CBCS SCHEME

USN

18EE53

Fifth Semester B.E. Degree Examination, June/July 2023
Power Electronics

Time: 3 hrs. Max. Marks: 100

Note: Answer any FIVE full questions, choosing ONE full question from each module.

Module-1

1 a. Explain the various types of power electronic converters with the help of circuit diagram, input and output waveforms. **(10 Marks)**

b. With the help of suitable waveforms, explain the reverse recovery characteristics of power diode. Define reverse recovery time and derive equations for t_{rr} and I_{rr}. **(10 Marks)**

OR

2 a. With the help of circuit diagram and waveform, explain the single phase full wave rectifier with 'R' load. **(06 Marks)**

b. With the help of circuit diagram and waveforms, Explain the operation of single phase diode rectifier feeding resistive load. Derive expression for average output voltage and rms value of output voltage. **(10 Marks)**

c. The reverse recovery time or a diode is 3μs and rate of fall of current is 30A/μs. Calculate:
i) Storage charge ii) Peak reverse current. **(04 Marks)**

Module-2

3 a. Explain steady state and switching characteristics of MOSFET. **(08 Marks)**

b. Explain the anti saturation control of BJT with the help of suitable circuit diagram and equations. **(06 Marks)**

c. Give a comparision between BJT, MOSFET and IGBT. **(06 Marks)**

OR

4 a. Explain the steady state and switching characteristics of BJT. **(09 Marks)**

b. Explain the switching limits. **(06 Marks)**

c. Explain the gate drive circuit of MOSFET with the help of circuit diagram. **(05 Marks)**

Module-3

5 a. Explain the V-I characteristics of SCR with the help of graph indicating all necessary details. Also define: i) Latching current ii) Holding current. **(08 Marks)**

b. Explain various method of turning on of a SCR. **(06 Marks)**

c. Design a SCR triggering circuit using UJT. The parameters of UJT are $V_s = 30V$, $\eta = 0.66$, $I_p = 15\mu A$, $V_v = 3V$ and $I_v = 10mA$. The frequency of oscillations is $f = 500Hz$ and width of gate pulse if $t_g = 30\mu s$. Assume $V_D = 0.5V$ and $C = 0.5\mu F$. **(06 Marks)**

OR

6 a. Derive an expression for the anode current of SCR with the help of two transistor analogy. **(06 Marks)**

b. Explain in brief why two thyristors of same rating when connected in parallel do not share equal currents. Suggest a method to equalize the currents and explain. **(06 Marks)**

c. Explain UJT triggering circuit for full control of SCR with waveforms. **(08 Marks)**

Module-4

7 a. Explain the operation of single phase half wave rectifier with RLE load. Draw relevant circuit diagram and waveforms. **(08 Marks)**

b. Explain the operation of single phase full wave ac voltage controller with inductive load. Draw the circuit diagram and waveforms. **(06 Marks)**

c. A single phase fully controlled bridge rectifier circuit is used for obtaining a regulated dc output voltage. The rms value of the ac input voltage is 230V and firing angle is maintained at $\pi/3$. So that the load current is 4A. Calculate:
i) DC output voltage
ii) Active power output
iii) Load resistance. **(06 Marks)**

OR

8 a. With the help of circuit diagram and waveforms, explain the working of integral cycle (on-off) control of ac voltage controller feeding resistive load. Derive an expression for rms output voltage. **(08 Marks)**

b. With the help of suitable circuit and waveforms. Explain the working of single phase dual converter circulating current mode of operation. **(07 Marks)**

c. Find the power consumed in the heater element if both SCRs are fired with delay angle of 45° for the Fig.Q.8(c). **(05 Marks)**

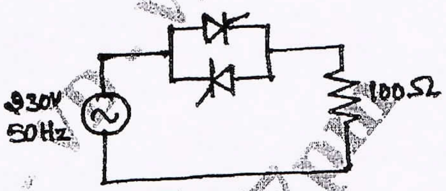

Fig.Q.8(c)

Module-5

9 a. With the help of schematic diagram and waveforms, explain the operation of step up chopper with RL load. Derive an expression for average output voltage. **(08 Marks)**

b. Explain the working of single phase bridge inverter feeding resistive load. Draw the circuit diagram and waveforms. **(06 Marks)**

c. A step up chopper has input voltage of 220V and output voltage of 660V. If the conducting time of chopper is 100μs, calculate turn off time of output voltage. In case output voltage pulse width is halved for constant frequency operation, find the average value of new output voltage. **(06 Marks)**

OR

10 a. Explain the performance parameters of DC-DC converters. **(06 Marks)**

b. Explain the construction and working of transistorized current source inverter. Draw the circuit diagram and waveforms. **(08 Marks)**

c. The DC-DC converter has a resistive load of R = 10Ω and the input voltage is $V_s = 220V$. When the converter switch remains on, its voltage drop $V_{ch} = 2V$ and the chopping frequency is f = 1kHz. If the duty cycle is 50%. Calculate:
i) Average output voltage
ii) Rms output voltage
iii) Converter efficiency. **(06 Marks)**

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Question Paper Solution of Power Electronics (18EE53)
VTU Degree Examination June/July 2023

Prepared By: Prof. Kirankumar H.

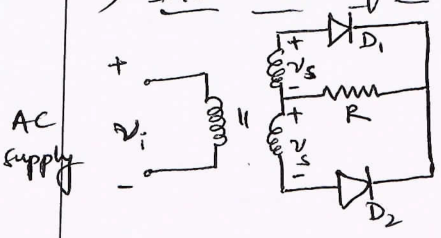
Module 01

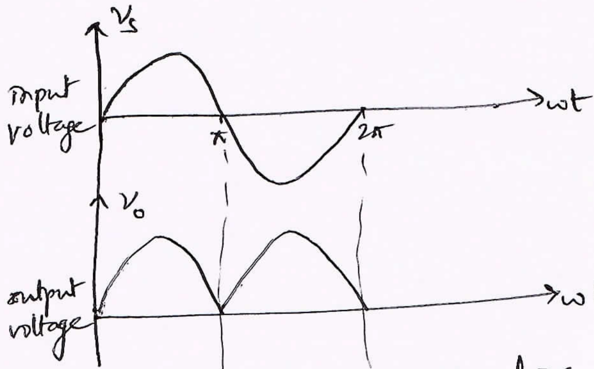
1) a) Explain the various types of power electronic converters with the help of circuit diagram, input and output waveforms (10 marks)

The power electronic circuits can be classified into five types

a) Diode rectifiers
b) AC-DC converters (controlled rectifiers)
c) AC-AC converters (AC voltage controllers)
d) DC-DC converters (DC choppers)
e) DC-AC converters (Inverters)

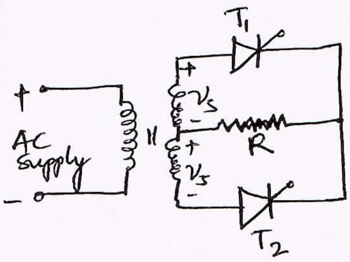
a) Diode rectifiers:

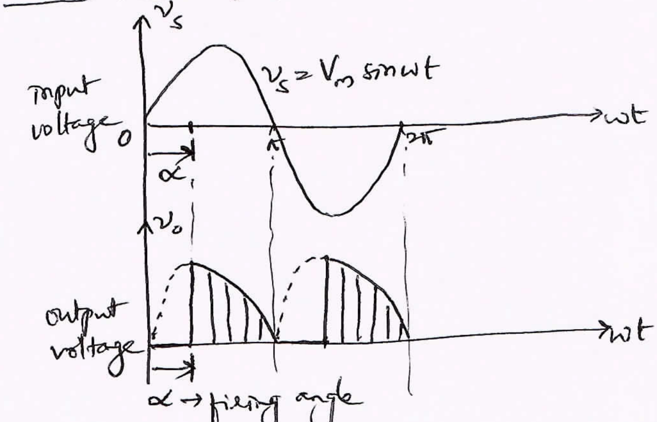




- A diode rectifier circuit converts AC voltage into a fixed DC voltage. The input voltage to the rectifier, v_i could be either 1-ϕ or 3-ϕ.

b) AC-DC Converters (Controlled Rectifiers):





- A single phase converter with two natural commutated thyristors is shown above circuit diagram. The average value of the o/p voltage V_o can be controlled by varying the conduction time of thyristors or firing delay (angle) 'α'. The input could be single phase or 3-phase source. These converters are also known as controlled rectifiers.

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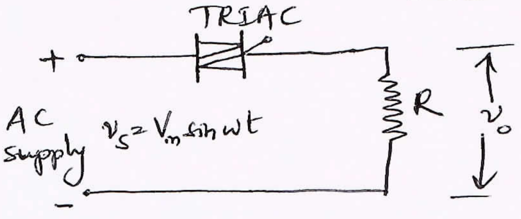
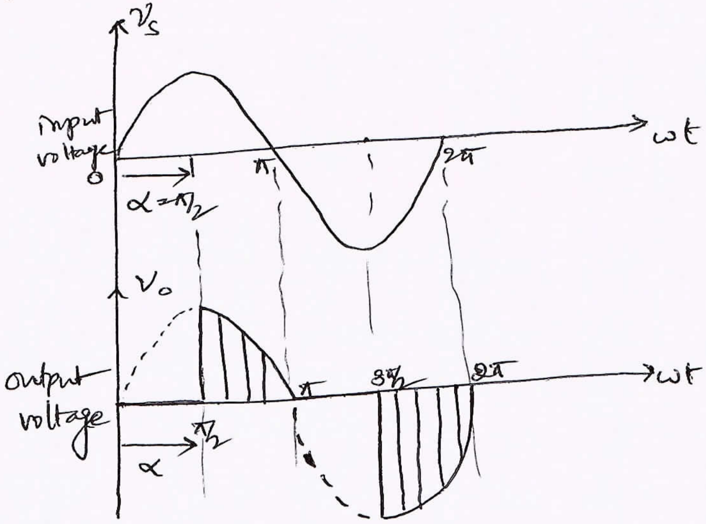
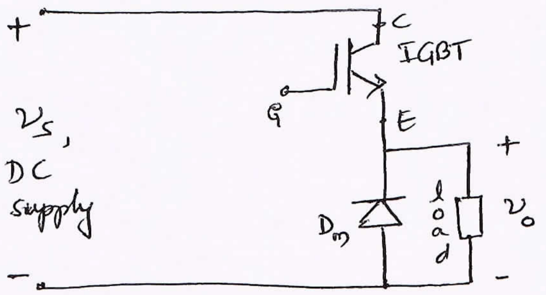
c) AC-AC Converters (AC voltage controllers) :

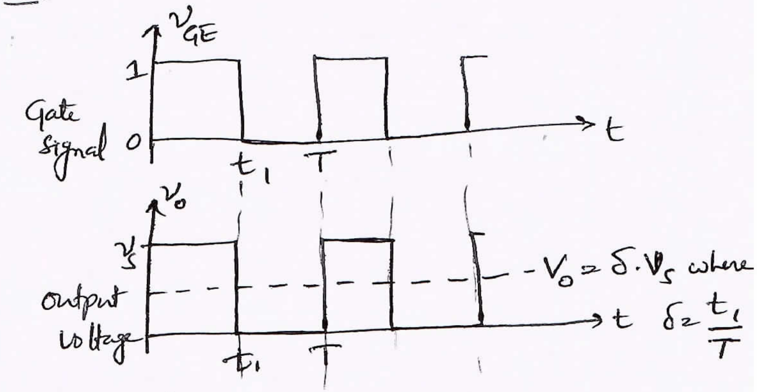




- These converters are used to obtain a variable AC o/p voltage v_o from fixe AC source and a single phase source with a TRIAC is shown in circuit diagram. The o/p voltage is controlled by varying the conduction time of a TRIAC or firing delay angle, α. These converters are also known as AC voltage controllers.

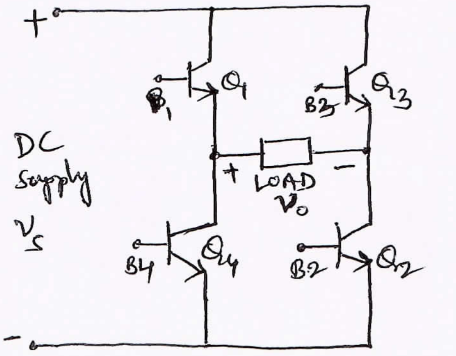
d) DC-DC Converters (DC Choppers)

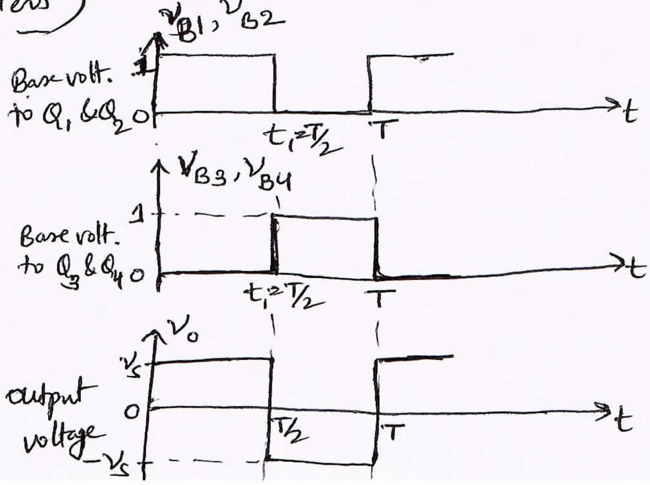




- A DC-DC converter is also known as a chopper or switching regulator. The average output voltage V_o is controlled by varying the conduction time t_1 of transistor Q_1. If the time period is 'T' (chopping period) then $t_1 = \delta \cdot T$. 'δ' is called as the duty cycle of the chopper.

e) DC-AC Converters (Inverters)





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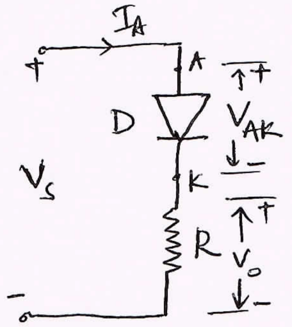
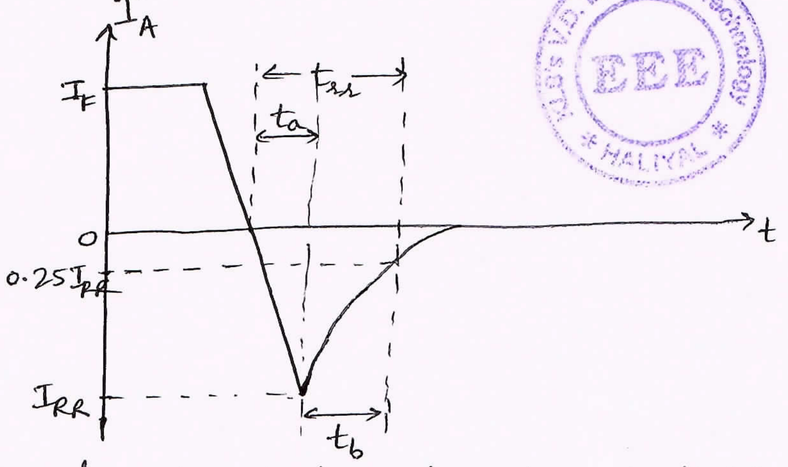
- A DC-AC converter is also known as an inverter. A single phase transistor inverter is shown in circuit diagram. If transistor (BJT) Q_1 & Q_2 conduct for one half of a period and Q_3 & Q_4 conduct for another half, the o/p voltage is of the alternating form. The output voltage can be controlled by varying the conduction time of transistors.

1) b) With a help of suitable waveforms, explain the reverse recovery characteristics of power diode. Define reverse recovery time and derive equations for t_{rr} & I_{RR}. (10 marks)





- The current in a forward biased junction diode is due to the net effect of majority and minority carriers.
- Once a diode is in a 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 charges and to be neutralized. This time is called the reverse recovery time of the diode.

- The above fig. shows the reverse recovery characteristics of junction diodes. The soft recovery type is more common. The reverse recovery time 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}' consists of two components, 't_a' & 't_b'

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

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The 't_b' is due to charge storage in the bulk semiconductor material. The
't_b / t_a' is known as the softeness factor (SF).

- For practicle purpose one needs to be concerned with the total recover time 't_{rr}' and the peak value of the reverse current 'I_{RR}'.

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

- The peak reverse current can be expressed in reverse '$\frac{di}{dt}$' as

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

- Also,

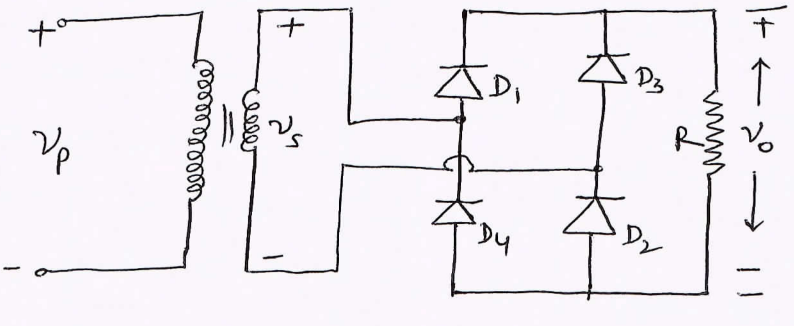
$$t_{rr} = \sqrt{\frac{2Q_{RR}}{(di/dt)}}$$ and

$$I_{RR} = \sqrt{2 \times Q_{RR} \times \left(\frac{di}{dt}\right)}$$

where 'Q_{RR}' is reverse recovery charge, which is the amount of charge carriers that flow across the diode in the reverse direction due to changeover from forward conduction to reverse blocking condition.

- These t_{rr} & I_{RR} depend on the storage charge Q_{RR} & reverse $\frac{di}{dt}$.

2) a) With a help of circuit diagram and waveform, explain the single phase full wave rectifier with 'R' load (06 marks)



Circuit diagram

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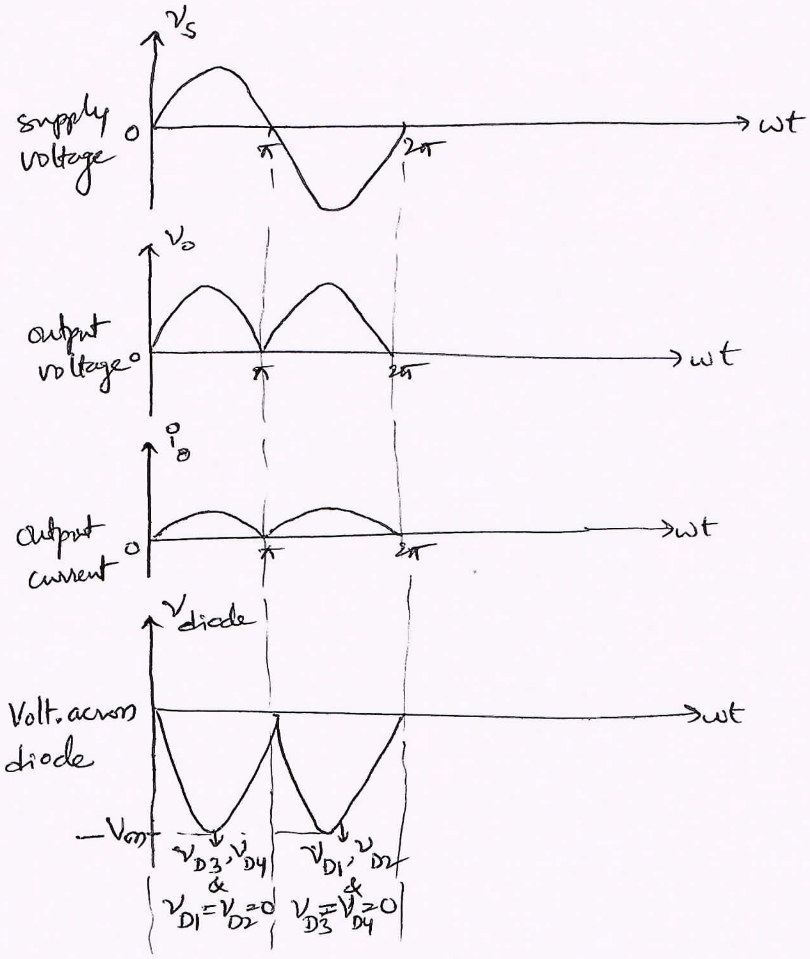

Waveforms.

- Circuit shows the bridge rectifier with R-load. There are four diodes in the circuit, hence called as bridge rectifier.
- There is no need of centre tapped transformer in this circuit.
- Diodes D_1 & D_2 conduct in positive half cycle and D_3 & D_4 conduct in the negative half cycle.
- The waveforms of output voltage, current & voltage across switch is shown above.
- The average value of output voltage is given by

$$V_{dc} = \frac{2}{T}\int_0^{T/2} V_m \sin\omega t \cdot dt = \frac{2V_m}{\pi} = 0.6366\ V_m$$

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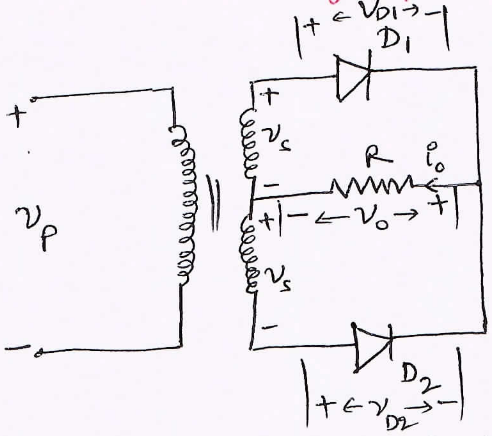
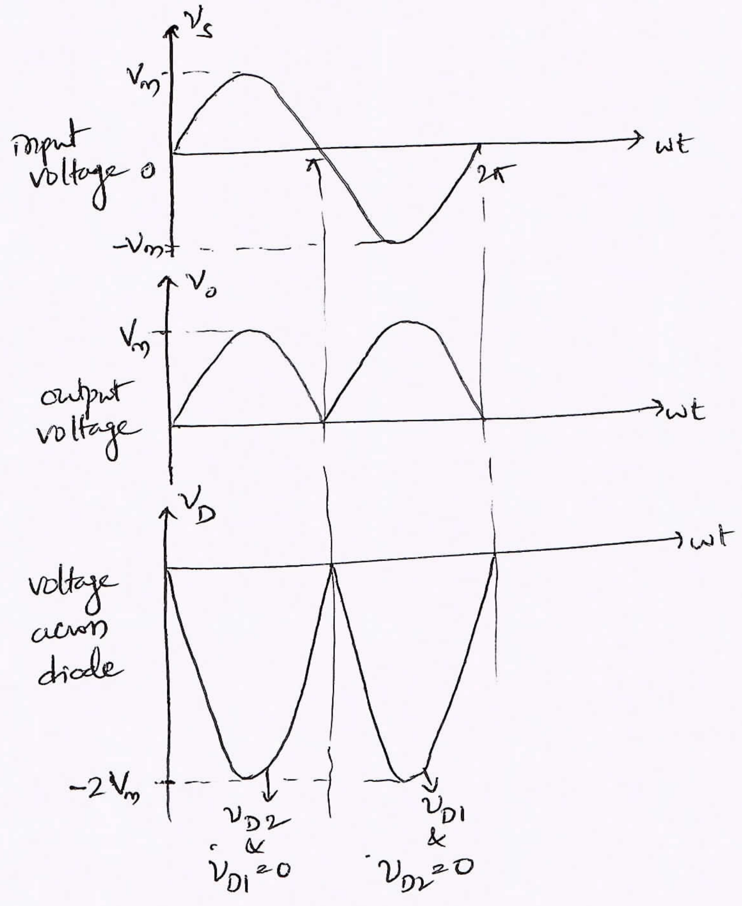
27 b) With a help of circuit diagram and waveforms, explain the operation of single phase diode rectifier feeding resistive load. Derive expression for average output voltage and rms value of output voltage. (10 Marks)



Full wave rectifier circuit with centre tapped transformer



Waveforms.

- A full wave rectifier with centre tapped transformer is shown in above circuit diagram. Each half of the transformer with its associated diode acts as a half wave rectifier and the o/p of a full wave rectifier is shown in above waveforms. Because there is no dc current flowing through the transformer, there is no dc current flowing through the transformer, there is no dc saturation problem of transformer core.

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- Diode D_1 conducts in positive half cycle of the supply voltage and diode D_2 conducts in the negative half cycle of the supply voltage. Here both the half cycles of the supply voltage are rectified.

- The average output voltage 'V_{dc}' is given by

$$V_{dc} = \frac{1}{T}\int_0^T V_o(\omega t)\cdot d\omega t$$

from the waveform we can observe that $T = \pi$ &

$$V_o(\omega t) = v_s = V_m \sin\omega t \quad \text{for } 0 \le \omega t \le \pi$$

$$\therefore V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_m \sin\omega t \cdot d\omega t$$

$$= \frac{V_m}{\pi}\left(-\cos\omega t\right)_0^{\pi}$$

$$= \frac{V_m}{\pi}\left(-\cos\pi + \cos 0\right)$$

The average output voltage.
$$\boxed{V_{dc} = \frac{2V_m}{\pi} = 0.6366\, V_m}$$

- The rms value of output voltage is given by

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

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

$$V_{rms} = \left[\frac{V_m^2}{\pi}\int_0^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right)\cdot d\omega t\right]^{1/2}$$

$$V_{rms} = \left[\frac{V_m^2}{2\pi}\left[(\pi - 0) - \left(\frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]\right]^{1/2}$$

$$V_{rms} = \left[\frac{V_m^2}{2\pi}\left(\pi - \frac{1}{2}(\underbrace{\sin 2\pi}_{0} - \underbrace{\sin 0}_{0})\right)\right]^{1/2}$$

$$V_{rms} = \left[\frac{V_m^2}{2\cancel{\pi}}\times\cancel{\pi}\right]^{1/2} = \frac{V_m}{\sqrt{2}} = 0.707\, V_m$$

$$\therefore \boxed{V_{rms} = \frac{V_m}{\sqrt{2}} = 0.707\, V_m}$$

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2) c) The reverse recovery time of a diode is 3 μS & rate of fall of current is 30 A/μS. Calculate i) Storage charge (Q_{RR}) ii) Peak reverse current (I_{RR})

Given $t_{rr} = 3\ \mu S$

$$\frac{di}{dt} = 30\ A/\mu S$$

$Q_{RR} = ?$ & $I_{RR} = ?$

W.K.T $$t_{rr} = \sqrt{\frac{2Q_{RR}}{(di/dt)}}$$

$$\therefore\ Q_{RR} = \frac{t_{rr}^2 \times (di/dt)}{2} = \frac{(3\times10^{-6})^2 \times 30\times10^6}{2} = 135\ \mu C$$ //

W.K.T

$$I_{RR} = \sqrt{2 Q_{RR} \cdot \frac{di}{dt}}$$

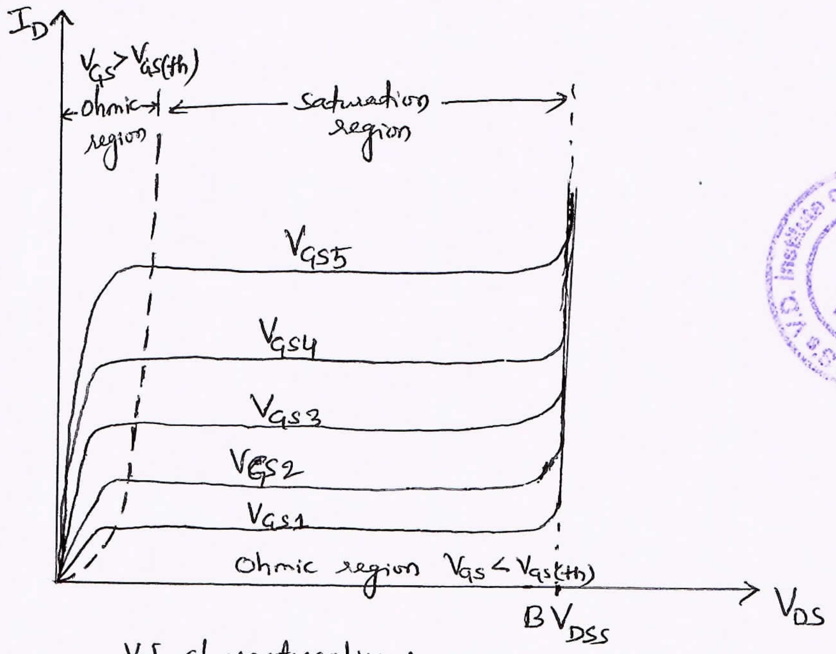
$$\therefore\ I_{RR} = \sqrt{2\times135\times10^{-6}\times30\times10^6}$$

$$I_{RR} = 90\ A$$ //

Module 02

3) a) Explain steady state and switching characteristics of MOSFET (08 Marks)

i) Steady state characteristics of MOSFETs (V-I Characteristics):



V-I characteristics of MOSFETs

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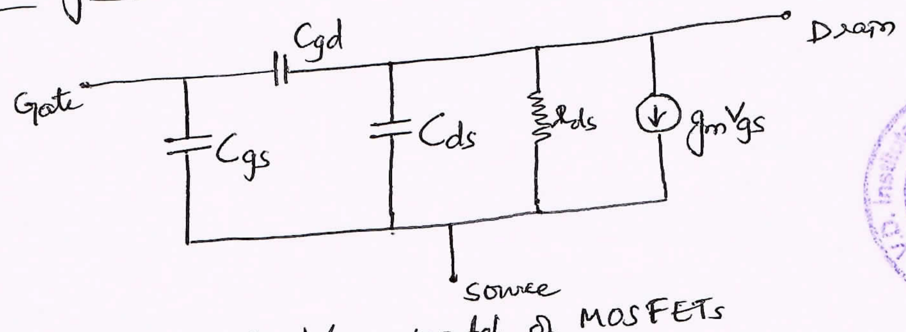
- Figure shows the V-I characteristics of n-channel enhancement type MOSFET. The drain current 'I_D' is plotted w.r.t drain to source voltage 'V_{DS}'. These characteristics are plotted for various values of gate to source voltages 'V_{GS}'. In figure we can observe 3 regions in the characteristics. ohmic region, saturation region and cut off region.

- In the cut-off region, the drain current is negligible and the MOSFET is said to be in 'OFF' state. The MOSFET is driven in cut off region by applying $V_{GS} < V_{GS(th)}$. The '$V_{GS(th)}$' is the threshold gate to source voltage. When this V_{GS} is less than threshold gate source voltage MOSFET is 'OFF' i.e. in cut off region.

- The MOSFET is driven into ohmic region when $V_{GS} >> V_{GS(th)}$. In the ohmic region the MOSFET conducts heavily.

- For switching applications, MOSFET is operated only in ohmic and cut-off regions. The 'BV_{DSS}' is the drain to source breakdown voltage, when the gate is open circuited. The MOSFET is damaged if drain to source voltage is increased above BV_{DSS}.

ii) Switching characteristics of MOSFETs:



Switching model of MOSFETs

- The internal capacitance of MOSFET affect the turn ON and turn OFF times of MOSFETs. These capacitances have no effect during steady state, which is shown in the switching model of MOSFET.

- In the figure Cgs is the gate to source capacitance and Cgd is the gate to drain parasitic capacitance. The MOSFET can be turned ON by applying positive gate voltage - source voltage.

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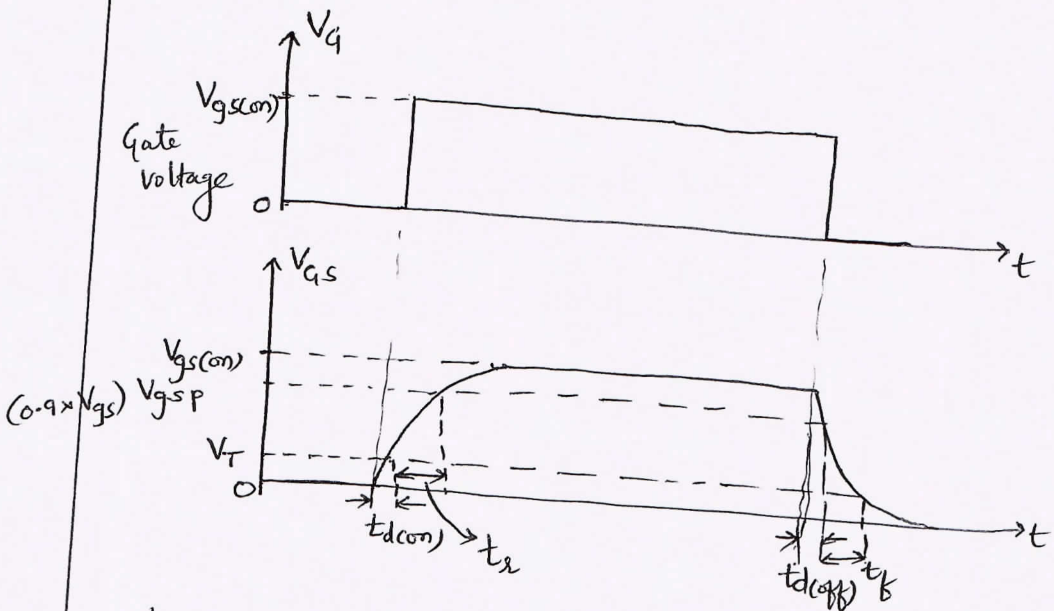

- When the gate voltage is applied C_{gs}, gate to source capacitance star charging. The turn ON delay '$t_{d(on)}$' is the time required to charge C_g to threshold voltage 'V_T'. After this voltage, the drain current 'I_D' rises. The C_{gs} charges from threshold voltage to full gate voltage 'V_{gsp}'. The time required for this charging is called rise time (t_r). The MOSFET is then said to be fully turned-ON. Thus the total turn ON time of the MOSFET is,

$$\boxed{t_{on} = t_{d(on)} + t_r}$$

- To turn OFF the MOSFET, the gate source voltage is made negative or zero. The gate to source voltage then reduces from $V_{gs(on)}$ to V_{gsp}. That is C_{gs} discharges from overdrive to pinch off region gate voltage. The time required for this discharge is called turn off delay time $t_{d(off)}$. The C_{gs} keeps on discharging and its voltage becomes equal to threshold voltage (V_T). The time required for discharging C_{gs} from V_{gsp} to V_T is called fall time (t_f). The drain current then becomes zero when $V_{gs} \leq V_T$. The MOSFET is said to be turned OFF. Thus the turn off time of MOSFET is,

$$\boxed{t_{off} = t_{d(off)} + t_f}$$

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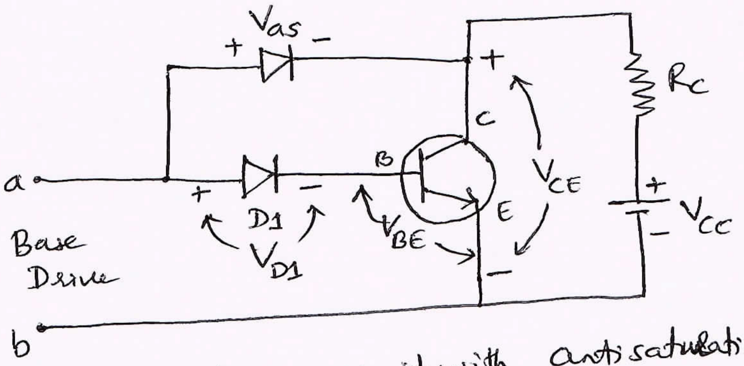
3) b) Explain the anti saturation control of BJT with the help of suitable circuit diagram and equations (06 Marks)



Base drive circuit with antisaturation diode

- We know that excess base current increases the storage time of the BJT. Hence the turn off time increases. Such excess of heavy base drive is called hard saturation. There for transistor must be operated in soft saturation. This means base must be given the carriers which are sufficient to drive the transistor in just saturation (quasi saturation).
- The above circuit diagram is designed to achieve quasi saturation. In this circuit the base drive is applied at terminals a-b. We can write following equation for loop consisting of a - D_1 - B - E - b,

$$v_{a-b} = V_{D1} + V_{BE}$$

similarly for loop a - D_{as} - C - E we can write

$$v_{a-b} = v_{Das} + v_{CE}$$

Hence equating the two equations, we get

$$v_{D1} + v_{BE} = v_{Das} + v_{CE}$$

Normally $v_{Das} = v_{D1}$. Hence above equation becomes

$$v_{CE} = v_{BE}$$

- This shows that collector emitter voltage will be equal to base emitter voltage. When BJT turns ON, the base emitter voltage is nearly 0.7 and collector emitter saturation voltage is 0.3. Because of antisaturation diode (v_{Das}), the collector emitter voltage is raised to V_{BE}, i.e 0.7 V. Hence the BJT is no longer in saturation. It is just above saturation. This effect takes place due to anti-saturation diode v_{Das}.

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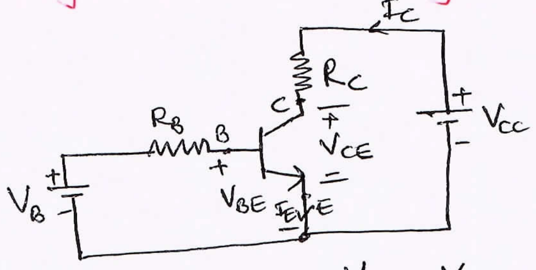
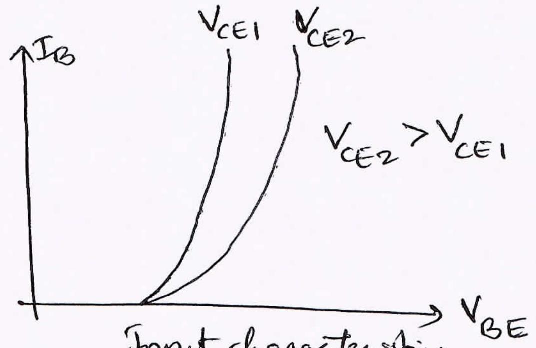
3) c) Give a comparison between BJT, MOSFET and IGBT. (06 Marks)

Sl. No.	Parameter	BJTs	MOSFETs	IGBTs
1	Type of carriers in device	Bipolar device	Majority carrier device	Majority carrier device
2	Control terminal	Base	Gate	Gate
3	ON state voltage drop	< 2 V	4 - 6 V	3.3 V
4	Switching frequency	upto 10 kHz	upto 100 kHz	upto 20 kHz
5	Current or Voltage controlled device	Current	Voltage	voltage
6	Voltage and current ratings	upto 2 kV / 1 kA	upto 1 kV/50 A	upto 1.5 kV/400
7	Snubber circuit	Polarized	Not essential	Not essential
8	Temperature coefficient	Negative	Positive	Approximately flat but positiv at high current
9	Applications	DC-AC converters, Induction motor drives, UPS, SMPS & choppers	Choppers, low power UPS, SMPS, BLDC motor drives	DC to AC converters, AC motor drives, UPS, choppers

4) a) Explain the steady state and switching characteristics of BJT. (09 Marks)





Input characteristics

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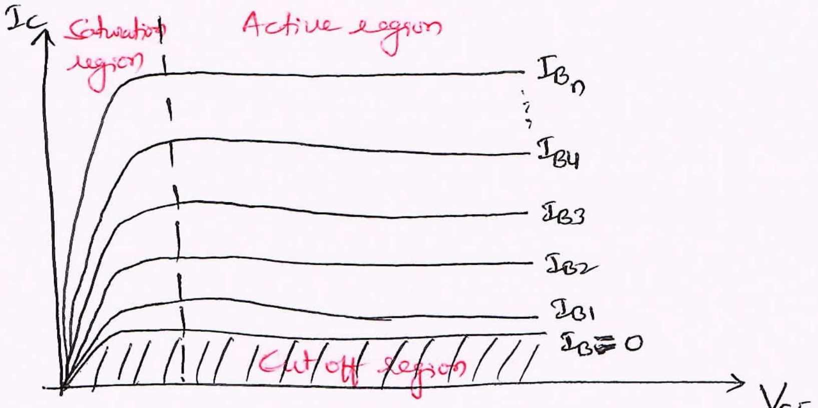
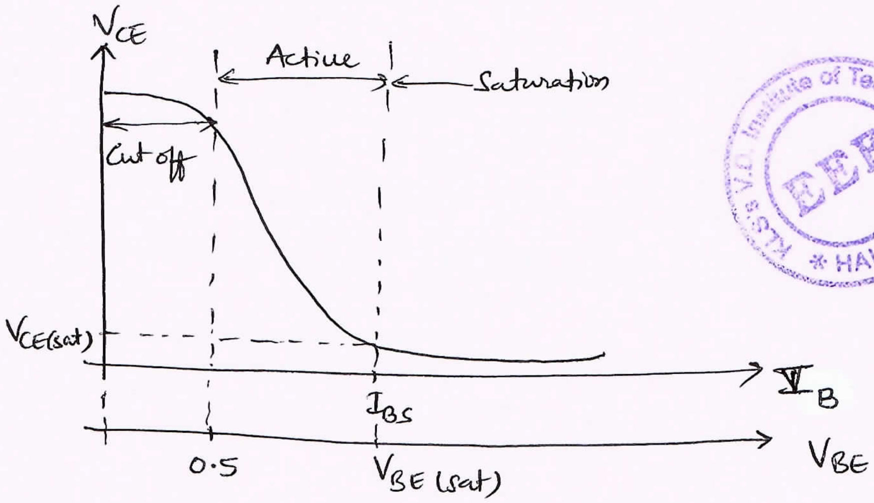


Output characteristics



Transfer characteristics

- Common emitter configuration is shown in the above circuit diagram, 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}, are shown in fig. Typical input characteristics of collector current I_C against collector-emitter voltage V_{CE}.

- For a PNP-transistor, the polarities of all currents & voltages are reversed.

- There are three operating regions of a transistor : cut off, active & saturation. In the cut off region of a transistor, the transistor is off or the base current is not enough to turn it on & both junctions are reverse biased.

- In the active region, the BJT acts as amplifier, where the base current is amplified by a gain & the collector-emitter voltage decreases with ~~the~~ the base current. The CBJ is reverse biased and BEJ is forward biased

- In the base current region, the base current is sufficiently high so that the collector-emitter voltages is low & the transistor acts as a switch

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- Both junctions CBJ & BEJ are forward biased. The transfer characteristic which is a plot of V_{CE} against I_B is shown in output characteristics.

- For NPN-transistor, the equation relating the current is

$$I_E = I_C + I_B$$

The base current is effectively the input current & the collector current is the o/p current. The ratio of the collector current I_C, to base current I_B, is known as the forward current gain β_F.

$$\beta_F = h_{FE} = \frac{I_C}{I_B}$$

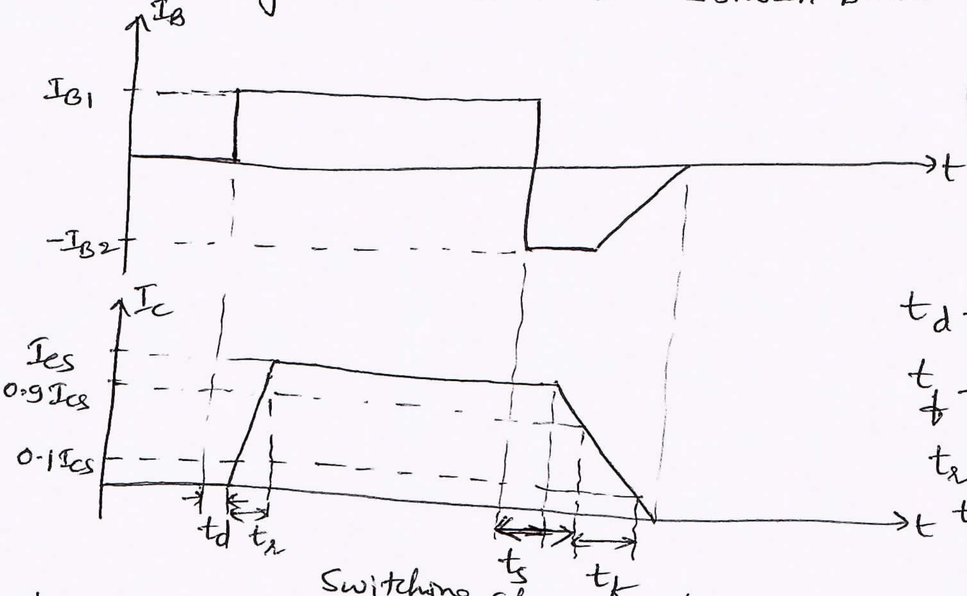
Referring to NPN transistor model figure, the collector current has two compon one due to the base current & the other is the leakage current of the CBJ.

So, $I_C = \beta_F I_B + I_{CEO}$

then, $I_E = I_B + I_C = I_B(1+\beta_F) + I_{CEO}$

$I_E \approx I_B(1+\beta_F)$ as I_{CEO} is negligible compared to $\beta_F I_B$.

- Due to internal capacitances, the transistor does not turn ON instantly. The switching characteristics is as shown below



Switching characteristics.

where

t_d → delay time

t_f → fall time

t_r → rise time

t_s → storage time

- The turn-on time is the sum of delay time & rise time

$$\boxed{t_{on} = t_d + t_r}$$

- The turn-off time is the sum of storage time & fall time

$$\boxed{t_{off} = t_s + t_f}$$

Kirankumar H.

4) b) Explain the Switching Limits (06 Marks)

The switching limits of power transistors are as follows.

i) Second Breakdown (SB):

- It is a destructive phenomenon, results from the current flow to only a small portion of the base, producing localized hot spots.
- If the energy in the hot spots is sufficient, the excess localized heating in that portion may damage the transistor. This problem may be caused by defects in the transistor structure.

ii) Forward Biased Safe Operating Area (FBSOA) Curve:

- During turn-ON & on-state conditions, the average junction temperature and second breakdown limit the power handling capability of a transistor. The manufacturer provides the FBSOA curves under specified test conditions.
- FBSOA indicates the $i_C - V_{CE}$ curve (limits) of the transistors & for reliable operation the transistor must not be allowed to greater dissipation than that shown by the FBSOA curve.

iii) (RBSOA) Reverse Biased Safe Operating Area Curve:

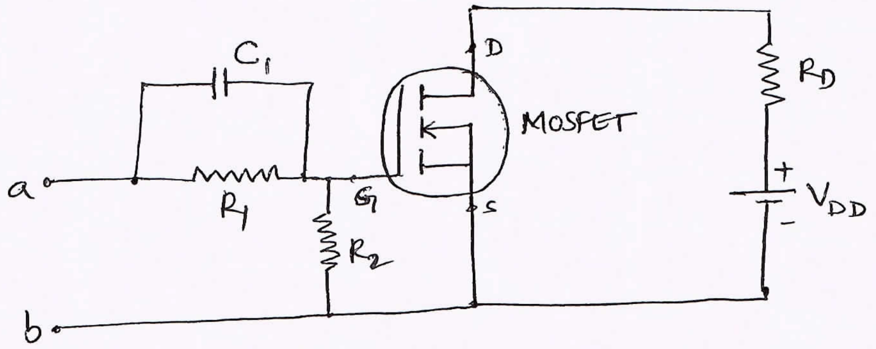
- During turn-off, a high current and high voltage must be sustained by the transistor, in most cases with the base to emitter junction reverse biased. The collector-emitter voltage must be held to a safe level at or below a specified value of the collector current.
- The manufacturers provide $I_C - V_{CE}$ limits during reverse biased turn off as RBSOA curve.

iv) Breakdown Voltages:

- A breakdown voltage is defined as the absolute maximum voltage between two terminals with third terminal open, short or biased in either forward or reverse direction. At breakdown the voltage remains relatively constant, where the current rises rapidly.

Onkumar N.

4) c) Explain the gate drive circuit of MOSFET with a help of circuit diagra
(05 Marks)



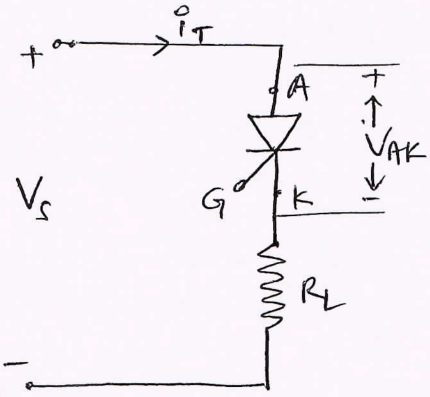
Gate drive circuit

- The gate drive circuit for MOSFET should satisfy the following requirements
  i) The gate-source input capacitance should be charged quickly.
  ii) MOSFET turn-ON when gate-source input capacitance is charged to sufficient level.
  iii) To turn off MOSFET quickly. The negative gate current should be sufficiently high to discharge gate-source input capacitance.
- Figure shows the gate drive as per above requirements. The gate drive is applied across the terminals a-b. Initially the resistance 'R_1' is bypassed by 'C_1' and full drive voltage is applied to the gate. This charges the gate source capacitance quickly. As per the capacitance C_1 charges, the gate current reduces. Once the ~~gate~~ MOSFET is turned on required gate current is very small. When MOSFET is to be turned off, the voltage V_{a-b} is made zero. This applies capacitor voltage across gate-source in '-ve' direction. Therefore charge in the gate source capacitance is removed quickly. 'C_1' then discharges through 'R_1'. The resistance 'R_2' provides additional discharge path for gate-source capacitance.

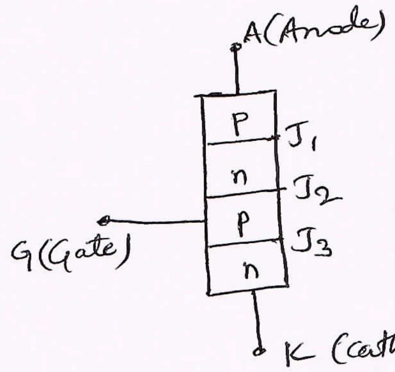
Kirankumar H.

Module 03

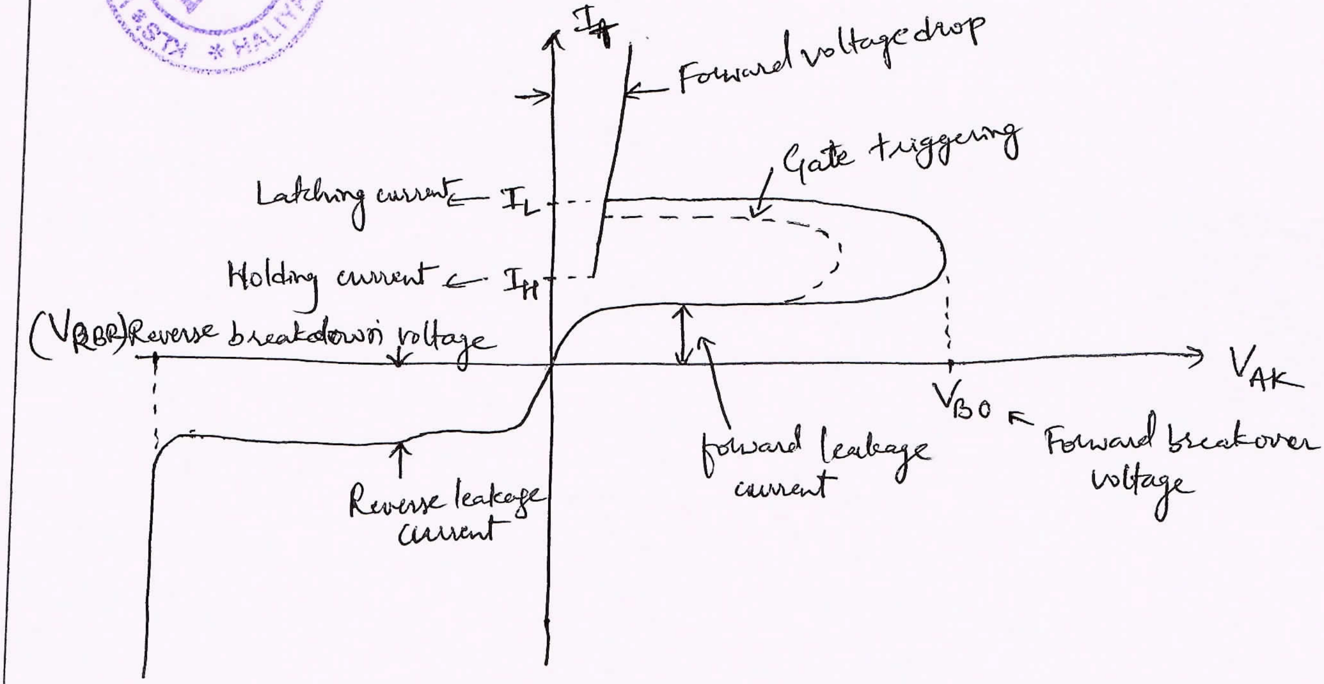
5)a) Explain the V-I characteristics of SCR with the help of graphs indicating all necessary details. Also define i) Latching current ii) Holding current (08 Marks)



Circuit diagram



SCR junction diagram



V-I characteristics of SCR

- When the anode voltage is made positive with respect to cathode, the Junction J_1 & J_3 are forward biased. The junction 'J_2' is reverse biased, and only a small leakage current flows from anode to cathode. The thyristor is then said to be in the forward blocking or off state and leakage current is known as off state current I_D.
- If the anode to cathode voltage 'V_{AK}' is increased to a sufficiently large value the reverse biased junction 'J_2' breaks. This is known as avalanche breakdown and the corresponding voltage is called forward breakdown voltage V_{BO}. Because the other junctions J_1 & J_3 are already forward biased there is free movement of carriers across all three junctions, resulting in a large forward anode current.

an H.

The device is then in a conducting state or on-state. The voltage drop would be due to ohmic drop in the four layers and its small, typically 1 V.

- The anode current must be more than a value known as latching current I_L to maintain the required amount of carriers flow across the junction as the anode to cathode voltage is reduced.

Latching current (I_L) is the minimum anode current required to maintain the thyristor in the on-state immediately after a thyristor has been turned on & gate signal has been removed

- Once the thyristor conducts, it behaves like a conducting diode & there is no control over the device. The device continues to conduct because there is no depletion layer on the junction 'J_2' due to free movement of carriers.

However if the forward anode current is reduced below a level known as the holding current I_H, a depletion region develops around junction J_2 due to reduced no. of carriers and the thyristor is in the blocking state.

Holding current (I_H) is the minimum anode current to maintain the SCR in the on-state. The holding current is less than the latching current

- When the cathode voltage is made positive w.r.t anode, the thyristor J_2 junction forward biased but J_1 & J_3 are reverse biased. This is like two series connected diodes with reverse voltage across them. The thyristor is in the reverse blocking state & a reverse leakage current, known as 'reverse current (I_R)' flows through the device.

5) b) Explain various method of turning on of a SCR (06 Marks)

A thyristor is turned-on by increasing the anode current. This can be accomplished in one of the following ways.

i) Thermals:

If the temperature of a thyristor is high, there is a increase in the no. of electron-hole pairs, which increase the leakage currents. This type of turn-on may cause thermal run away and is normally avoided.

irankumar H.

ii) Light :

If light is allowed to strike the junctions of a thyristor, the electr hole pairs increase and thyristor may be turned on. The light acti thyristors are turned-on by allowing light to strike the silicon waf

iii) High voltage :

If the anode to cathode forward voltage is greater than the forwar breakover voltage V_{BO}, sufficient leakage current flows to initiat regenerative turn-on. This type of turn-on may be destructive & shou be avoided.

iv) Gate current :

If a thyristor is forward biased, the junction of gate current by applying positive gate voltage between the gate and cathode terminals turns-on the thyristor. As the gate current is increased, the forward blocking voltage is decreased.

5) c) Design a SCR triggering circuit using UJT. The parameters of UJT are $V_S = 30V$, $\eta = 0.66$, $I_p = 15 \mu A$, $V_V = 3V$ & $I_V = 10mA$. The frequency of oscillations is $f = 500 Hz$ and width of gate pulse if $t_g = 30 \mu S$. Assume $V_D = 0.5V$ & $C = 0.5 \mu F$. (06 Marks)

Given $\underset{(V_{BB})}{V_S} = 30\ V$, $\eta = 0.66$, $I_p = 15 \mu A$, $V_V = 3V$, $I_V = 10mA$

$f = 500 Hz$, $t_g = T_2 = 30 \mu S$, $V_D = 0.5$ & $C = 0.5 \mu F$

The frequency, $f = \frac{1}{T}$, $\therefore T = \frac{1}{500} = 0.002\ S$ (or $2 ms$)

We have $T = R_C C \ln\left(\frac{1}{1-\eta}\right)$

$$0.002 = R_C C \ln\left(\frac{1}{1-0.66}\right)$$

$$\therefore R_C C = 0.0109$$

$$\therefore R_C = \frac{0.0109}{0.5 \times 10^{-6}} = 21.8\ k\Omega$$

Kirankumar M.

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

$$\therefore V_p = 0.66 \times 30 + 0.5$$
$$V_p = 20.3 \text{ V}$$

The minimum value of R_C can be calculated by

$$R_{C(min)} = \frac{V_{BB} - V_V}{I_V} = \frac{30 - 3}{10 \times 10^{-3}} = 2.7 \text{ k}\Omega$$

Value of R_2 can be calculated by

$$R_2 = \frac{10^4}{\eta V_{BB}} = \frac{10^4}{0.66 \times 30} = 505.05 \, \Omega$$

Width of pulse $T_2 = 30 \mu s$ & $T_2 = R_1 C$

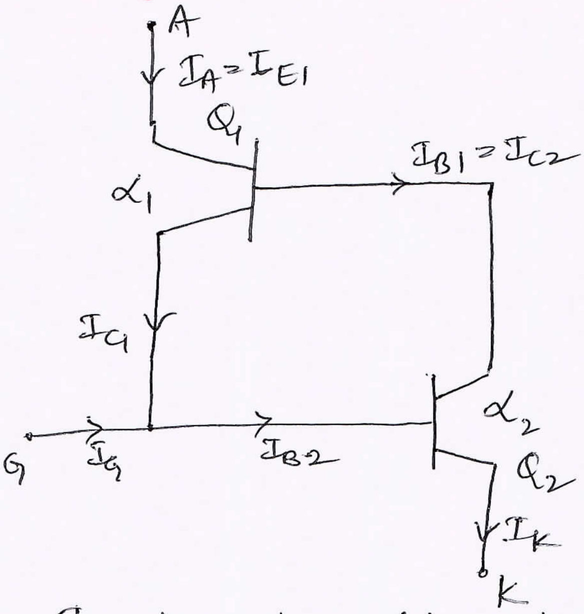
$$\therefore R_1 = \frac{30 \times 10^{-6}}{0.5 \times 10^{-6}} = 60 \Omega$$

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

$R_1 = 60 \Omega$, $R_2 = 505.05 \Omega$ &

$R_{C(min)} = 2.7 \text{ k}\Omega$.

6) a) Derive an expression for anode current of SCR with the help of two transistor analogy. (06 Marks).



Two transistor model of thyristor.

- The regenerative or latching action due to positive feedback can be demonstrated by using a two-transistor model of thyristor. A thyristor can be considered as two complementary transistors, one PNP (Q_1) & other NPN (Q_2) as shown in figure above.

inkumar H.

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

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

where α → common base current gain & I_{CBO} is leakage current.

∴ for Q_1 transistor, the collector current I_{C1} is given by

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

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

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

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

$$I_A = I_{C1} + I_{C2} = \alpha_1 I_A + I_{CBO1} + \alpha_2 I_K + I_{CBO2} \quad — ④$$

For gating current of I_g, $I_K = I_A + I_g$ & solving eqn ④ for I_A gives

The anode current, $$\boxed{I_A = \frac{\alpha_2 I_g + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}}$$

6) b) Explain in brief why two thyristors of same rating when connected in parallel donot share equal currents. Suggest a method to equalize the currents and explain. (06 Marks)

- When thyristors of same rating are connected in parallel, the load current is not shared equally due to differences in their characteristics. If a thyristor carries more current than that of others, its power dissipation increases, there by increasing the junction temperature and decreasing the internal resistance. This in turn, increases its current sharing & may damage the thyristor. This thermal run away may be avoided by having a common heat sink, ~~so~~ so that all units operate at the same temperature.
- A small resistance as shown in figure, may be connected in series with each thyristor to force the equal current sharing, but there may be considerable power loss in series resistance.

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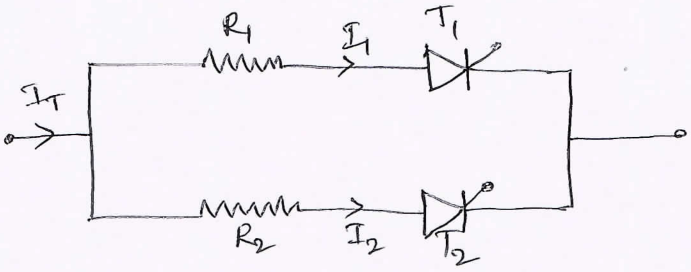
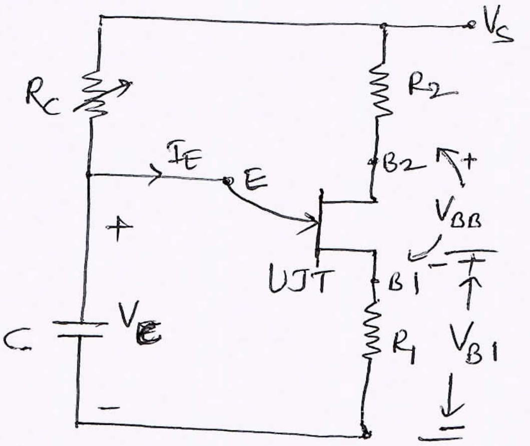
kumar M.



static current sharing

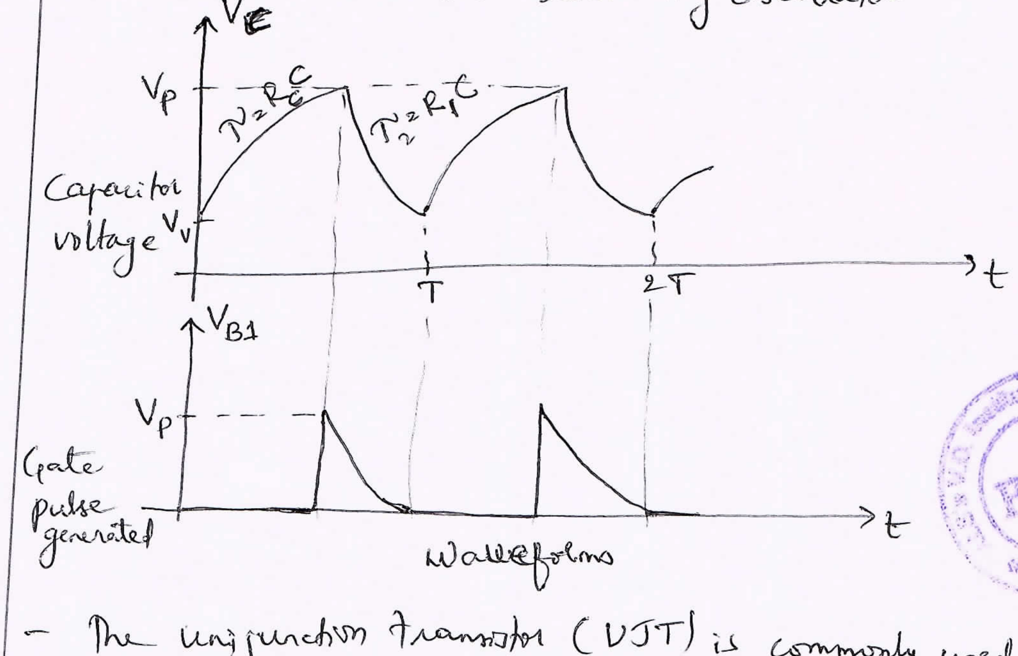
- Figure shows the static current sharing which uses resistances R_1 & R_2 used in series with SCRs for achieving equal current sharing.

6) c) Explain UJT triggering circuit for full control of SCR with waveforms (08 Marks)



⇒ To gate terminal of SCR through pulse transformer

UJT relaxating oscillator



Waveforms

- The unijunction transistor (UJT) is commonly used for generating triggering signals for SCRs. A basic UJT-~~tstggering~~ triggering circuit is shown in above figure. A UJT has 3 terminals, called the emitter E, base-one B_1 & base-two, B_2. Between B_1 & B_2 the unijunction has the characteristics of an ordinary resistance. This resistance is called interbase resistance R_{BB} ranges from 4.7 to 9.1 kΩ

- When the DC supply voltage 'V_s' is applied the capacitor 'C' is charged through resistor 'R_C' because the emitter circuit of the UJT is in the open state. The time constant of the charging circuit is $\tau_1 = R_C C$.

- When the emitter voltage V_E which is the same as the capacitor voltage 'V_C' reaches the peak voltage 'V_E' decays to the valley point voltage V_V. The emitter ceases to conduct, the UJT turns off & the charging cycle is repeated. The waveforms of the capacitor & triggering voltages are shown in figure.

- The equation for firing angle (α) of UJT triggering circuit is

$$\alpha = \omega \cdot R_C \cdot C \ln\left(\frac{1}{1-\eta}\right)$$

where $\omega = 2\pi f$ & 'f' is the frequency of UJT oscillator.
& 'η' is intrinsic stand off ratio provided by manufacturer.

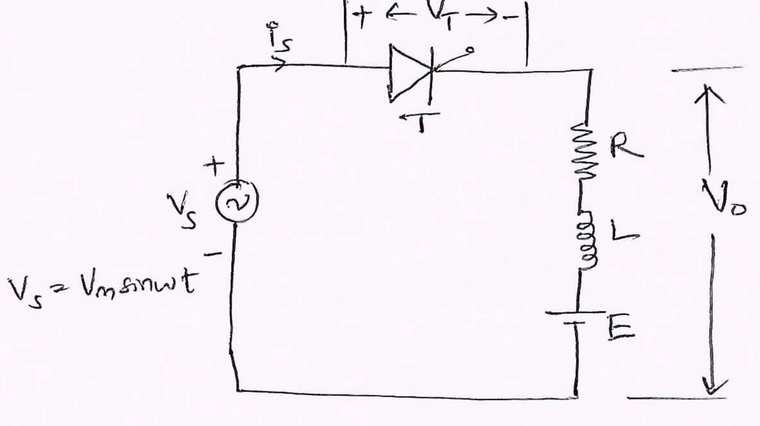
- maximum value & minimum value of R_C is given by

$$R_{C(max)} = \frac{V_{BB} - V_P}{I_P} \quad \text{where } V_{BB} = V_s$$

$$\& \; R_{C(min)} = \frac{V_{BB} - V_V}{I_V}$$

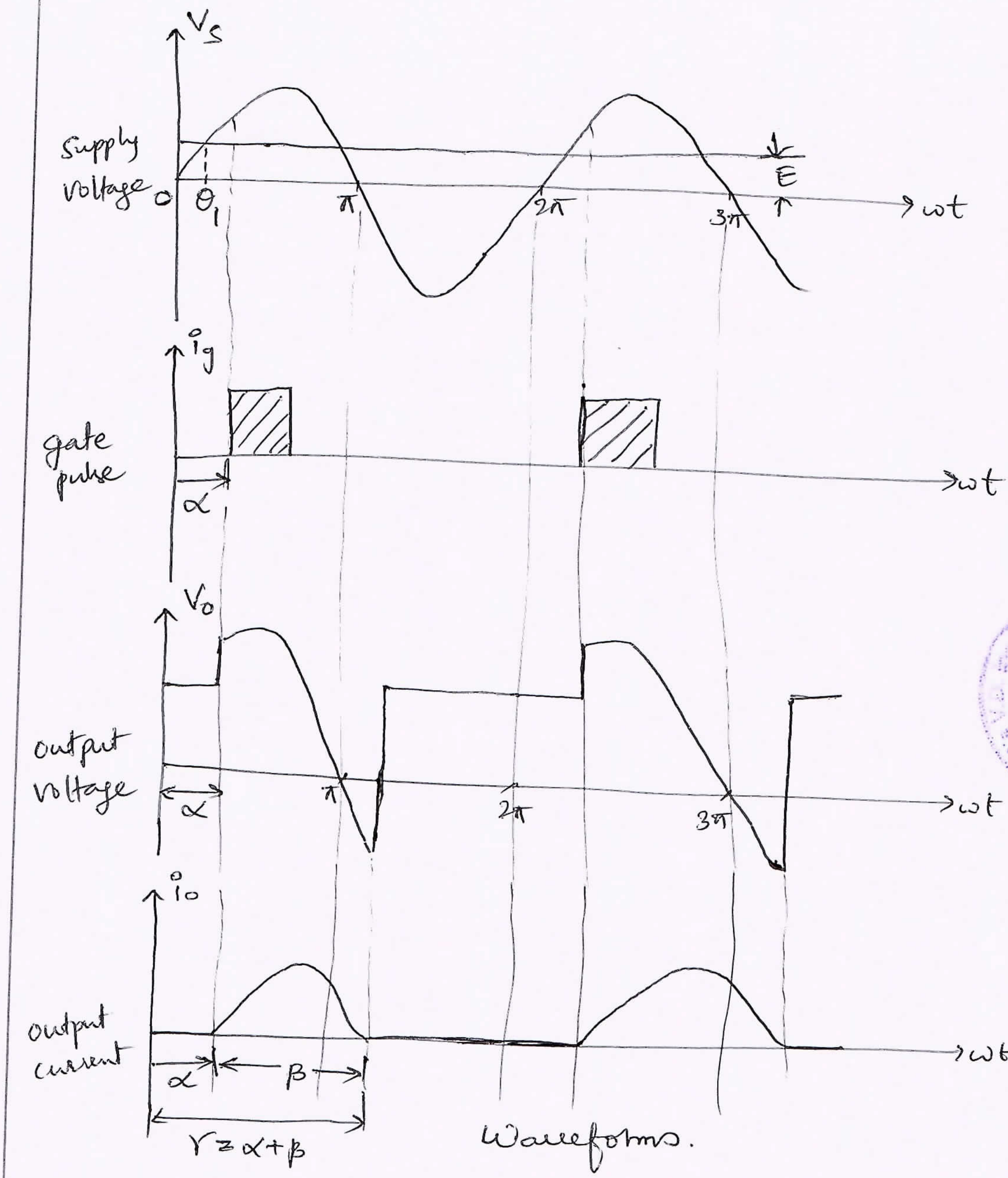
Module 04

7) a) Explain the operation of single phase halfwave rectifier with RLE load. Draw relavent circuit diagram & waveforms. (08 Marks)



Circuit diagram

Kirankumar K.



Waveforms.

- A single phase half wave controlled converter with RLE load is shown in above figure. The counter emf 'E' in the load may be due to battery or a DC motor. The minimum value of firing angle is obtained from relation $V_m \sin \omega t = E$. This is shown to occur at an angle 'θ_1' where

$$\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right)$$

- In case thyristor 'T' is fired at an angle $\alpha < \theta_1$, then $E > V_s$, SCR is reverse biased and therefore it will not turn-on. Similarly maximum value of firing angle is $\theta_2 = \pi - \theta_1$.

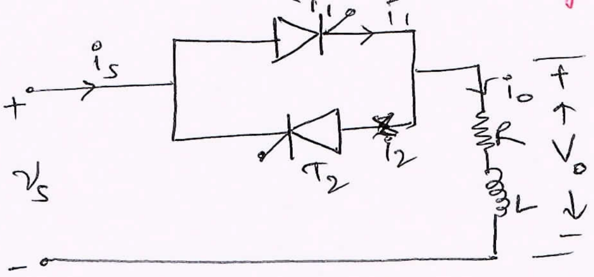
- During the interval load current i_0 is zero, load voltage $V_0 = E$ & during the time i_0 is not zero, V_0 follows V_s curve. For the circuit of fig. KVL gives the voltage differential equation as,

ivankumar M.

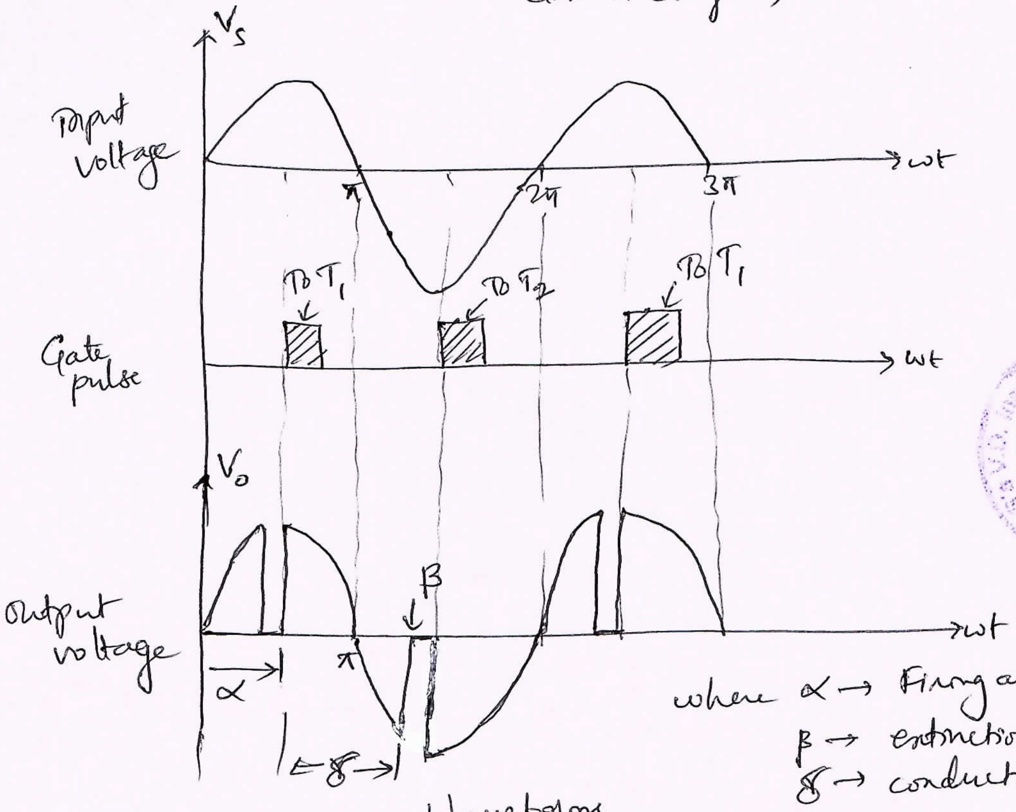
$$V_m \sin\omega t = R\cdot i_o + L\cdot\frac{di_o}{dt} + E$$

The solution of this equation is made up of two components; namely steady state current component i_s & transient current component i_t.

7) b) Explain the operation of single phase full wave AC voltage controller with inductive load. Draw the circuit diagram and waveforms (06 Marks)



Circuit diagram



where $\alpha \rightarrow$ Firing angle
$\beta \rightarrow$ extinction angle
$\delta \rightarrow$ conduction angle

Waveforms

- Thyristor T_1 is turned on during the positive half cycle & carries the load current. Due to inductance in the circuit, the current of thyristor T_1 would not fall to zero, at $\omega t = \pi$, when the input voltage starts to be negative. Thyristor continues to conduct until its current i_1 falls to zero at $\omega t = \beta$.
- The conduction angle of thyristor T_1 is $\delta = \beta - \alpha$.
- The rms o/p voltage, $V_o = V_s\sqrt{\dfrac{\beta-\alpha+\frac{\sin 2\alpha}{2}-\frac{\sin 2\beta}{2}}{\pi}}$

Kirankumar M.

7c> A single phase fully controlled rectifier circuit is used for obtaining a regu DC output voltage. The rms value of the AC input voltage is 230V & firing angle is maintained at $\pi/3$. So that the load current is 4 Calculate i) DC o/p voltage ii) Active power output iii) Load resista

(06 Marks)

$V_{rms} = 230\,V \Rightarrow V_m = 230 \times \sqrt{2} = 325.269\,V$

$\alpha = \pi/3$

$I_0 = 4\,A$

W.K.T. i) V_0, DC o/p voltage is given by

$$V_0 = \frac{V_m}{\pi}(1+\cos\alpha)$$

$$= \frac{325.269}{\pi}(1+\cos\pi/3)$$

$$V_0 = 155.3\,V$$

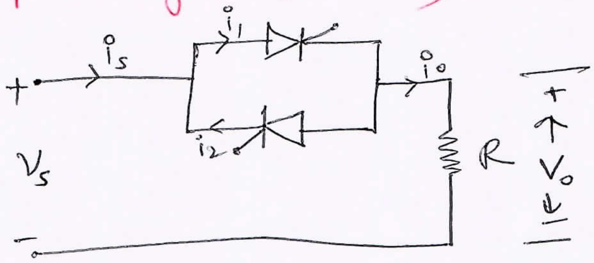
ii) Active power output, $P_0 = V_0 \times I_0$

$$= 155.3 \times 4$$

$$= 621.22\,W$$

iii) Load resistance, $R = \frac{V_0}{I_0} = \frac{155.3}{4} = 38.83\,\Omega$

8>a) With a help of circuit diagram & waveforms, explain the working of on-off control of AC voltage controller feeding resistive load. Derive an expression for rms output voltage. (08 Marks)



Circuit diagram

– The above figure shows the circuit diagram of 1-ϕ full wave controller. It has two SCRs, T_1 & T_2. In the positive half cycle of the supply T_1 controls the power flow to the load. In the negative half cycle of the supply T_2 controls the power flow to the load.

ankumar H.

- The output waveforms of current & voltage are shown below for resistive load. ~~It~~ waveform is similar to the V_o waveform. The output voltage can be controlled in positive as well as negative half cycles due to two SCRs.

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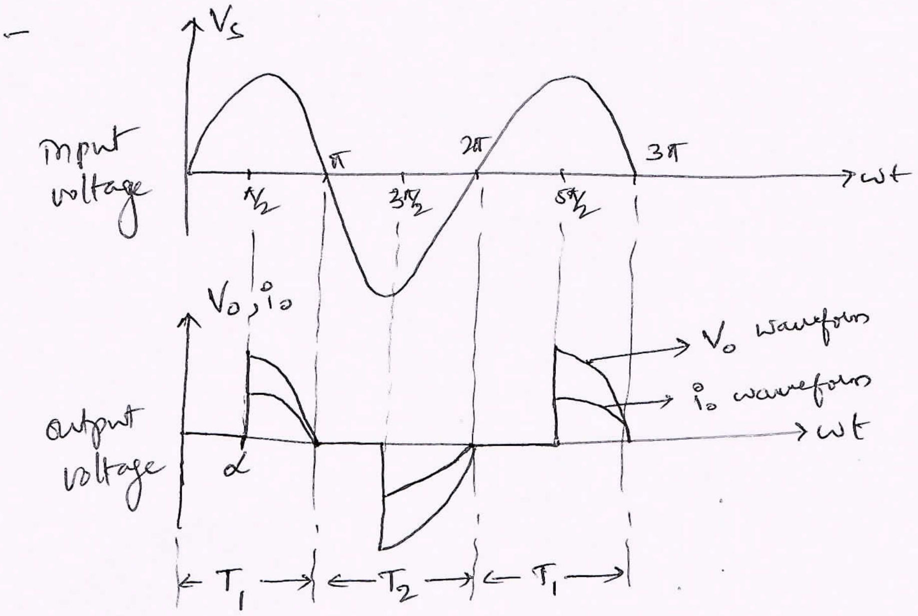

Waveforms

- The rms value of o/p voltage is given by

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

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

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

$$= \left[\frac{V_m^2}{2\pi}\left(\pi - \cancel{\frac{\sin 2\pi}{2}}^{\,0} - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

$$V_o = V_s\sqrt{\frac{\pi - \alpha + \frac{\sin 2\alpha}{2}}{\pi}}$$

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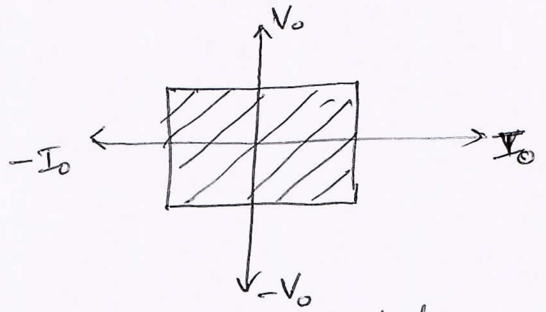
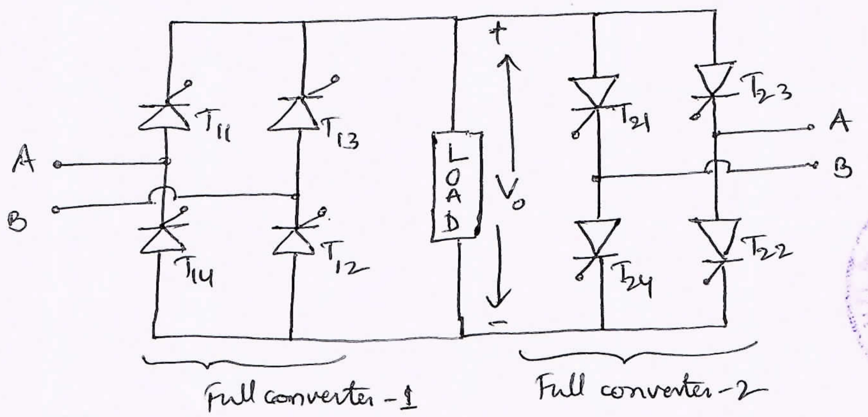
Kirankumar H.

8) b) With the help of suitable circuit and waveforms, Explain the working of single phase dual converter circulating current mode of operation.

(07 Marks)

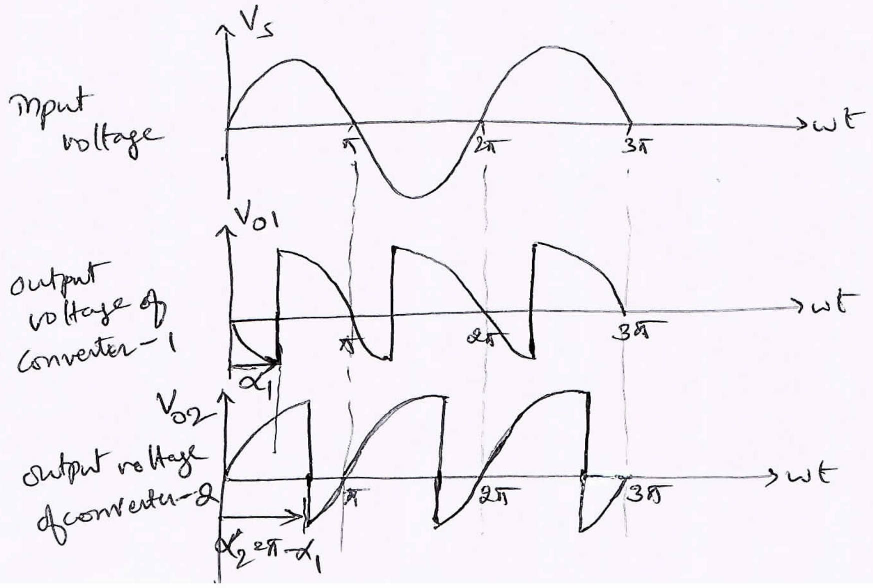


Four quadrant diagram



Circuit diagram

- Semiconverters are single quadrant converters. But in full converter output voltage polarity can be reversed but current direction cannot be reversed because of the unidirection properties of SCRs. Thats a full converter operates as a rectifier in first quadrant (both V_o & I_o +ve) for $\alpha = 0°$ to $90°$ & as a inverter (V_o negative but I_o positive) from $\alpha = 90°$ to $\alpha = 180°$ in the fourth quadrant. This shows that a full converter can operate in two quadrant or acts as two quadrant converter.



$$\boxed{\alpha_1 + \alpha_2 = \pi}$$

$$\therefore \alpha_2 = \pi - \alpha_1$$

Kirankumar H.

The average values of converter ① & ② are given by

$$V_{01(av)} = \frac{2V_m}{\pi}\cos\alpha_1 \quad \& \quad V_{01} = \frac{2V_m}{\pi}\cos\alpha_2$$

As one converter operates in rectifying mode when the other converter operates in inversion mode, their avg. values must be equal & opposite in sign.

$$V_{01(av)} = -V_{02(av)}$$

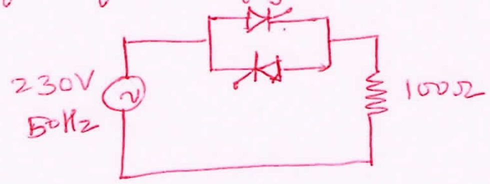
$$\frac{2V_m}{\pi}\cos\alpha_1 = -\frac{2V_m}{\pi}\cos\alpha_2$$

$$\therefore \cos\alpha_1 = -\cos\alpha_2 = \cos(\pi-\alpha_2)$$

$$\therefore \alpha_1 = \pi-\alpha_2$$

$$\therefore \boxed{\alpha_1+\alpha_2=\pi}$$

8) c) Find the power consumed in the heater element if both SCRs are fired with delay angle of 45° for the figure Q.8(c) (05 Marks)



$\alpha = 45°$, $V_s = 230\text{ V} \Rightarrow V_m = 230\sqrt{2}$

Load resistance, $R = 100\Omega$

i) we have for bidirection converter, $V_{o(rms)} = V_m\sqrt{\dfrac{\pi-\alpha+\frac{\sin 2\alpha}{2}}{2\pi}}$

$$= 230\sqrt{2}\sqrt{\frac{\pi-\frac{\pi}{4}+\frac{\sin 2\times\frac{\pi}{4}}{2}}{2\pi}}$$

$$V_{o(rms)} = 219.3\text{ V}$$

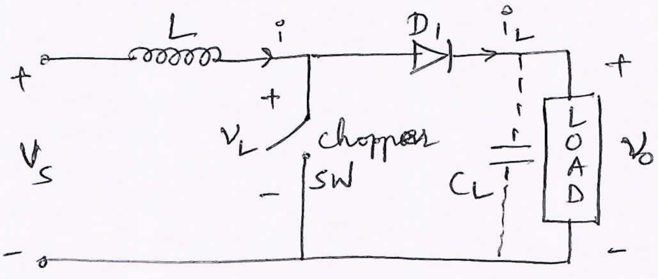
ii) The power absorbed in the load can be calculated as

$$P_o = \frac{V_{o(rms)}^2}{R} = \frac{219.3^2}{100} = 480.92\text{ W}$$

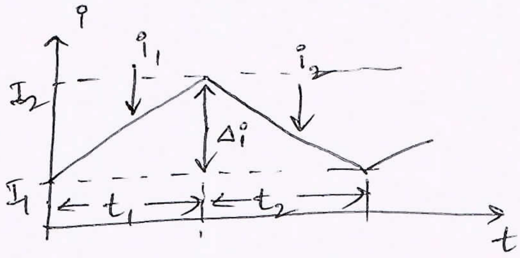
Kirankumar M.

Module 05

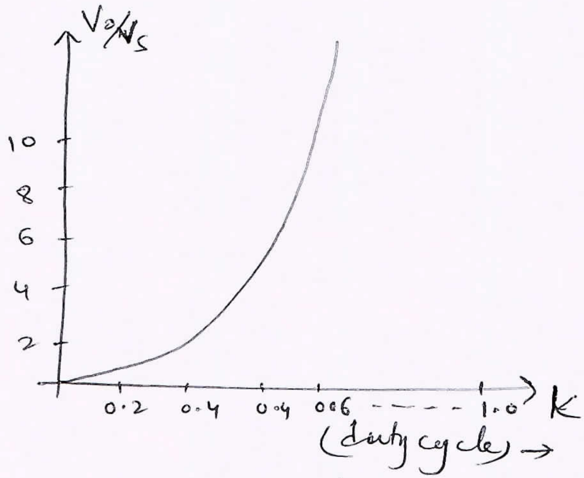
9) a) With a help of schematic diagram and waveforms, explain the operation of step up chopper with R L load. Derive an expression for average output voltage. (08 Marks)



Circuit diagram



Current waveform



Output voltage

- A converter can be used to step up a DC voltage and an arrangement for step up operation is shown in above figure. 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 the load through diode D_1 & the inductor current falls. Assuming a continuous conduction current flow, the waveform of the inductor current is shown in above figure.

- 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

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

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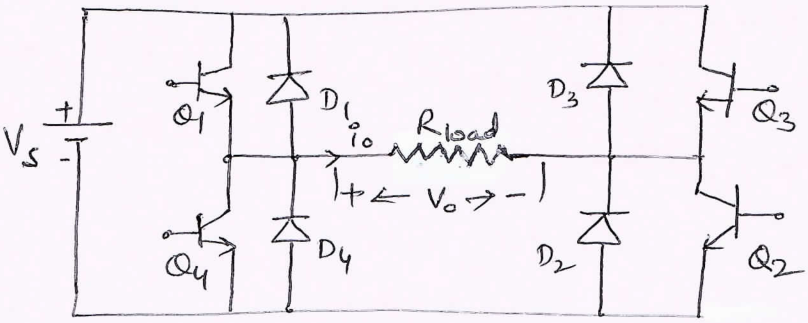
The average output voltage is given by

$$V_0 = V_s + L \cdot \frac{\Delta I}{t_2}$$

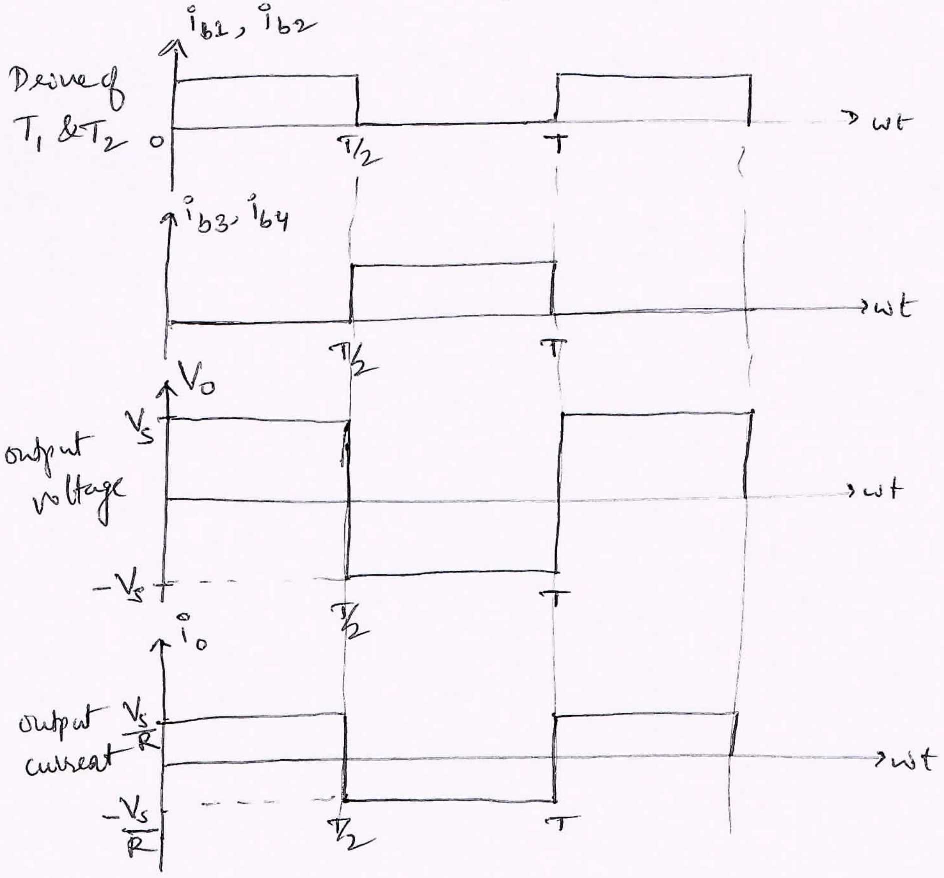
$$= V_s\left(1 + \frac{t_1}{t_2}\right)$$

$$\boxed{V_0 = V_s\left(\frac{1}{1-k}\right)}$$ where k is duty cycle of chopper.

9)b) Explain the working of single phase bridge inverter feeding resistive load. Draw the circuit diagram & waveforms (06 Marks)



Circuit diagram



Kirankumar N.

- Full bridge inverter consists of 4 transistors & four diodes for feedback when load is inductive.
- When the load is resistive, the diodes doesnot carry any current. The transistors T_1 & T_2 conduct from 0 to $T/2$. ~~At~~ At $T/2$, transistors T_1 T_2 are turned off. T_3 & T_4 conduct from $T/2$ to T.

The rms output voltage can be found from

$$V_o = \left(\frac{2}{T_o}\int_0^{T_o/2} V_s^2 . dt\right) = V_s .$$ //

a) c) A step up chopper has input voltage of 220 V & output voltage of 660 V. If the conducting time of chopper is 100 μs, calculate turn off time of output voltage. In case output voltage pulse width is halved ~~for~~ for constant frequency operation, find the average value of new output voltage. (06 Marks)

Supply voltage, $V_s = 220\,V$

output voltage, $V_o = 660\,V$

$T_{off} = 100\,\mu S$

i) To calculate T_{on}

W.K.T $V_o = \frac{V_s}{1-k} \Rightarrow 660 = \frac{220}{1-k}$

$\therefore k = 0.667$

duty cycle, $k = \frac{T_{on}}{T_{on}+T_{off}}$

$\therefore 0.667 = \frac{T_{on}}{T_{on} + 100\times10^{-6}}$

$\therefore T_{on} = 200\,\mu S$ //

ii) Chopper frequency is, $f = \frac{1}{T} = \frac{1}{T_{on}+T_{off}} = \frac{1}{200\mu s + 100\,\mu s} = \frac{1}{300\times10^{-6}}$

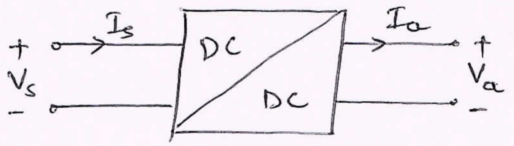
Hence chopper period is, $T = \frac{1}{f} = 300\times10^{-6}\,S = 300\,\mu S$

Since T_{on} is halved, $T_{on}' = \frac{200\,\mu s}{2} = 100\,\mu s$

$\therefore$ duty cycle, $\delta = \frac{T_{on}}{T} = \frac{100}{300} = \frac{1}{3}$ $\therefore V_o = \frac{220}{1-\frac{1}{3}} = 330\,V$ //

Kirankumar H.

10) a) Explain the performance parameters of DC-DC converters (06 marks)



Block diagram

i) AC output power is, $P_{ac} = V_o \times I_o$

where V_o & I_o are rms values of load voltage & current

ii) DC output power is, $P_{dc} = V_a \times I_a$

where V_a & I_a are average load voltage & current values

iii) The converter efficiency is given by

$$\eta_c = \frac{P_{dc}}{P_{ac}}$$

iv) The ripple factor of the input current is

$$RF_s = \frac{I_r}{I_s}$$ where, $I_r = \sqrt{I_i^2 - I_s^2}$ &

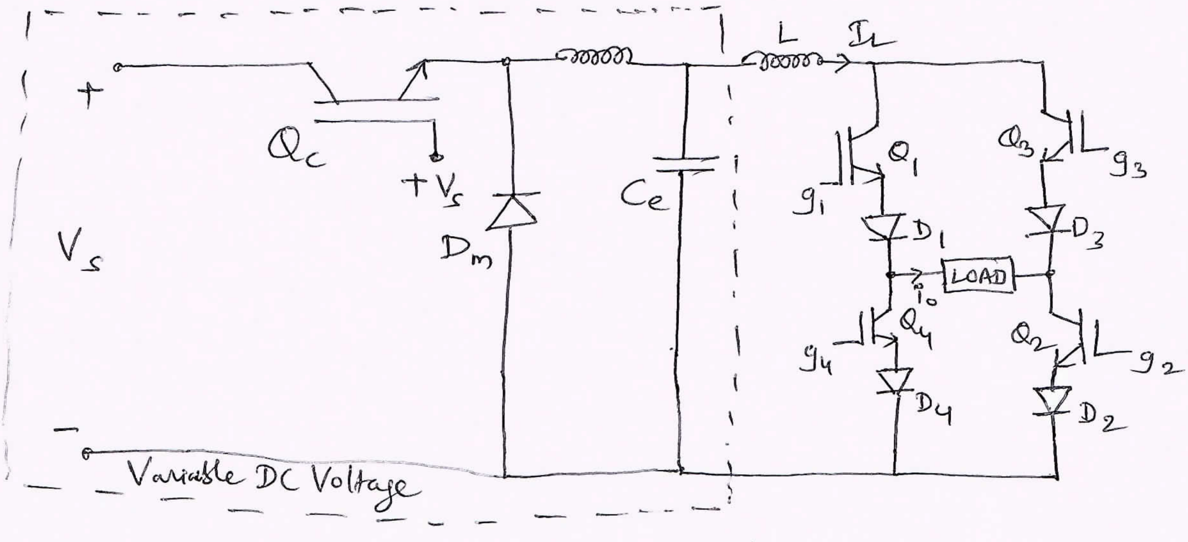
I_i is rms value and I_s is avg value of DC supply.

v) The ripple content of output voltage is given by

$$V_r = \sqrt{V_o^2 - V_a^2}$$

where V_o is rms value & V_s is avg value of dc o/p voltage

10) b) Explain the construction and working of transistorized current source inverter (CSI). Draw the circuit diagram & waveforms. (08 Marks).



Transistorized CSI

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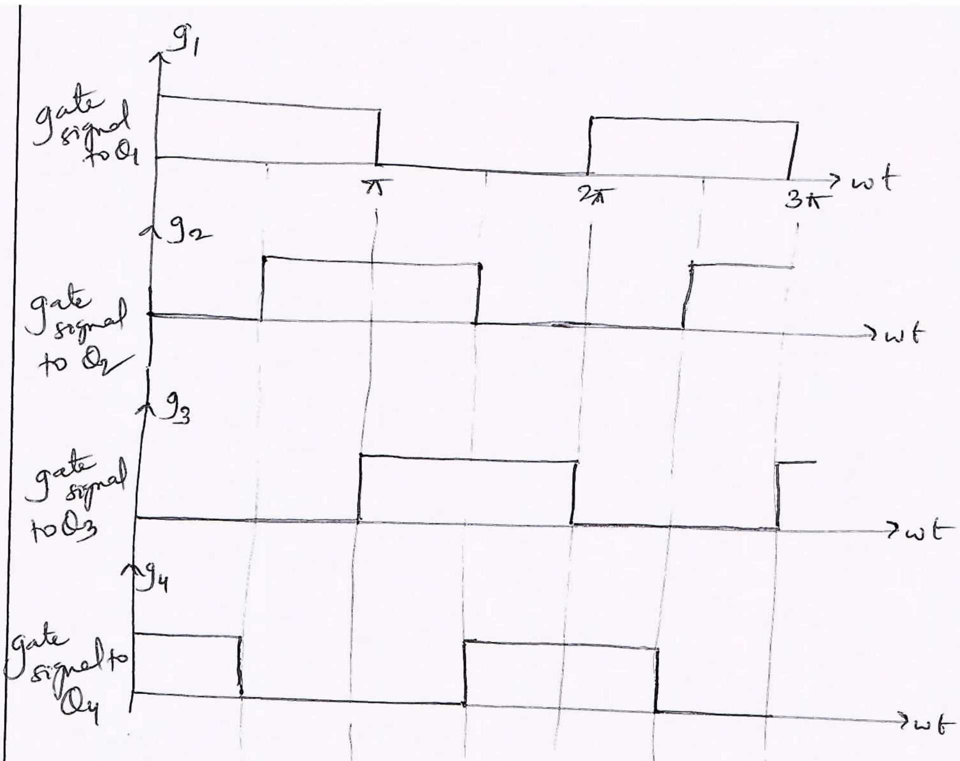
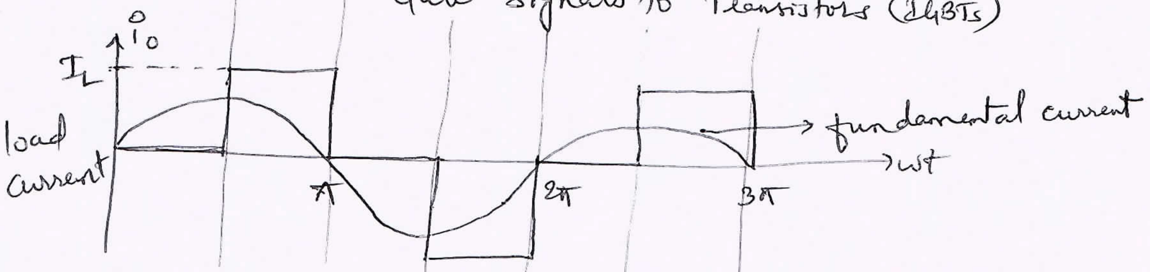


Gate signals to Transistors (IGBTs)



Load current waveform

- In CSI, the input behaves as a current source. The output current is maintained constant irrespective of load on the inverter and the output voltage is forced to change. The circuit diagram of a single phase transistorized inverter is shown above. Because there must be a continuous current flow from the source, two switches must always conduct - one from the upper & one from the lower switches. The conduction sequence is 12, 23, 34 & 41 as shown above.

- Let the current flows for the duration of ' ' in the load for half cycle, Then the load current can be expressed in fourier series as,

$$i_{on} = \sum_{n=1,3,5\ldots}^{\infty} \frac{4I}{n\pi} \sin\frac{n\delta}{2} \sin n\omega t$$

- Advantages of CSI are
  - i) The input current is constant. Hence there is no possibility of short circuit
  - ii) CSI can handle reactive or regenerative loads without freewheeling diodes
  - iii) The maximum current of the power devices is limited i.e. fixed.

ankumar H.

10) c) The DC-DC converter has a resistive load of $R = 10\,\Omega$ & the input voltage is $V_s = 200\,V$. When the converter switch remains on, its voltage drop is $V_{ch} = 2V$ & chopping frequency is $f = 1\,kHz$. If the duty cycle is 50%. Calculate:

i) Average o/p voltage
ii) RMS o/p voltage
iii) Converter efficiency

(06 Marks)

$V_s = 200\,V$, $V_{ch} = 2V$
$R = 10\,\Omega$, $k = 0.5$

i) Average output voltage, $V_{o(av)} = k(V_s - V_{ch}) = 0.5(200-2)$
$= 99\,V$

ii) RMS output voltage,
$$V_{o(rms)} = \sqrt{K}\,(V_s - V_{ch}) = \sqrt{0.5}\,(200-2)$$
$$= 140\,V$$

iii) Converter efficiency,
$$P_o = \frac{k(V_s - V_{ch})^2}{R} = \frac{0.5(198)^2}{10} = 1960.2\,W$$
$$P_s = k V_s \cdot \frac{(V_s - V_{ch})}{R} = \frac{0.5 \times 200\,(198)}{10} = 1980\,W$$
$$\therefore \eta = \frac{P_o}{P_s} = \frac{1960.2}{1980} = 0.99 \text{ or } 99\%$$

EEE

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