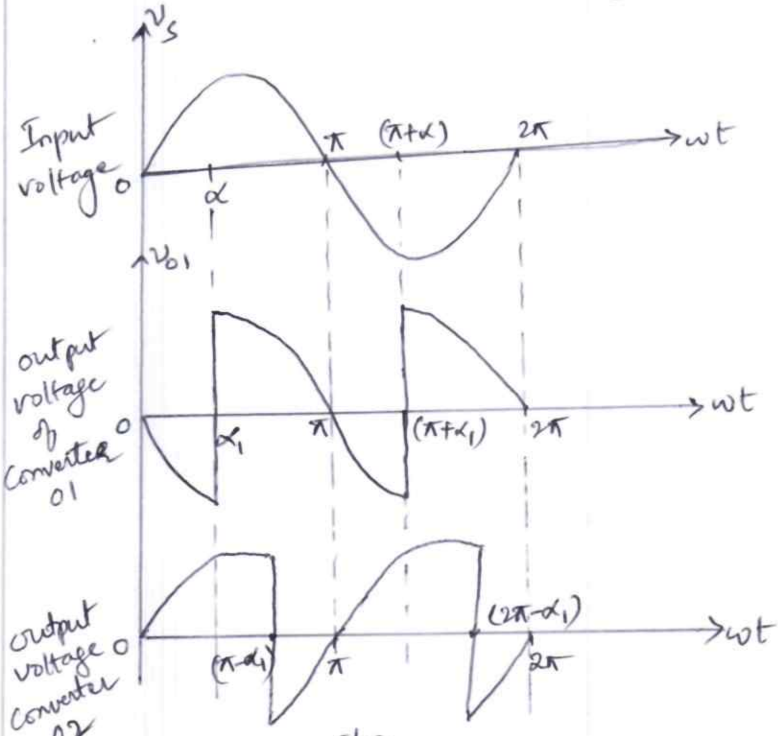
$R_1 = 50\,\Omega$, $R_2 = 833.3\,\Omega$

$R_c = 10.91\,k\Omega$, $C = 1\,\mu F$

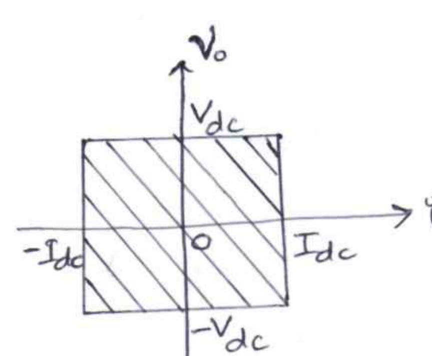
Q7 a) With a neat diagram & waveform explain single phase dual converter. (10 Marks)



(a)



(b)



(c)

Fig. 7 (a) Single phase dual converter (a) Circuit diagram (b) Waveforms & (c) Quadrant diagram.

- If two full converters are connected back to back both the output voltage and the load current flow can be reversed. The system provides four quadrant operation and is called a dual converter.
- If α_1 & α_2 are the delay angles of converters 1 & 2, respectively, the corresponding average output voltages are V_{dc1} & V_{dc2}.
- The average output voltages are

$$V_{dc1} = \frac{2V_m}{\pi}\cos\alpha_1 \quad \& \quad V_{dc2} = \frac{2V_m}{\pi}\cos\alpha_2$$

because one converter is rectifying and the other one is inverting

$$V_{dc1} = -V_{dc2} \quad \underline{\text{or}} \quad \cos\alpha_2 = -\cos\alpha_1 = \cos(\pi-\alpha_1)$$

Therefore, $\alpha_2 = \pi - \alpha_1$

Q 7> b> A single phase halfwave converter is operated from 120V, 50Hz supply and the load resistance of 10Ω. If average output is 25% of the maximum possible average output voltage calculate: i) Delay angle
ii) The rms & average o/p current iii) The rms & average thyristor current
iv) The input power factor. (10 Marks)

Ans: Given data: $V_s = 120V \rightarrow V_m = \sqrt{2}\times 120 = 169.7\ V$

$R = 10\Omega$

Avg. output voltage, $V_{o(av)} = 25\%$ of $V_{o(av)\,max}$

i) To obtain delay angle, α

$$V_{o(av)} = \frac{V_m}{2\pi}(1+\cos\alpha)$$

$V_{o(av)}$ will be maximum at $\alpha = 0$

Hence $V_{o(av)max} = \frac{2V_m}{2\pi} = \frac{V_m}{\pi} = \frac{169.7}{\pi} = 54\ V$

$\therefore V_{o(av)} = 25\%\ V_{o(av)max} = 0.25\times 54 = 13.5\ V$

Consider again $V_{o(av)} = \frac{V_m}{2\pi}(1+\cos\alpha)$

$$13.5 = \frac{169.7}{2\pi}(1+\cos\alpha)$$

$\therefore \alpha = 120^\circ$

ii) To obtain rms and average output currents

Average output current is given as

$$I_{o(av)} = \frac{V_{o(av)}}{R} = \frac{13.5}{10} = 1.35\text{ A}$$

RMS value of o/p voltage is given by

$$V_{o(rms)} = \frac{V_m}{2}\left[1 - \frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}\right]^{1/2} = \frac{169.7}{2}\left[1 - \frac{2.09}{\pi} + \frac{\sin(2\times 2.09)}{2\pi}\right]^{1/2} = 37.7\text{ V}$$

∴ RMS output current will be

$$I_{o(rms)} = \frac{V_{o(rms)}}{R} = \frac{37.7}{10} = 3.77\text{ A}$$

iii) RMS & avg thyristor currents

here rms & average values of thyristor current will be same, therefore,

$$I_{T(av)} = I_{o(av)} = 1.35\text{ A}$$

$$I_{T(rms)} = I_{o(rms)} = 3.77\text{ A}$$

iv) To obtain input power factor

here $I_{s(rms)} = I_{o(rms)} = 3.77$ A

Total supply power $= V_{s(rms)} I_{s(rms)} = 120 \times 3.77 = 452.4$ VA

The active load power will be $= \frac{V_{o(av)}^2}{R} = \frac{(13.5)^2}{10} = 18.225$

$$\text{Power factor} = \frac{\text{Active load power}}{\text{Total supply power}} = \frac{18.225}{452.4} = 0.04\ (\text{lagging})$$

Q 8) a) With neat circuit and waveform, explain the operation of single phase bidirectional AC voltage controller with resistive load. Obtain the equation for output voltage (10 Marks)

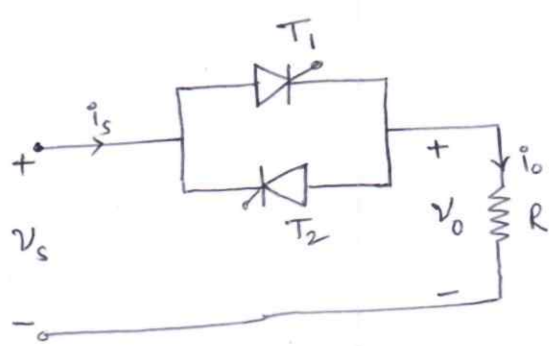


Fig. 8(a)(i) : Circuit diagram

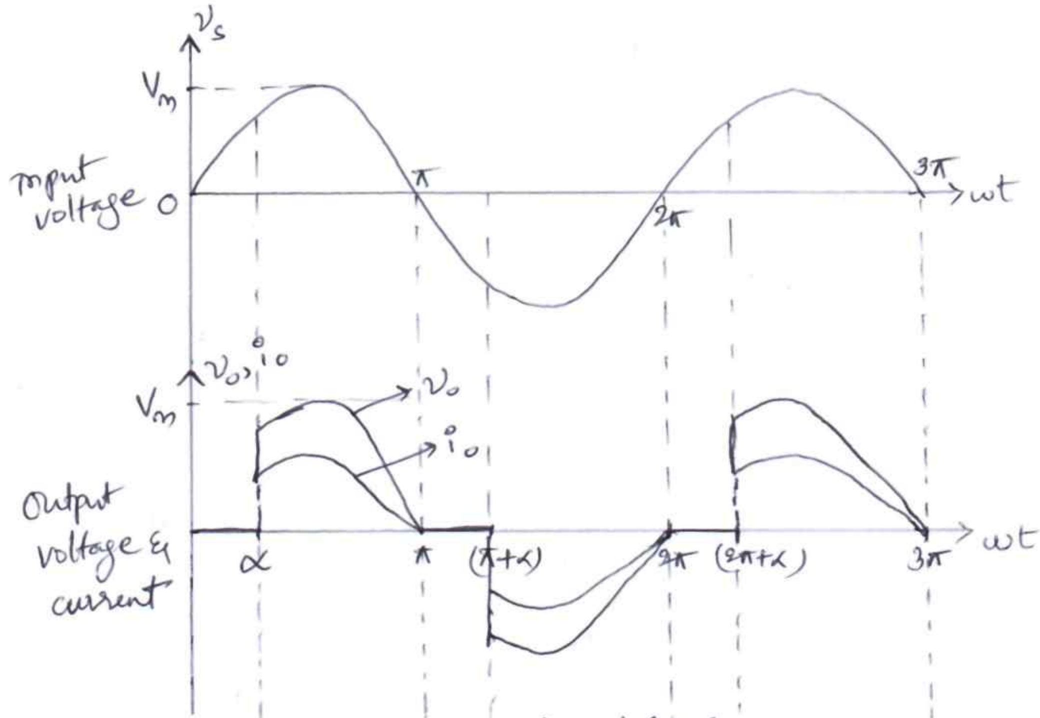


Fig. 8(a)(ii): Waveforms

- A single phase full wave controller with a resistive load is shown in above fig. During positive half cycle of input voltage, the power flow is controlled by varying the delay angle of thyristor T_1; thyristor T_2 controls power flow during the negative half cycle of input voltage.
- If $v_s = \sqrt{2} \cdot V_s \sin \omega t$ is the input voltage and the delay angle of thyristors T_1 & T_2 are equal ($\alpha_2 = \pi + \alpha_1$). The rms output voltage can be found from

$$V_o = \left\{ \frac{2}{2\pi} \int_{\alpha}^{\pi} 2 V_s^2 \sin^2 \omega t \cdot d\omega t \right\}^{1/2}$$

$$V_o = \left\{ \frac{4V_s^2}{4\pi} \int_{\alpha}^{\pi} (1 - \cos 2\omega t) \cdot d\omega t \right\}^{1/2}$$

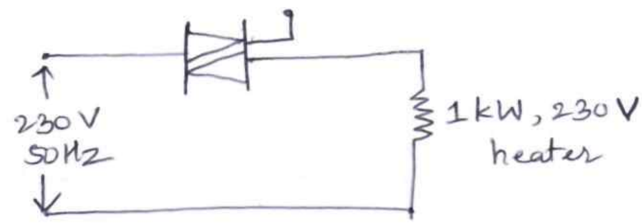
$$V_o = V_s \left[\frac{1}{\pi} \left(\pi - \alpha + \frac{\sin 2\alpha}{2} \right) \right]^{1/2}$$

By varying the firing angle, α from 0 to π, V_o can be varied from V_s to 0.

- The gating circuits for thyristors T_1 & T_2 must be isolated. It is possible to have a common cathode for T_1 & T_2 by adding two diodes in the circuit.

Q8) b) The single phase full wave AC voltage controller operates on single phase supply voltage of 230 V rms at 50 Hz. If the triac is triggering at a delay angle of 45°, during each half cycle of Input supply. Calculate

i) RMS value of output voltage
ii) RMS value of current through heater
iii) Average value of triac current and RMS
iv) Input power factor (10 Marks)



Ans:

Given: $V_s = 230\ V \quad \therefore V_m = 230\sqrt{2}$

$\alpha = 45°$ i.e $\pi/4$

i) To obtain $V_{0(rms)}$

The rms value of o/p voltage is given by

$$V_{0(rms)} = V_m \sqrt{\frac{\pi - \alpha + \frac{\sin 2\alpha}{2}}{2\pi}} = 230\sqrt{2}\sqrt{\frac{\pi - \pi/4 + \frac{\sin(2\pi/4)}{2}}{2\pi}} = 219.3\ V$$

ii) To obtain rms value of output current

Resistance of heater coil will be

$$R_L = \frac{230^2}{1000} = 53\ \Omega$$

hence rms current through heater will be

$$I_{0(rms)} = \frac{V_{0(rms)}}{R_L} = \frac{219.3}{53} = 4.137\ A$$

iii) Average value of triac current

The output current, triac current and supply current are same. Since the '+ve & '-ve half cycles of current flowing through triac are symmetric, the average value is zero.

iv) RMS value of triac current

The triac current is same as output current

$$\therefore I_{T(rms)} = I_{0(rms)} = 4.137\ A$$

v) To obtain input PF.

Active load power $= I_{O(rms)}^2 R_L = 4.137^2 \times 53 = 907\ W$

Supply current is same as output current

$I_{s(rms)} = I_{O(rms)} = 4.137\ A$

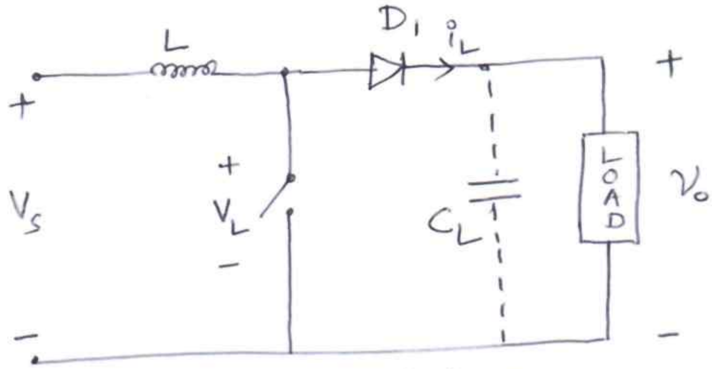
$\therefore$ Total rms input power $= V_{s(rms)} \times I_{s(rms)} = 230 \times 4.137$

$= 951.5\ VA$

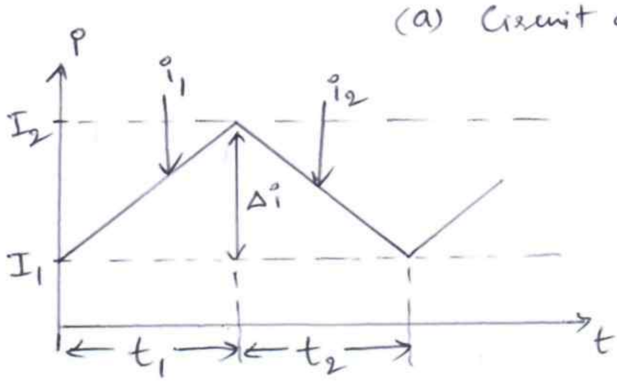
$\therefore$ The input power factor will be

$$P.F = \frac{\text{Active load power}}{\text{Total input power}} = \frac{907}{951.5} = 0.953$$

Q9) a) Explain the principle of operation of a step-up chopper with suitable circuit diagram and waveform. Derive the expression for average output voltage. (10 Marks)

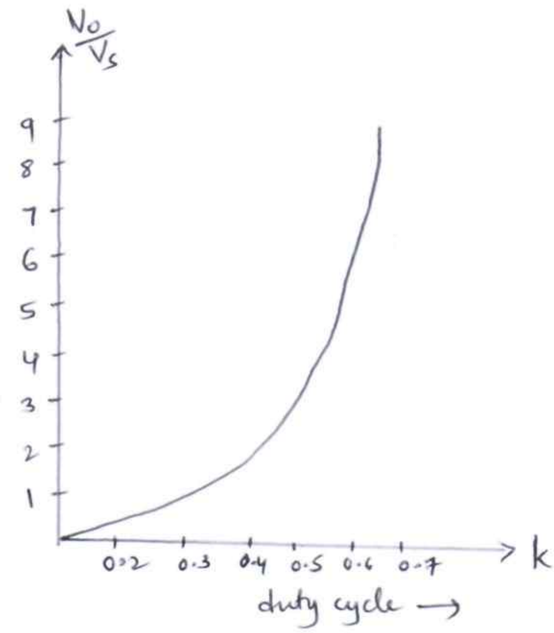


(a) Circuit diagram



(b) Current waveform

Fig. 9(A): Stepup Chopper



(c) output voltage

- A converter can be used to step up a DC voltage and an arrangement for step up operation is shown in fig. When switch 'SW' is closed for time 't_1' the inductor current rises and energy is stored in the inductor 'L'. If the switch is opened for time t_2, the energy stored in the inductor is transferred to load through diode D_1 & the inductor current falls. Assuming a continuous current flow, the waveform for the inductor current is shown in fig.

- When the converter is turned on, the voltage across the inductor is

$$v_L = L \cdot \frac{di}{dt}$$

and this gives the peak to peak ripple current in the inductor as

$$\Delta I = \frac{V_s}{L} \cdot t_1$$

The average output voltage is

$$v_0 = V_s + L \cdot \frac{\Delta I}{t_2} = V_s\left(1 + \frac{t_1}{t_2}\right) = V_s\left(\frac{1}{1-k}\right)$$

where $k \rightarrow$ duty cycle

Q9) b) A step up chopper is 200V. The output required is 600 V. If the conducting time of thyristor is 200 μS. Compute i) Chopping frequency ii) If pulse width is halved for constant frequency of operation, find the new output voltage. (10 Marks)

Ans: Given data: $V_s = 200V$, $V_{o(av)} = 600\ V$, $T_{on} = 200\ \mu S$

i) To obtain chopping frequency

for step up chopper, $V_{o(av)} = \frac{V_s}{1-k}$

$$600 = \frac{200}{1-k}$$

$$k = 0.6667$$

The duty cycle 'k' is given as, $k = \frac{T_{on}}{T}$

$$= f\, T_{on} \quad \text{since } f = \frac{1}{T}$$

$$\therefore f = \frac{\delta}{T_{on}} = \frac{0.6667}{200 \times 10^{-6}} = 3.3\ kHz$$

where $f \rightarrow$ chopping frequency

ii) To obtain new output voltage

$$T = \frac{1}{f} = \frac{1}{3333.33} = 300\,\mu S$$

the T_{on} pulse width is halved. Hence new T_{on} will be $\frac{200\mu S}{2} = 100\mu S$

Hence duty cycle will be,

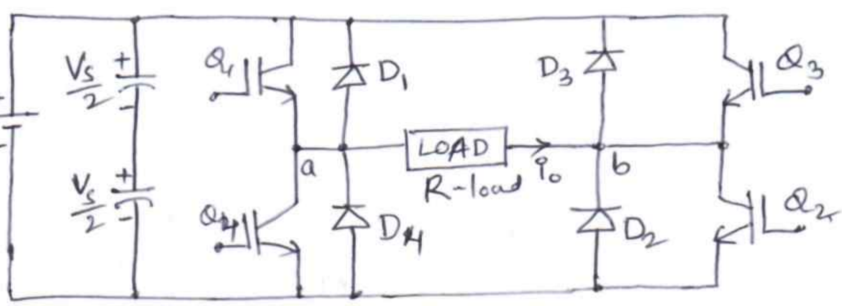
$$k = \frac{T_{on}}{T} = \frac{100\times10^{-6}}{300\times10^{-6}} = 0.3333$$

The new output voltage of chopper will be

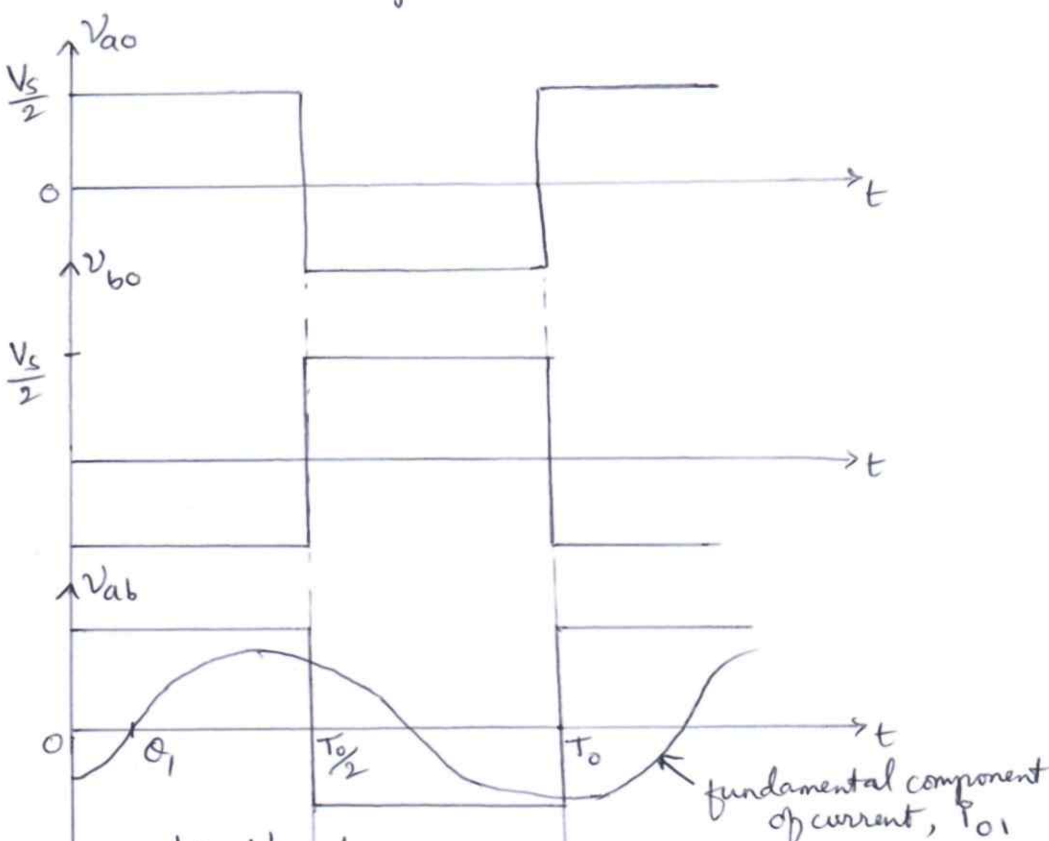
$$V_{O(av)} = \frac{V_s}{1-k} = \frac{200}{1-0.3333} = 300\,V$$

Thus the output voltage is also reduced by half.

Q 10> a> With circuit diagram, explain the operation of 1-ϕ full bridge inverter with R-load. (10 Marks)



(a) Circuit diagram



(b) Waveforms

- A single phase full bridge inverter is shown in figure. It consists of four choppers. When transistors Q_1 & Q_2 are turned on simultaneously the input voltage V_s appears across the load. If transistors Q_3 & Q_4 are turned on at the same time, the voltage across the load is reversed and is $-V_s$. The waveforms for the output voltage is also shown in fig.

- RMS value of output voltage (fundamental component) is given by

$$V_{01} = \frac{4V_s}{\sqrt{2}\pi} = 0.90 V_s$$

- the instantaneous load current i_0 for an RL load becomes

$$i_0 = \sum_{n=1,3,5}^{\infty} \frac{4V_s}{n\pi\sqrt{R^2+(n\omega L)^2}} \sin(n\omega t - \theta_n)$$

where $\theta_n = \tan^{-1}(n\omega L/R)$.

Q 10) b) The single phase full bridge inverter has a resistance load of 2.4 Ω & DC input voltage of 48 V. Determine
i) rms output voltage at fundamental frequency
ii) The output ~~supply~~ power
iii) The peak & average currents of each transistor (10 Marks)

Ans: Given: $V_s = 48$ V, $R = 2.4\,\Omega$

i) To determine rms value of the fundamental

fundamental component is given by $V_1 = 0.9\,V_s = 0.9 \times 48 = 43.2$ V

ii) To determine output power

rms output voltage is, $V_{o(rms)} = V_s = 48$ V

∴ output power can be calculated as,

$$P_o = \frac{V_{o(rms)}^2}{R}$$

$$= \frac{48^2}{2.4} = 960 \text{ W}$$

iii) To determine transistor currents

peak transistor current is given by

$$i_{T(peak)} = \frac{V_s}{R} = \frac{48}{2.4} = 20\ A$$

Each transistor current is a square wave of duty cycle 0.5.
Hence average transistor current will be equal to average value of square wave i.e

$$i_{T(av)} = i_{T(peak)} \times \text{duty cycle}$$

$$i_{T(av)} = 20 \times 0.5$$

$$i_{T(av)} = 10\ A$$

Prof. Kirankumar H.

HEAD
Dept. of Electrical & Electronics Engg
KLS's V. D. Institute of Technology
HALIYAL-581 329.

Dean, Academics
KLS VDIT, HALIYAL