13

POWER ELECTRONICS (5th semester E&E)

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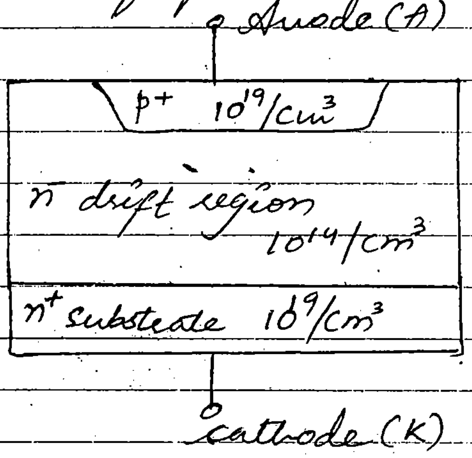
UNIT - I

1- Draw the layered structure of power diode

Ans:



→ There are three regions
1- n^+ substrate
2- n^- drift region
3- p^+ region

→ n^+ substrate is heavily doped with doping level of $10^9/cm^3$ forms cathode of the diode.

→ lightly doped n^- epitaxial layer is grown is called drift region with doping level of $10^{14}/cm^3$

→ pn junction is formed by diffusing a heavily doped p^+ region. p^+ region forms anode of the diode.

→ The doping level of p^+ region is $10^{19}/cm^3$.

→ The thickness of p^+ region is 10 μm.

→ The thickness of n^+ substrate is 250 μm.

→ The thickness of n^- drift layer depends upon the breakdown voltage of diode.

2- List types of power diodes & their applications

Ans: There are three types of power diodes
1- general purpose diodes
2- Fast recovery diodes
3- schotty diodes

Applications of three types of diodes

general purpose diode:-

These diodes have high reverse recovery time of 25 μs. These are used in battery charging, electric traction, electroplating, welding & power supplies.

Fast recovery diodes:-

These diodes have low reverse recovery time of 5 μs. These are used in choppers, communication circuits, switches mode power supplies, & induction heating.

Schotty diodes:-

The applications of Schotty diode includes high frequency instrumentation & ~~[illegible]~~ Switching power supplies.

3. List types of power transistors & their applications.

Ans: There are three types of power transmitters:

1] Bipolar junction transistor (BJT).
2] Metal oxide Semiconductor field effect transistor (MOSFET)
3] Insulated gate bipolar transistor (IGBT)

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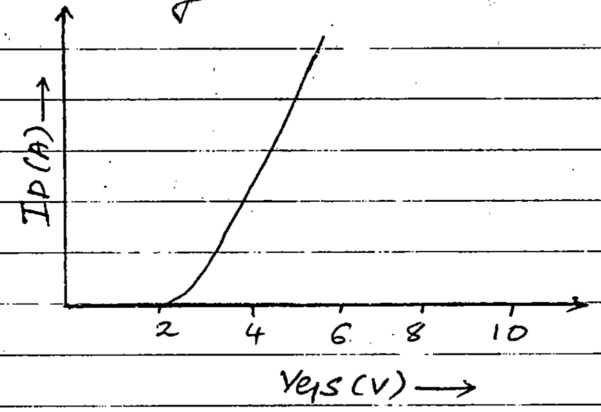
Applications :-

1] Power transistors are used in high power devices such as motor, Solonoid & Lamps.

2] Bipolar power transistors are widely used in the medium- and low power inverter & ~~copper~~ chopper drives, that have voltage ratings 230V & less.

4- Draw the transfer characterstic curve & list the applications of MOSFET.

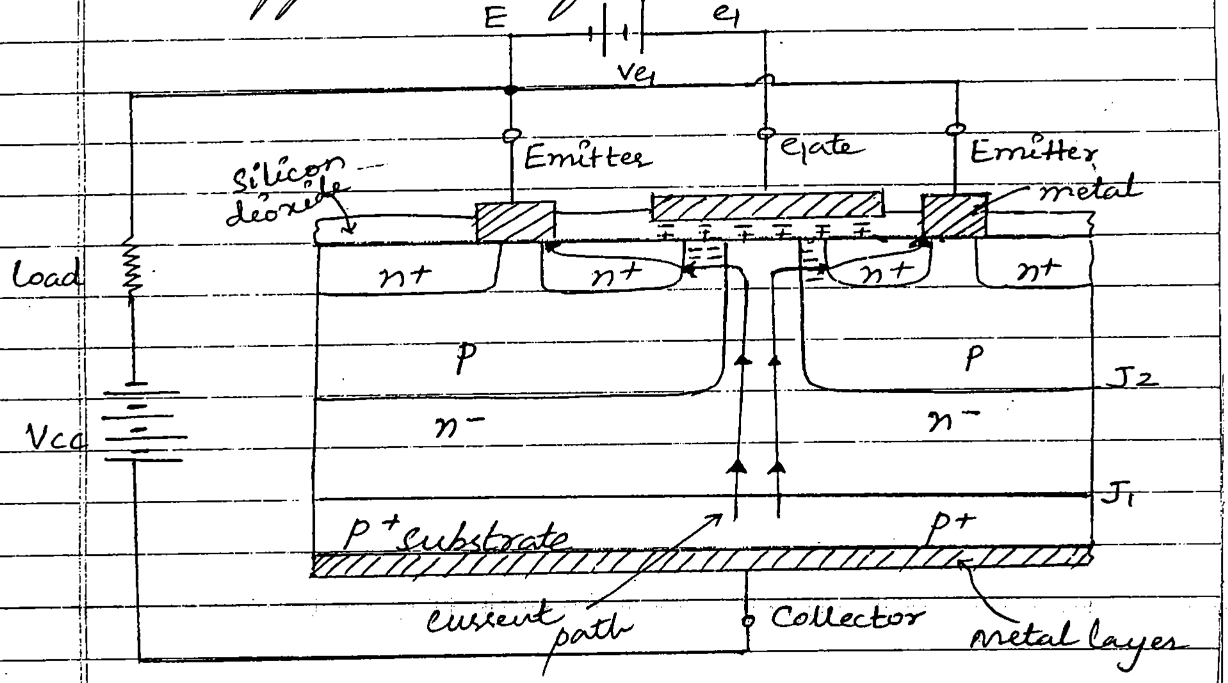


The above graph shows transfer characterstics of n-channel power MOSFET. there is a threshold voltage V_{GST} below which the device is off the magnitude of V_{GST} is of order 2 to 3V.

Applications

- → High frequency & low power inverters
- → High frequency SMPS (Switch mode power supply)
- → High frequency inverters & choppers
- → Low power AC & DC drives.

5- Draw the structure of IGBT & list the applications of IGBT.



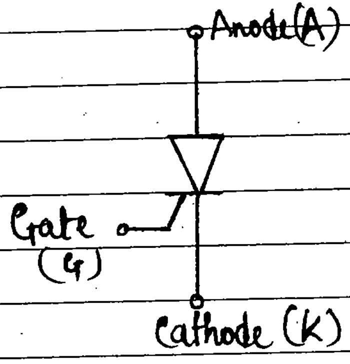
→ As shown in figure, n-channel short circuits the n^- region with n^+ emitter regions. an electron movement in the n-channel causes hole injection from p^+ substrate to n^- epitaxial

→ Three layers p^+, n^- & p constitute a pnp transistor with p^+ as emitter, n^- as base & p as collector.

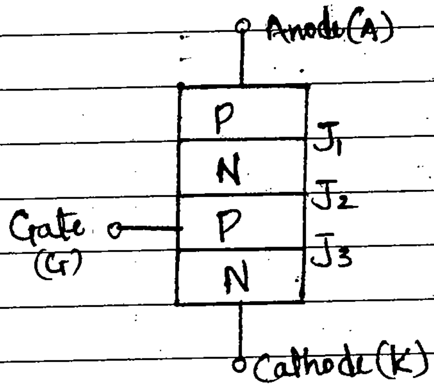
Applications

They are widely used in medium power applications such as dc & ac motor drives, UPS systems, power supplies & drives for solenoides.

6. Draw the layer diagram of SCR.



ⓐ Symbol



ⓑ Internal Construction

→ Thyristor is a four layer, three junction, P-n-P-n semiconductor switching device.

→ It has three terminals, Anode, cathode & Gate.

→ It is p-type & n-type silicon semiconductor forming three junctions J_1, J_2, J_3

→ The terminal connected to outer p-region is called anode (A), the terminal connected to outer n-region is called cathode and that connected to inner p-region is called the gate (G).

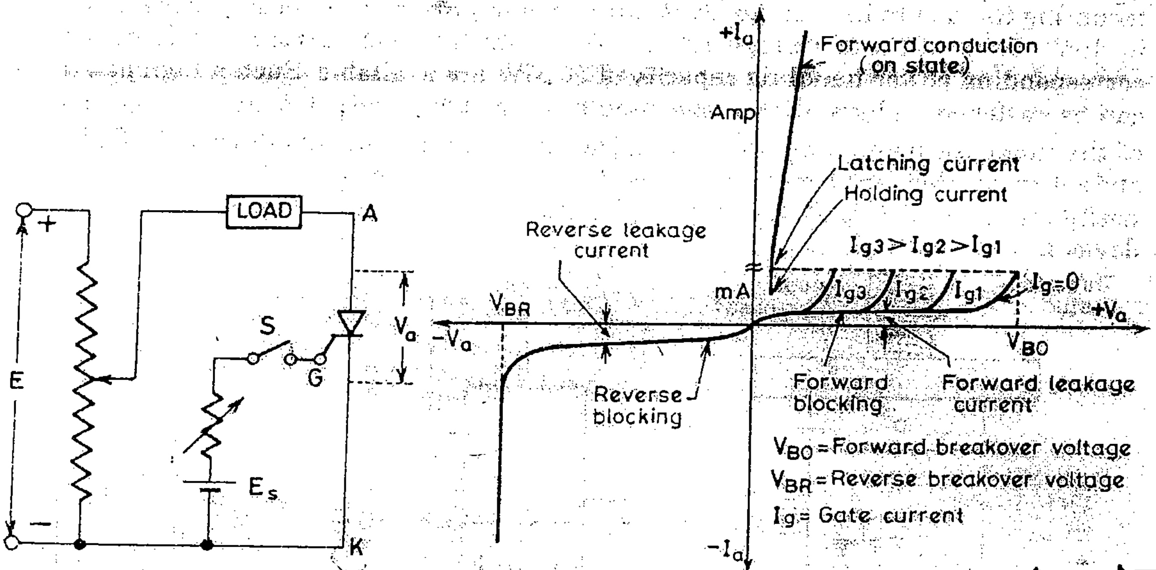
→ An SCR is so called because silicon is used for its construction and its operation as a rectifier (very low resistance in the forward conduction and very high resistance in the reverse direction) can be controlled.

7] Enumerate reverse blocking, Forward blocking forward conduction mode.

OR.

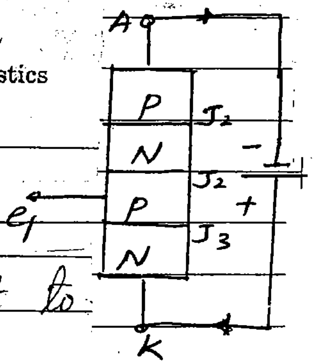
Explain static V-I ~~curve~~ of characteristic curve of SCR.

- ★ Fig 4.2 (b) Shows Static V-I characterstics of a thyristor.
- ★ Here V_a is the anode voltage across thyristor terminals A, K & I_a is anode current.
- ★ Typical SCR V-I characterstics shown in fig 4.2(b),
- ★ reveals that a thyristor has three basic modes of operation namely reverse blocking mode, forward blocking mode, & forward conduction mode.
- ★ These three modes of operation are now discussed below.



(a) (b)

Fig. 4.2. (a) Elementary circuit for obtaining thyristor V-I characteristics (b) Static V-I characteristics of a thyristor.



Reverse blocking mode:-

→ The anode is made −ve with respect to cathode.

→ The gate is kept open, there are 3 P-N junctions in thyristor J_1, J_2 & J_3, due to reverse

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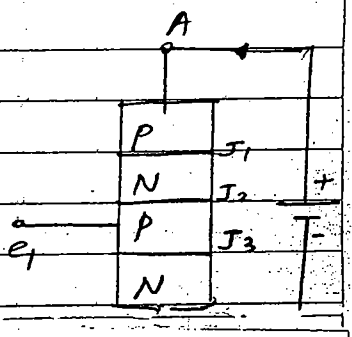
biased junction J_1 & J_3 are also reversed biased. & junction J_2 is forward biased. the thyristor doesnot conduct due to this reverse biase. Small current flows from cathode to anode. this current is called reverse leakage current. & this mode is called reverse blocking mode.

Forward blocking mode



→ The thyristor is said to be forward biased when anode is made positive with respect to cathode

→ due to this forward biased the junction J_1 & J_3 are forward biased & J_2 is reverse biased. hence the forward voltage is to be hold by junction J_2. Small current flows from anode to cathode. this current is called forward leakage current

Forward conduction mode

when the thyristor is forward biased, then it can go into forward conduction by following techniques.

(i) when $V_{AK} > V_{BO}$
(ii) when gate drive is applied
(iii) when $\frac{dv}{dt}$ exceeds permissible value
(iv) when gate cathode junction is exposed to light

7- Define GTO & list its applications

Gate turn off thyristor (GTO)

It is similar to SCR, but can be turned off by gate terminal. thus gate has full control over the conduction of the thyristor.

Applications

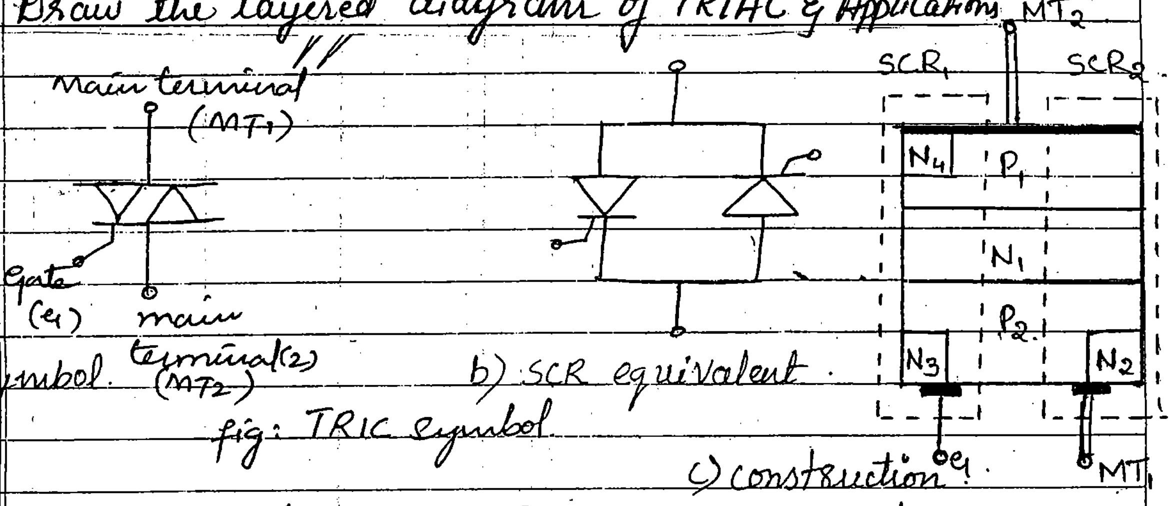
→ GTO's are used for low power applications. the gate drive required for turned off is very ~~low~~ large hence drive circuit of GTO requires more power.

→ GTO's are used for high-performance drive Systems, Such as the field-oriented control Scheme used in rolling mills, robotics & machines tools

→ Used for traction purposes because of their lighter weight. &

→ Used in adjustable frequency inverter drives

9] Draw the layered diagram of TRIAC & Applications



a) Symbol b) SCR equivalent

fig: TRIC symbol

c) construction

→ TRIAC can be considered as antiparallel SCR. it conducts in both directions & has single gate

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→ TRIAC is the word derived by combining the capital letters from the words TRIode & AC.

→ The circuit ~~&~~ Symbol & its characteristics are shown in figure (a) & (b) respectively.

→ As the TRIAC can conduct in both the directions, the terms anode & cathode are not applicable to TRIAC.

→ Its 3 terminals are usually designed as MT_1 (main terminal 1), MT_2 and the gate by G, as in thyristors.

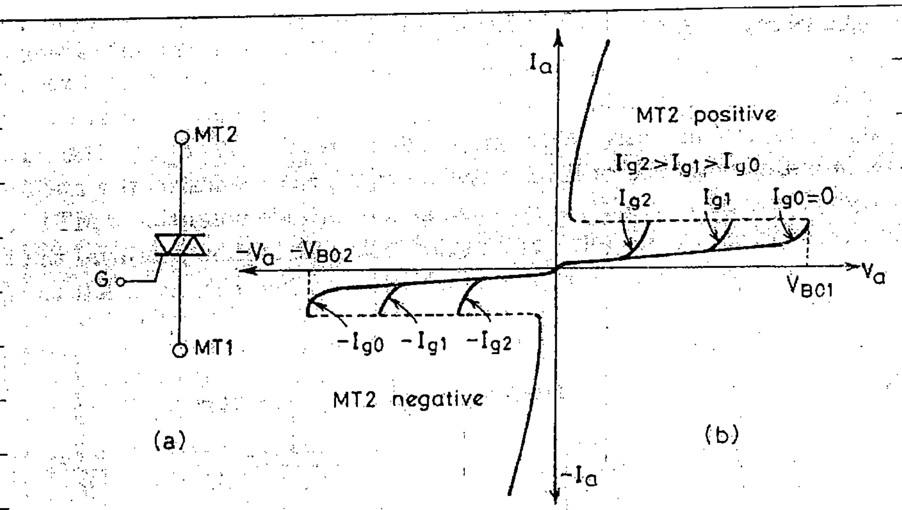


Fig. 4.47. (*a*) Circuit symbol and (*b*) static *V-I* characteristics of a triac.

Applications:-

→ TRIAC's are used for heat control, light control, motor control, & lamp dimmers.

10- State the preferred modes of turn-on of TRIAC

Ans:- There are four modes of TRIAC operation:

Modes	gate	MT_2	MT_1	Current flow path.
1	positive	positive	Negative	MT_2 to MT_1. $(P_1 - N_1 - P_2 - N_2)$
2.	positive	Negative	positive	MT_1 to MT_2. $(P_2 - N_1 - P_1 - N_4)$
3	Negative	positive	Negative	MT_2 to MT_1. $(P_1 - N_1 - P_2 - N_2)$
4.	Negative	Negative	positive	MT_1 to MT_2. $(P_2 - N_1 - P_1 - N_4)$

Modes 1 & 4 are efficient modes - **Sona Roopa**

11- Draw the V-I characteristics of DIAC & lists its application & also operation

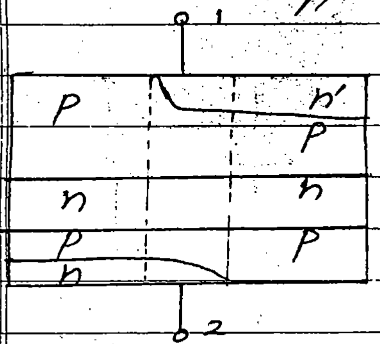


fig: cross sectional view.

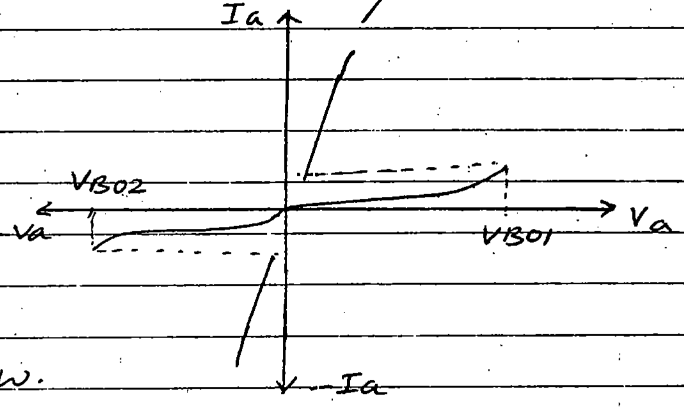


fig: V-I characteristics.

operation

→ If voltage V_{12}, with terminal 1 positive with respect to terminal 2, exceeds break-over voltage V_{BO1}, then structure pnpn conducts

→ If terminal 2 is positive with respect to terminal 1 & when V_{21} exceeds break-over voltage V_{BO2}, then structure pnpn' conducts.

V-I characteristic

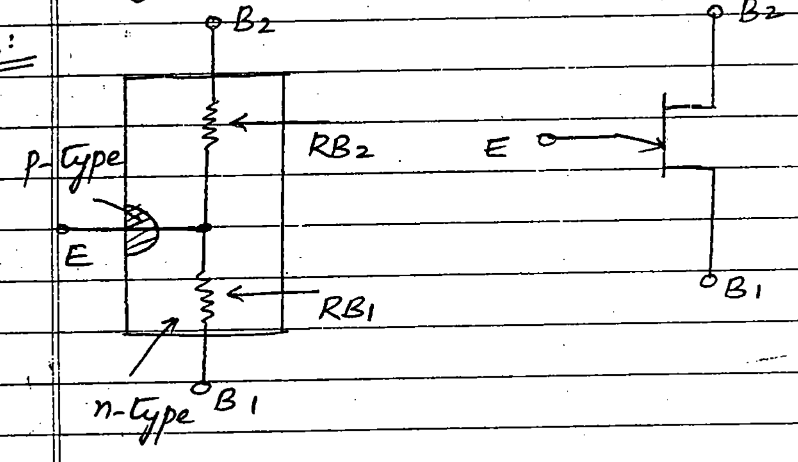
→ DIAC has symmetrical breakdown characteristics. its leads are interchangeable.

→ Its turn-on voltage is about 30V.

→ when conducting, acts like a low resistance with about 3V drop across it when not conducting, acts like an open switch.

12. Explain the UJT construction, layered diagram & lists its applications.

Ans:

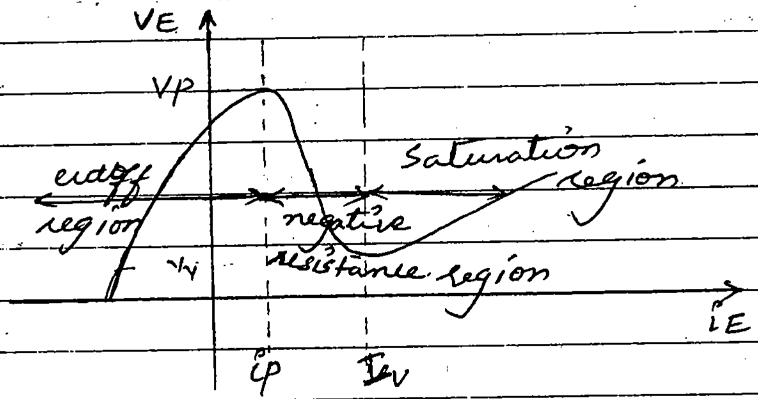


→ An UJT is made up of an n-type silicon base to which p-type emitter is embedded.

→ It has 3-terminals, emitter E, base-one B_2, & base-two B_2,

→ Between B_1 & B_2, the unijunction behaves like an ordinary resistance.

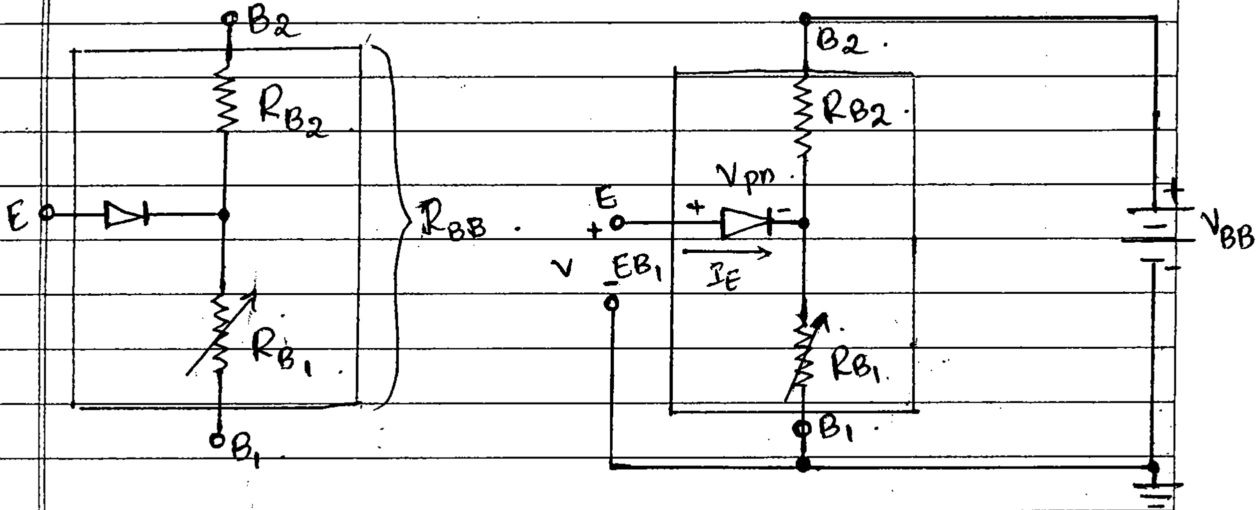
→ R_{B1} & R_{B2} are the internal resistances



characteristics

→ It is biased to operate as relaxation oscillator in the negative resistance region.

Equivalent circuit:-



(A) (B)

UJT equivalent ckt.

→ The total resistance between the base terminals is the sum of ~~IB,~~ R_{B_1} & R_{B_2} and is called the inter base resistance R_{BB}.

$$R_{BB} = R_{B_1} + R_{B_2}$$

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→ The voltage across the resistance R_{B_1} can be expressed as

$$V_{RB_1} = \frac{R_{B_1}}{R_{BB}} \times V_{BB}.$$

Stand off ratio:-

→ Intrinsic stand off ratio is a UJT characteristic & is designated by η (greek eta)

$$\eta = \frac{R_{B_1}}{R_{BB}}.$$

UJT Applications:-

- * Trigger device for SCR's & TRIAC's.
- * Non-Sinusodal oscillators.
- * Sawtooth generators.
- * Phase control.
- * Timing Circuits.

UNDERSTAND.

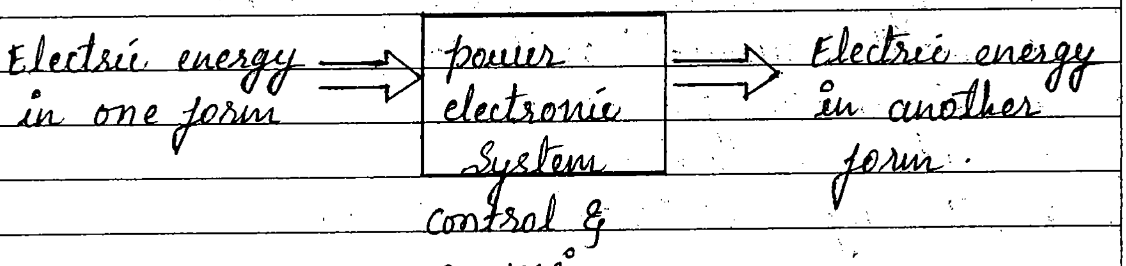
1) Describe the concept of power electronics.

Ans: power electronics belongs partly to power engineers & partly to electronics engineers

→ power engineering is mainly concerned with generation, transmission, distribution & utilization of electric energy at high efficiency.

→ electronics engineering is guided by distortionless production, transmission & reception of data & signals of very low power level

→ power electronics is defined as subject that deals with the apparatus & equipment working on the principle of electronics but rated at power level rather than signal level.



→ Figure Shows the basic functioning of power Electronic System.

→ The electric energy in one form is given at the input.

→ The power electronic System converts the electric energy into other form.

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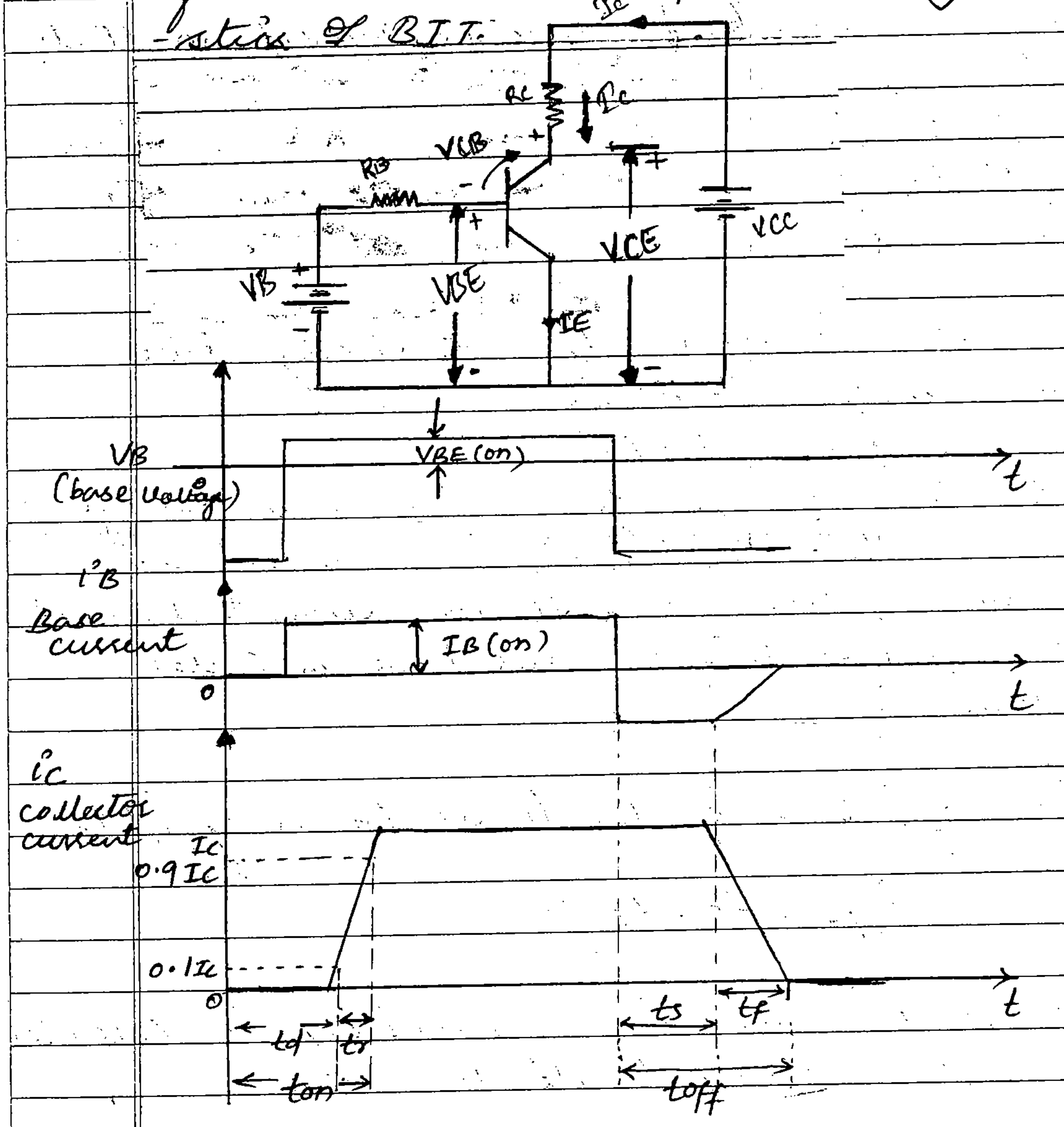
Explain with circuit diagram the operation of BJT as switch & switching characteristics of BJT.



→ collector-base junction capacitance (Ccb) & base-emitter junction (Cbe) used in turn-on & turn-off of transistor.

→ In the waveform the base-emitter voltage is made positive to turn on BJT. & base current also starts flowing.

→ the collector current does not start flowing as soon as base drive is applied. because the collector-base junction capacitance starts charging when base drive is applied.

→ delay time (td): time delay involved when collector current starts increasing after base drive is applied.

→ tr (rise time) is time required to raise collector current to its steady state.

→ turn on time (ton) is

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

→ for turn off the transistor, base voltage is made negative & base current is also negative, & collector current does not change for time ts. this time is called <u>storage time</u>

→ turn off time of the transistor is equal to

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

→ tf is the fall time required by the collector current to decay to its 10% value.

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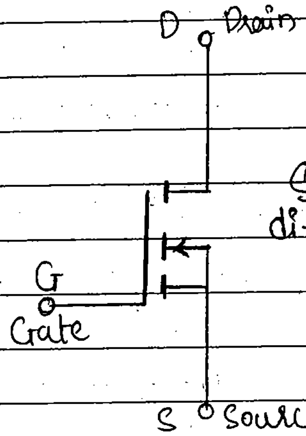
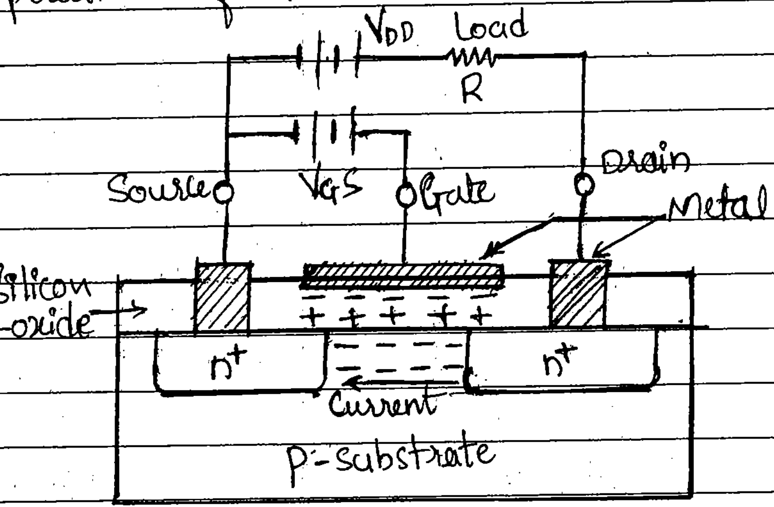
Explain the operation of N-channel enhancement MOSFET.





ⓐ Circuit symbol ⓑ Basic structure.

N-channel enhancement power MOSFET:-

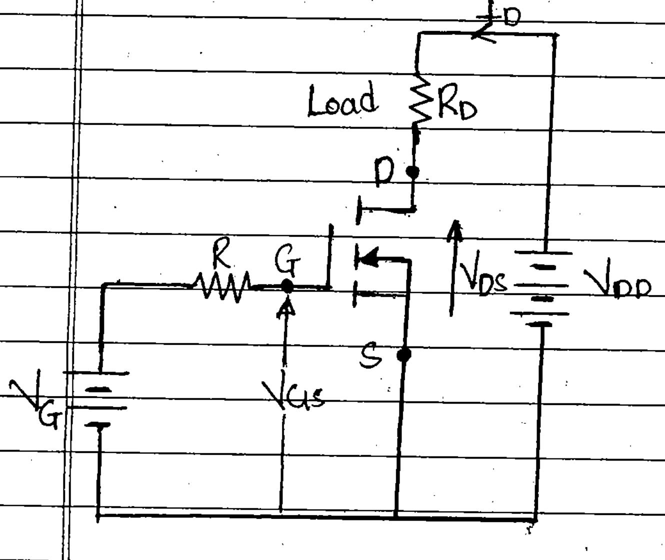
→ Power MOSFET's are two types; n-channel ehancement MOSFET and p-channel enhancement MOSFET. Out of these two types, n-channel chancement MOSFET is more common because of higher mobility of elections.

→ A simplified structure of n-channel planar MOSFET of low power rating is shown in fig (b)

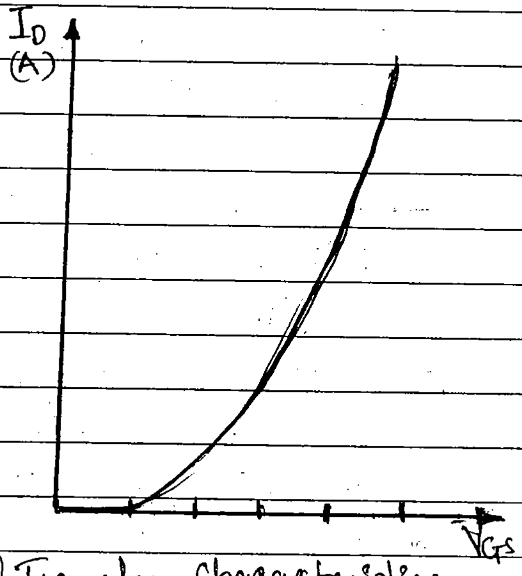
→ On p-substrate, two heavily doped n^+ regions are diffused. An insulating layer of silicon di-oxide (SiO_2) is grown on the surface. Now this insulating layer is etched in order to embed metallic source and drain terminals.

→ Note that n^+ regions make contact with source and drain terminals as shown. A layer of metal is also deposited on SiO_2 layer so as to form the gate of MOSFET.

- → When gate circuit is open, no current flows from drain to source and load because of one reverse-biased n^+-p junction.
- → When gate is made positive with respect to source an electric field is established as shown in fig ⓑ
- → These negative charges, called electrons, from n-channel and current can flow from drain to source as shown by the arrow.
- → If V_{GS} is made more positive, n-channel becomes more deep and therefore more current flows from D to S.
- → This shows that drain current I_D is enhanced by the gradual increase of gate voltage, hence the name enhancement MOSFET.



(a) Circuit diagram



ⓑ Transfer Characteristics.

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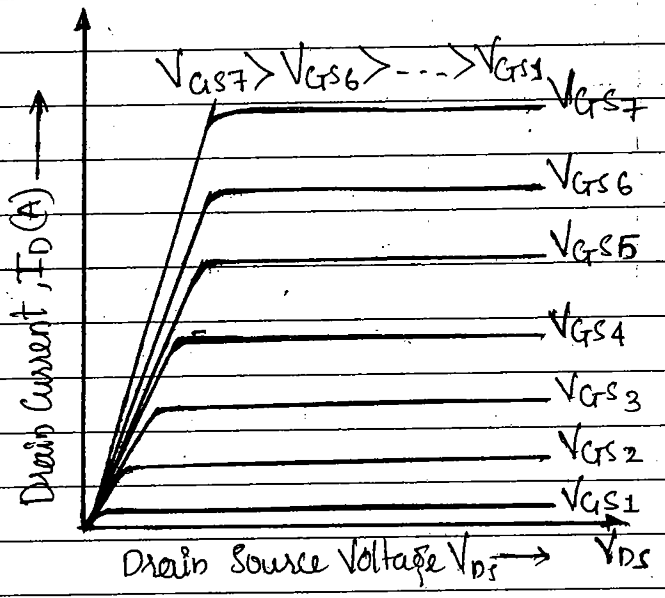


ⓒ Output characteristics.

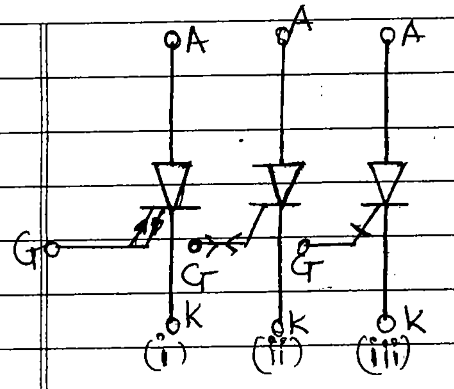
Explain the principle of operation of GTO.

→ Gate turn Off (G.T.O) Thyristor, a pnpn device, can be turned on like an ordinary thyristor by a pulse of positive gate current.

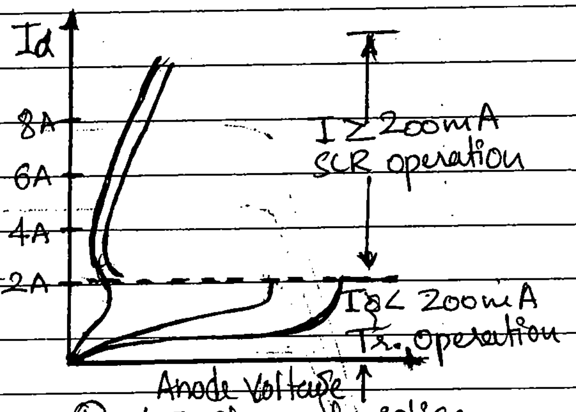
→ In inverter and chopper circuits, a thyristor can be turned off by forced commutation. For such applications, a GTO is, however, a more versatile device;

→ It can be easily turned off by a negative gate pulse of appropriate amplitude.

→ Fig ⓐ gives the circuit symbols of a GTO. The symbols shown in ⓐ (i) and (ii) are self explanatory, gate current can go in for turning on and out for turning off. But the symbol a (iii) looks easy when circuit configurations using GTOs are to be drawn.



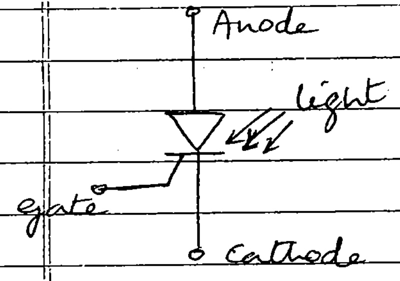
(a) Circuit symbol



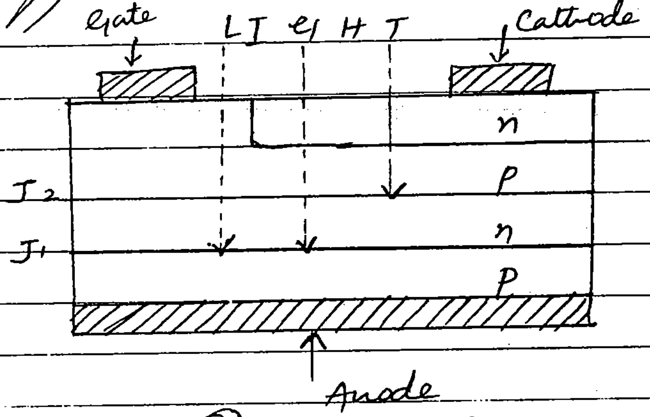
(b) V-I characteristics.

Q16. Draw the layer structure of LASCR & explain its operation & lists applications

Ans:



(a) Symbolic representation



(b) schematic

→ As shown in figure, electron-hole pairs are generated due to light radiation on silicon wafer, this produces triggering current.

→ The gate structure is designed to have good sensitivity to light.

Applications

* It is used in high voltage, high current power systems such as HVDC transmission & static reactive volt-ampere.

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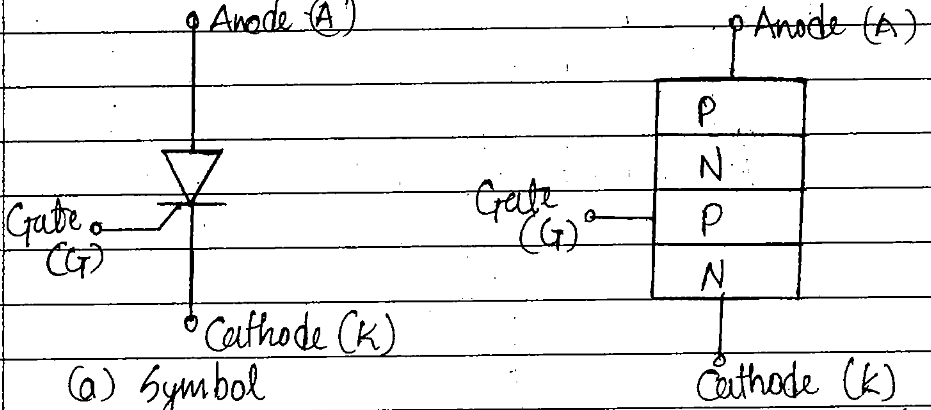
Draw the layer diagram of SCR and explain the concept of two transistor analogy.



(a) Symbol

(b) Internal construction.

Layer diagram

1) → Thyristor is a four layer, three junction, P-n-P-n semiconductor switching device.

2) → It has three terminals, Anode, Cathode & Gate.

3) → It is p-type & n-type silicon semiconductor forming three junctions J_1, J_2, J_3.

Two-transistor Analogy

1) → The principle of thyristor operation can be explained with the use of its two-transistor model.

2) → Fig (a) shows schematic diagram of a thyristor. From this figure, two-transistor model is obtained by bisecting the two middle layers, along the dotted line, in two seperate halves as shown in fig (b)

3) → In figure (b), junctions $J_1 - J_2$ and $J_2 - J_3$ can be considered to constitute pnp and npn transistor seperately.

4) → The circuit representation of the two-transistor model of a thyristor is shown in fig (c)

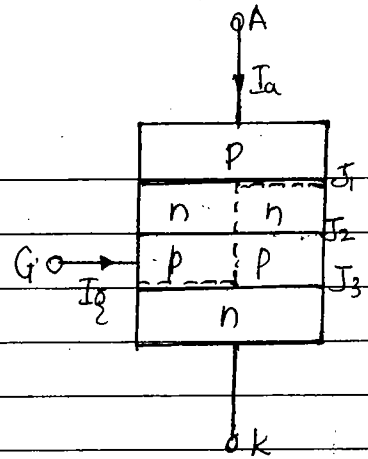


fig (a) Schematic diagram

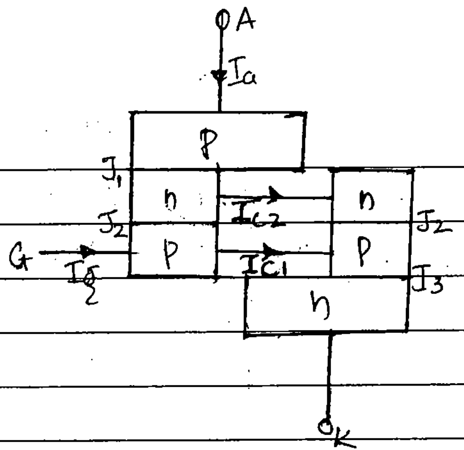


fig (b)

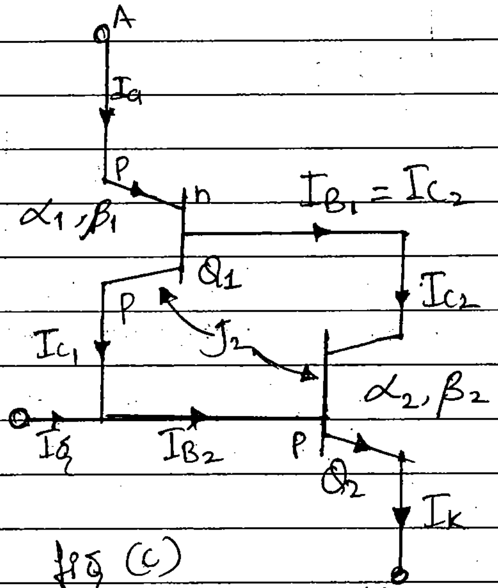


fig (c)

fig (b) & (c) Two-transistor model

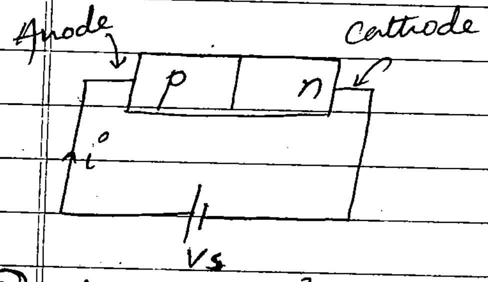
14 Explain V-I characteristics of power diode

* → when anode is positive with respect to cathode, diode is said to be forward biased.

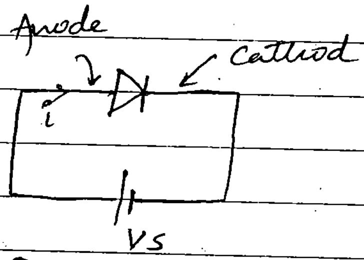
→ with increase in source voltage Vs from zero value, initially diode current is zero. from Vs = 0 to cut in voltage, the forward diode current is very small.

→ Beyond cut-in voltage, the diode current rises rapidly & diode is said to conduct. & cut-in voltage is around 0.7 V.

* → when cathode is positive with respect to anode, the diode is said to be in reverse biased. in this small leakage current flows.



ⓐ p-n junction



ⓑ Diode symbol.

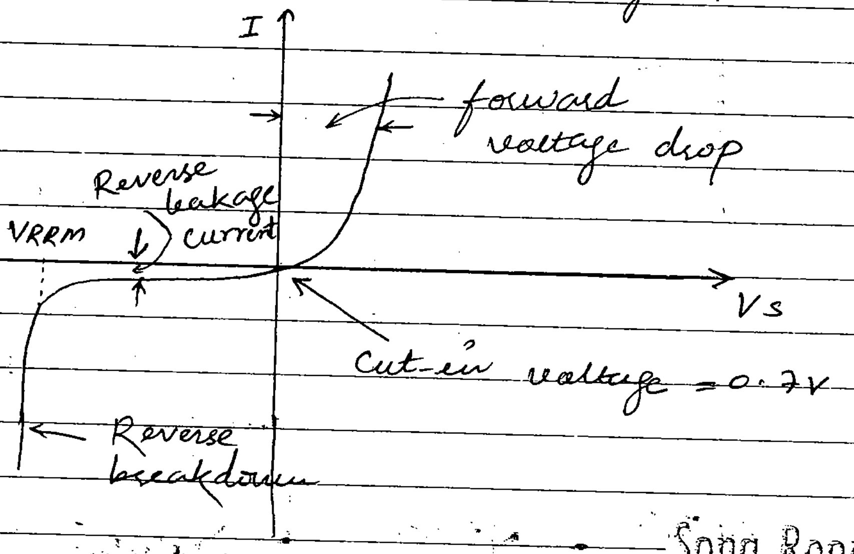


fig: V-I characteristics

10. Draw the V-I characteristics of DIAC & lists its application & also operation.

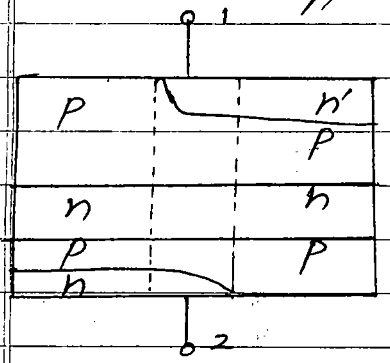


fig: Cross Sectional View.

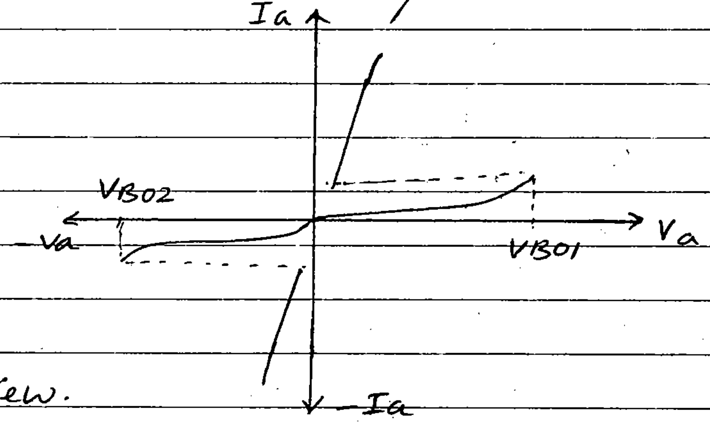


fig: V-I characteristics.

operation

→ If voltage V12, with terminal 1 positive with respect to terminal 2, exceeds break-over voltage VBO1, then structure pnpn conducts.

→ If terminal 2 is positive with respect to terminal 1 & when V21 exceeds break-over voltage VBO2, then structure pnpn' conducts.

V-I characteristic

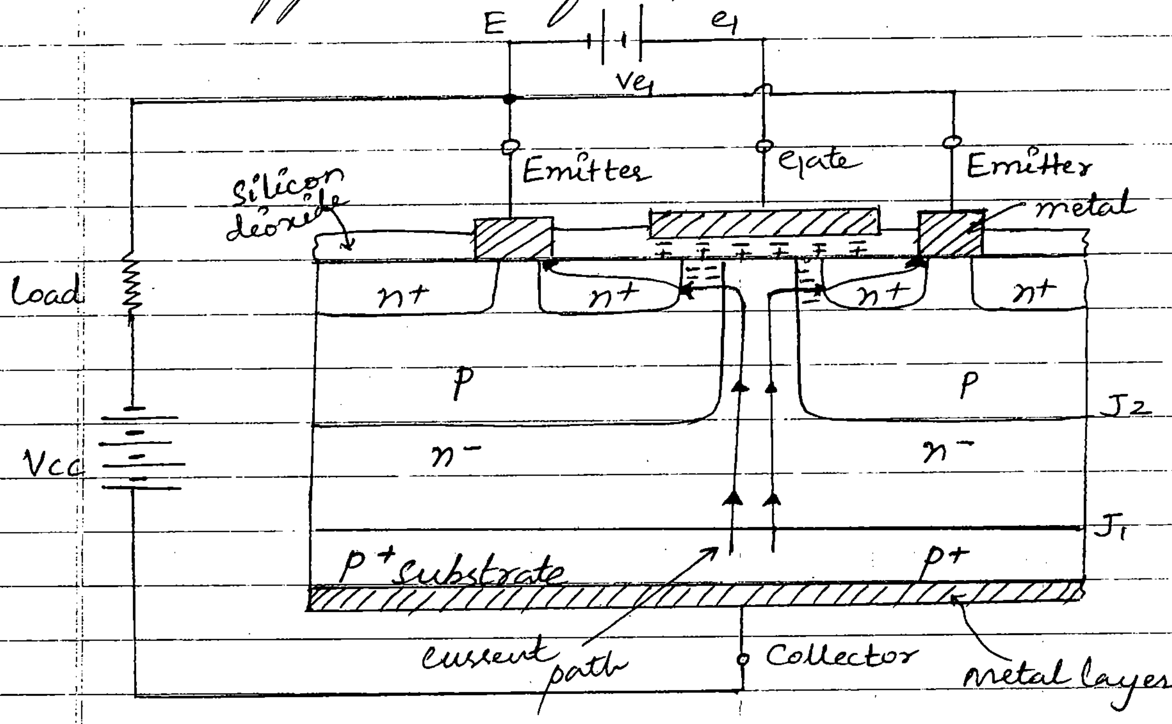
→ DIAC has symmetrical breakdown characteristics. its leads are interchangeable.

→ Its turn-on voltage is about 30V.

→ when conducting, acts like a low resistance with about 3V drop across it when not conducting, acts like an open switch.

STUDENT'S NAME		TOTAL MARKS OBTAINED
CLASS	SUBJECT	
ROLL NO.	DATE	

5- Draw the structure of IGBT & list the applications of IGBT.



→ As shown in figure, n-channel short circuits the n^- region with n^+ emitter regions. an electron movement in the n-channel causes hole injection from p^+ substrate to n^- epitaxial

→ Three layers p^+, n^- & p constitute a pnp transistor with p^+ as emitter, n^- as base & p as collector.

Applications

They are widely used in medium power applications such as dc & ac motor drives, UPS systems, power supplies & drives for solenoides.

15+a. List the difference between MOSFET, BJT & IGBT

	power MOSFET	BJT	IGBT
1-	It is voltage-operated device	current-controlled device	voltage controlled device
2-	A negligible current is required at its control terminal to maintain in ON-state	It needs an appreciable value of control current for keeping it in ON-state	A small current is required at control terminal to maintain it in ON-state
3-	It's switching speed is high	It's switching speed is lower than MOSFET	Its switching speed is very high.
4-	The current & voltage ratings are low	the current & voltage ratings are higher than MOSFET	the current & voltage ratings are above those of MOSFET
5-	ON-state voltage drop is higher than the BJT	ON-state voltage drop is lower than the MOSFET	ON-state voltage drop is mini-mum.

Jasmeen. 2 unit

2.1 Methods to Turn-ON SCR May-11, 12, 14, 15, 16, Nov.-11, Dec.-12, 14, 15

Thyristor can be turned on by following :

i) Forward break over voltage

ii) $\frac{dv}{dt}$ triggering

iii) Exceeding internal device temperature

iv) Focusing light beam on the junction

v) Gate triggering.

The gate triggering is the most widley used method of turning on the thyristor.

2.1.1 Functions to be Fulfilled by Gate Drive

The gate drive has to satisfy the following requirements :

i) The maximum gate power should not be exceeded by gate drive, otherwise SCR will be damaged.

ii) The gate voltage and current should be within the limits specified by gate characteristics for successful turn-on.

iii) The gate drive should be preferably pulsed. In case of pulsed drive the following relation must be satisfied :

(Maximum gate power × pulse width) × (Pulse frequency) ≤ Allowable average gate power

iv) The width of the pulse should be sufficient to turn-on the SCR successfully.

v) The gate drive should be isolated electrically from the SCR. This avoids any damage to the trigger circuit if in case SCR is damaged.

vi) The gate drive should not exceed permissible negative gate to cathode voltage, otherwise the SCR is damaged.

vii) The gate drive circuit should not sink current out of the SCR after turn-on.

2.1.2 Pulsed Gate Drive

Instead of applying a continuous (DC) gate drive, the pulsed gate drive is used. The gate voltage and current are applied in the form of high frequency pulses. The frequency of these pulses is upto 10 kHz. Hence the width of the pulse can be upto 100 micro seconds. The pulsed gate drive is applied for following reasons (advantages) :

(i) The SCR has small turn-on time i.e. upto 5 microseconds. Hence a pulse of gate drive is sufficient to turn-on the SCR.

(ii) Once SCR turns-on, there is no need of gate drive. Hence gate drive in the form of pulses is suitable.

(iii) The DC gate voltage and current increases losses in the SCR. Pulsed gate drive has reduced losses.

(iv) The pulsed gate drive can be easily passed through isolation transformers to isolate SCR and trigger circuit.

2.1.3 Gate Turn-On Methods

Gate triggering is the most convenient method of triggering the SCR. Various methods are listed below :

i) R-firing circuit ii) RC-half wave firing circuit

iii) RC-full wave firing circuit iv) UJT triggering circuit

Review Questions

1. *State various methods of turn-on of SCR.* May-11, Marks 7, Nov.-11, Dec.-14, Marks 4, May-12, Marks 6, May-14, 15, Marks 3, Question Bank, Model Q. P., Marks 5
2. *List various gate turn-on methods of SCR.* Dec.-12, Marks 4
3. *List the general functions to be fulfilled by gate control circuits.* Dec.-12, Marks 2, Dec.-15, Marks 4, May-14, Marks 3

2.2 General Layout Diagram of Firing Circuit Dec.-14

The triggering circuits are called firing circuits. We have already discussed the requirements of gate trigger circuits. The following features or requirements must be fulfilled by the firing circuit in addition to those discussed earlier.

i) The firing circuit should produce the triggering pulses for every thyristor at appropriate instants.

ii) The triggering pulses generated by the control circuit need to be amplified and passed through the isolation circuit. The triggering pulses generated by the control circuit have very small power. Hence their power is increased by pulse amplifier. Fig. 2.2.1 shows the scheme. The firing circuit operates at low voltage levels (5 to 20 volts). And the thyristor operates at high voltage levels (greater than 250 volts). Hence there must be electrical isolation between firing circuit and thyristor. This isolation is provided by the pulse transformer or optocouplers.

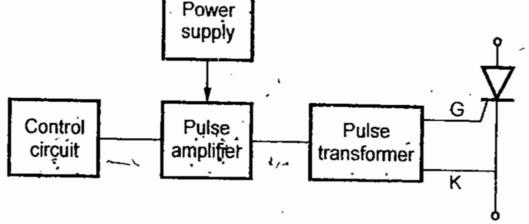


Fig. 2.2.1 Main blocks of firing circuit

Review Question

1. *Draw the general layout diagram firing circuit and explain it.* **Dec.-14, Marks 5, Question Bank**

2.3 R-Firing Circuit

Nov.-11, May-11, 13, Dec.-14, 16

Fig. 2.3.1 shows the simple R-firing circuit.

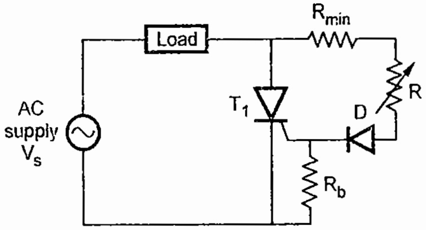


Fig. 2.3.1 R-firing circuit

The resistance R_{min} is used to limit the gate current to its maximum value. If $I_{g(max)}$ is maximum gate current and V_m is the peak supply voltage, then R_{min} will be,

$$R_{min} \geq \frac{V_m}{I_{g(max)}}$$

The resistance R_b is the stabilizing resistance. The voltage across R_b should not exceed minimum gate voltage $\left(V_{g(min)}\right)$ otherwise thyristor will turn-on directly. Then the variable resistance R is used to trigger the thyristor T_1. When 'R' is zero, the triggering angle is minimum. The triggering angle increases as value of 'R' is increased. Fig. 2.3.2 shows the waveforms of this circuit.

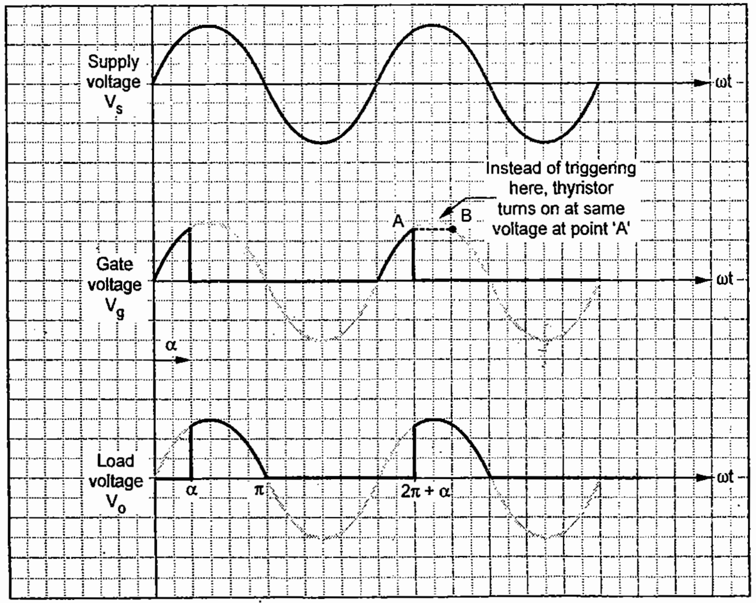


Fig. 2.3.2 Waveforms of R-firing circuit

The anode to cathode voltage and the gate current are in phase. Hence the triggering angle of T_1 cannot be delayed beyond 90°. In the above waveforms, observe that at points 'A' and 'B' gate voltage is same.

If it is desired to trigger thyristor at point 'B', similar voltage appears at point 'A'. Hence thyristor will turn-on at point 'A' only. Hence maximum triggering angle will be 90°. This is because the gate current and anode voltage are in phase.

Review Question

1. *Explain briefly the simple resistance triggering circuit.* **May-11, Dec.-16, Marks 5**

OR

With a neat sketch and waveforms explain working of R-firing circuit. **Nov.-11, May-13, Dec.-14, Marks 6, Question Bank**

2.4 RC Firing Circuit

May-12, 15, 16, Dec.-13, 15

Fig. 2.4.1 shows the circuit diagram of RC-firing circuit. In the negative half cycle, the capacitor charges through diode D_2 to negative supply voltage. The capacitor charges to $-V_m$ (i.e. negative peak) of the supply. This is shown in waveforms of Fig. 2.4.2. The capacitor then discharges (i.e. charges towards positive) through resistance R during the positive half cycle of the supply. The thyristor triggers when capacitor charges to value greater than $v_{g(min)}$. Observe the capacitor voltage and load voltage waveforms in Fig. 2.4.2. 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 (i.e. maximum firing angle), the following relation holds :

$$RC \geq \frac{1.3}{2f} \qquad \dots (2.4.1)$$

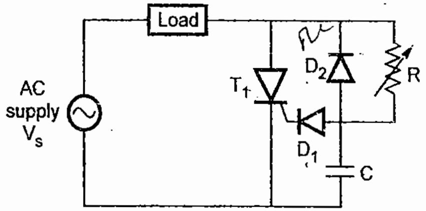


Fig. 2.4.1 RC half wave firing circuit

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

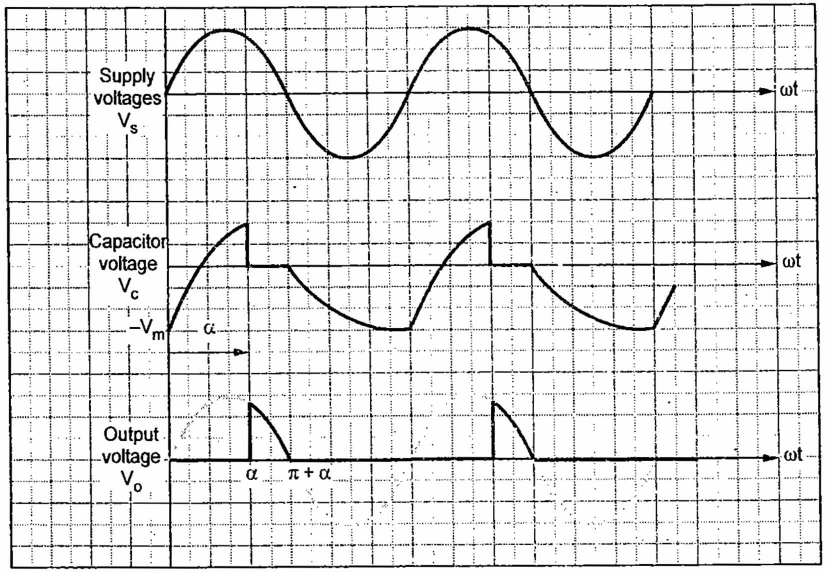


Fig. 2.4.2 Waveforms of half wave RC firing circuit

Review Question

1. *Draw RC-firing circuit and explain its operation with waveforms.*

May-12, Marks 4, Dec.-13, Marks 5, May-15, Marks 8, Dec.-15, Marks 7, May-16, Marks 6

Question Bank

2.5 Full Wave RC-Firing Circuit

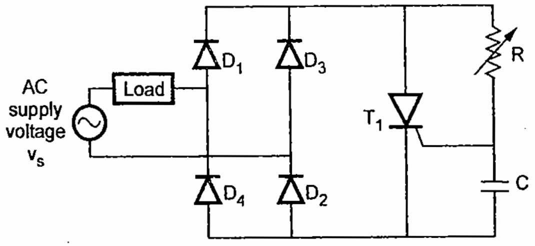


Fig. 2.5.1 Full wave RC firing circuit

Fig. 2.5.1 shows the full wave RC-firing circuit. The supply to the thyristor is given through the uncontrolled rectifier. Hence both the half cycles are positive half cycles to the thyristor. The capacitor starts charging in every half cycle at the beginning. Whenever the capacitor voltage reaches to the value greater than $v_{g\,(min)}$, the thyristor turns-on. Fig. 2.5.2 shows the waveforms of this circuit. Once the thyristor turns-on, the capacitor voltage is clamped to zero, till next half cycle. The capacitor again starts charging from zero. The firing angle can be varied from 0 to 180°. The triggering is controlled in both the cycles. The following relation holds for maximum firing angle,

---

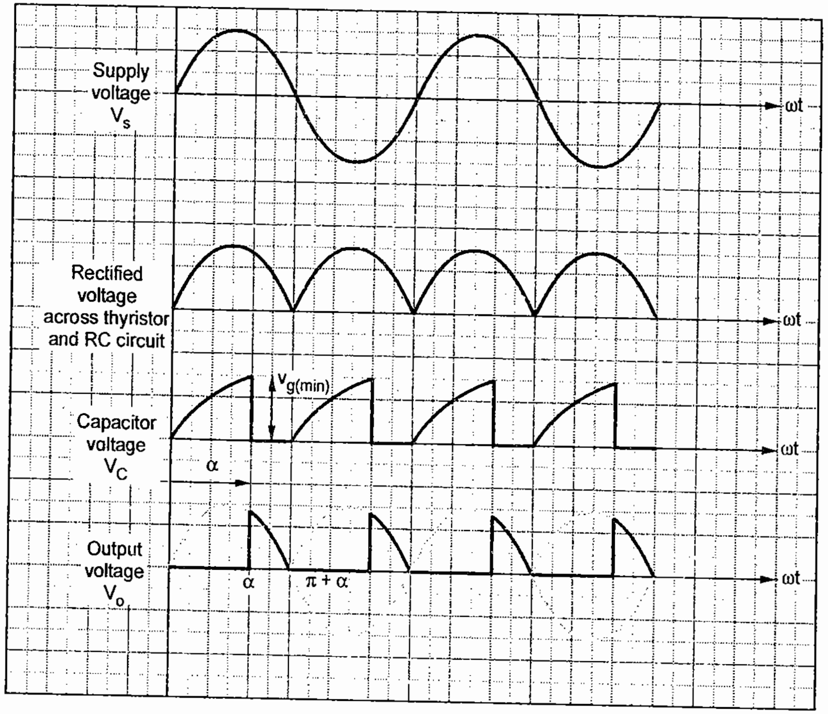


Fig. 2.5.2 Waveforms of full wave RC firing circuit

$$RC \geq \frac{0.157}{2\pi f} \qquad \text{... (2.5.1)}$$

Here f is the frequency of the supply.

Review Question

1. *Explain full wave RC firing circuit with the help of circuit diagrams and waveforms.*

Question Bank

2.6 Unijunction Transistor (UJT)

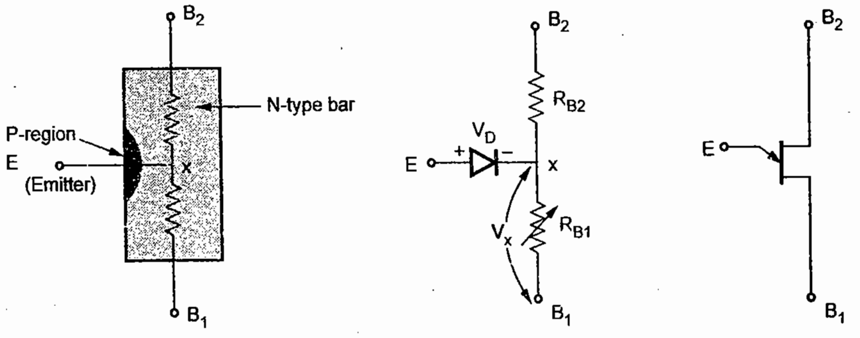
2.6.1 Principle of UJT

It has N-type bar. A P-type region is alloyed into one side of this bar. It forms one p-n junction. Hence it is called uni-junction transistor.

- It starts conducting when certain voltage is reached at the emitter. It operates in negative resistance region of the current-voltage characteristics.
- This negative resistance characteristic makes UJT to act an relaxation oscillator.

2.6.2 Construction, Working and Characteristics of UJT

- Fig. 2.6.1 shows the construction and equivalent circuit of UJT. Observe that emitter and N-type bar forms a PN junction.



(a) Construction (b) Equivalent circuit (c) Symbol

Fig. 2.6.1 Unijunction transistor

- As shown in Fig. 2.6.1 (b), the internal resistance of the bar is represented by R_{B2} and R_{B1}. Note that R_{B1} is variable since it changes in on and off states of UJT.

- **UJT turn-on** : When the voltage at point x increases above ηV_{BB}, UJT turns on. Here $\eta = 0.63$ typically is called intrinsic stand-off ratio. V_{BB} is the bias voltage of UJT as shown in Fig. 2.6.2.

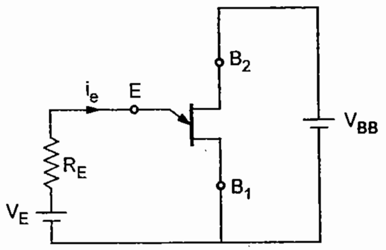


Fig. 2.6.2 UJT bias circuit

- When $V_x = \eta V_{BB}$, holes from heavily doped emitter are injected in the N-type bar. Because of these large number of holes, resistance R_{B1} reduces. This causes voltage V_x to drop. (Refer Fig. 2.6.1) (b)). At the same time emitter current I_E increases further. This forms a negative resistance region as shown in Fig. 2.6.3. It is the region between point A and B of the characteristic.

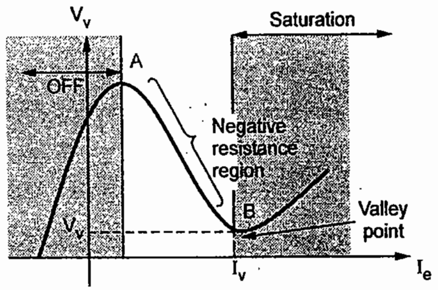


Fig. 2.6.3 UJT characteristics

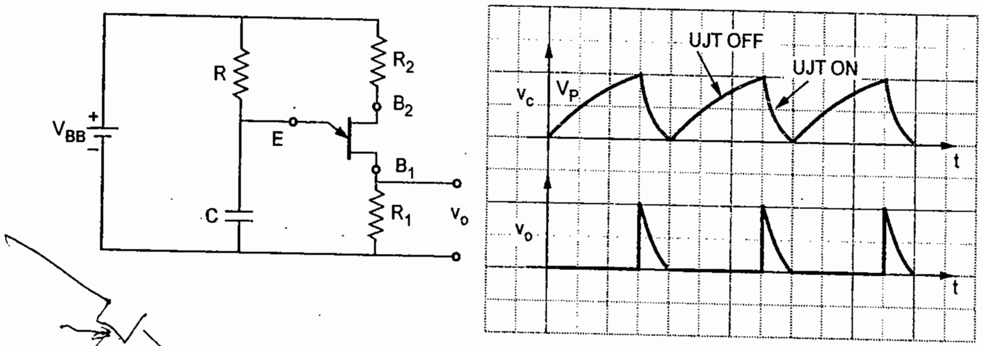
- Note that before point 'A' the UJT is said to have off state, and after point 'B' it is saturated.

- **UJT turn-off** : When the emitter current is less than valley current (I_V), the UJT turns-off. Thus valley current acts like holding current for the UJT.

2.6.3 UJT Relaxation Oscillator

- Fig. 2.6.4 (a) shown the circuit diagram and waveforms of the UJT relaxation oscillator. The capacitor 'C' is charged through resistance 'R' from zero voltage. UJT is off at this time.

- When capacitor voltage is equal to V_P, the UJT turns ON. The capacitor discharges through emitter, B_1 and R_1. Note that R_1 is external resistance connected to UJT. The voltage across R_1 is v_0. The waveforms are shown in Fig. 2.6.4 (b).



(a) Circuit (b) waveforms

Fig. 2.6.4 UJT relaxation oscillator

- As the capacitor discharges to valley voltage V_v, UJT again turns-OFF and capacitor starts charging. Then the cycle repeats. Hence this circuit is called oscillator.

- The voltage V_P is given as,

$$V_P = V_x + V_D \qquad (V_D \text{ is internal diode voltage see Fig. 2.5.3 (b)})$$

$$= \eta V_{BB} + V_D \qquad (\text{Here } V_x = \eta V_{BB})$$

2.6.4 Typical Parameters for UJT

Following are the typical parameters for UJT :

1. Intrinsic stand-off ratio (η) : 0.56 to 0.75

2. Internal resistance (R_{B_1}) : 4 kΩ *to* 2 Ω
3. Valley voltage (V_v) : 2 V
4. Valley current (I_v) : 4 mA

2.6.5 Applications

1. UJT is used as a trigger device for SCR, GTO and Triac etc.
2. It is used as flasher in low power switching circuit.
3. Due to negative resistance characteristic it is used as oscillator.

2.6.6 Pulse Triggering using UJT

Dec.-12, 13, 16, May-13, 14

The unijunction transistor (UJT) triggering circuit is used in most of the applications. Fig. 2.6.5 shows the circuit diagram of UJT triggering circuit.

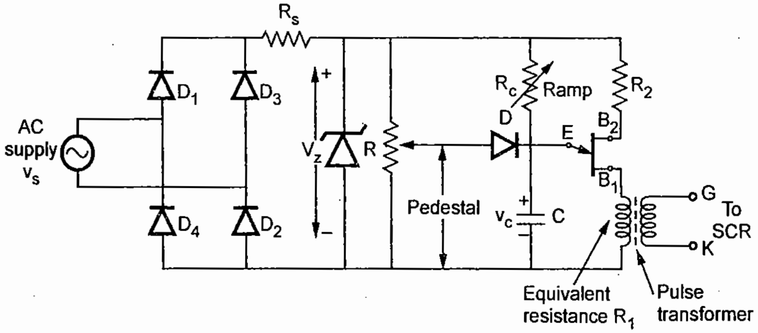


Fig. 2.6.5 UJT triggering circuit

Operation

- The supply voltage is rectified and given to the zener regulator. The voltage of zener diode is V_z. The zener diode clamps the rectified voltage to V_z as shown in the waveforms of Fig. 2.6.6. Hence voltage V_z is applied to the UJT circuit.
- The pedestal control indicates initial voltage level in the capacitor. It can be adjusted through resistance *R*. The ramp control indicates charging of capacitor from pedestal level. The waveforms of Fig. 2.6.6 shows these levels.

i) The capacitor charges through resistance R_c. When the capacitor voltage becomes equal to V_p, the peak voltage of the UJT, it turns-on. The capacitor discharges through emitter (*E*), base (B_1) and primary of pulse transformer. The UJT is turned-on when the capacitor discharges. Since current flows through the primary of pulse transformer, a pulse is generated. This pulse as shown in Fig. 2.6.6 is the gate triggering pulse.

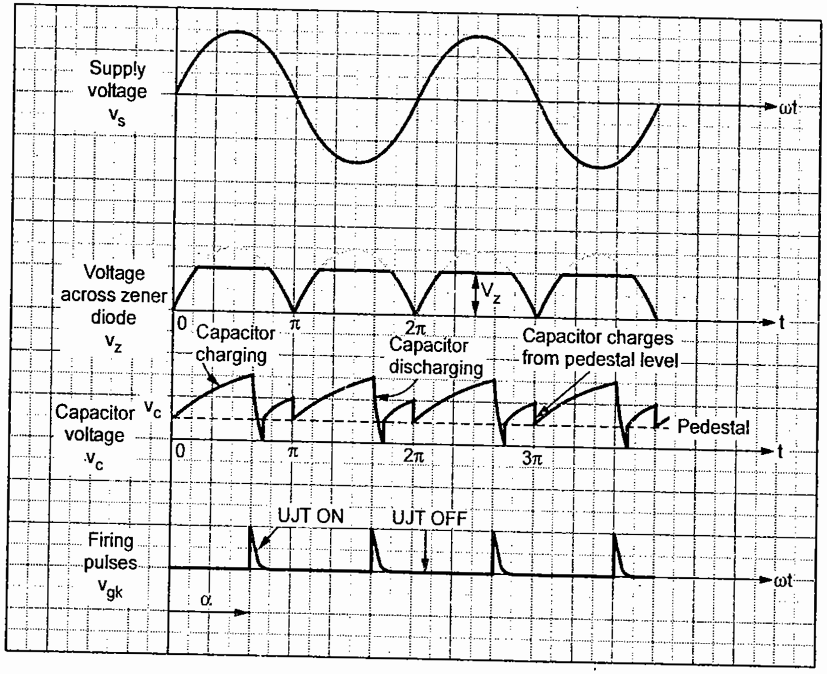


Fig. 2.6.6 Waveforms of UJT triggering circuit

ii) When the capacitor discharges to a voltage called valley voltage (V_v), the UJT turns-off and capacitor again starts charging from pedestal level. This mode of working of UJT is called *relaxation oscillator.*

iii) The delay angle 'α' is the angle when first triggering pulse is generated in the half cycle. The charging of the capacitor can be varied by resistance R_c. Hence delay angle can also be varied. The UJT trigger circuit has the firing angle range from 0 to 180°.

The zener voltage acts as a supply voltage for UJT relaxation oscillator. This voltage becomes zero at 0, π, 2π, 3 π, ...etc. The capacitor voltage also becomes zero at these instants. Thus synchronization with zero crossings is achieved. The UJT trigger circuit can be used to trigger SCRs in 1 ϕ converters, 1 ϕ AC regulators etc.

Mathematical analysis

The peak voltage at which UJT turns on is given as,

$$V_p = \eta V_{BB} + V_D \qquad \text{... (2.6.1)}$$

Here V_p is the peak voltage

V_{BB} is the supply voltage of UJT circuit

V_D is forward drop of UJT

η is intrinsic stand-off ratio.

The intrinsic stand-off ratio (η) depends upon the UJT. The period of oscillation of the UJT relaxation oscillator is given as

$$\boxed{T = R_c\, C\, ln\left(\frac{1}{1-\eta}\right)} \quad \text{... (2.6.2)}$$

Fig. 2.6.7 shows the waveforms of free running UJT relaxation oscillator.

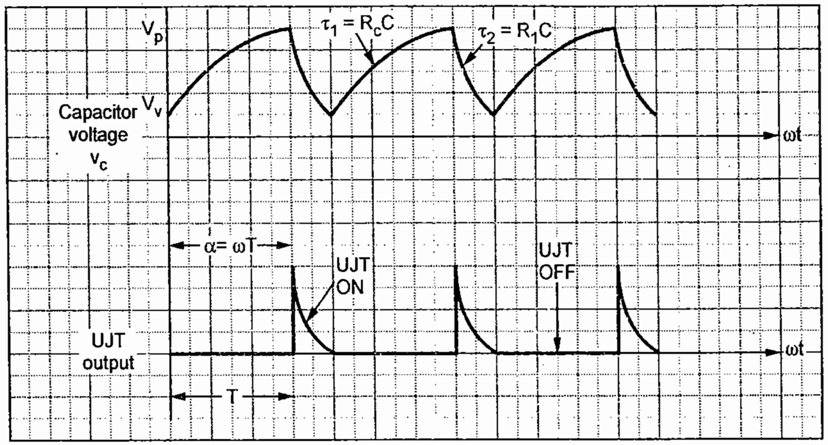


Fig. 2.6.7 Waveforms of free running UJT relaxation oscillator

The capacitor voltage waveform and UJT output are shown in the above figure. From Fig. 2.6.6, it is clear that triggering angle will be,

$$\alpha = \omega T$$

Hence from equation (2.6.2) we can write,

$$\boxed{\alpha = \omega\, R_c\, C\, ln\left(\frac{1}{1-\eta}\right)} \quad \text{... (2.6.3)}$$

This equation gives firing angle of UJT triggering circuit. Here $\omega = 2\pi f$ and f is the frequency of UJT oscillator. The resistance R_2 should be selected as follows :

$$\boxed{R_2 = \frac{0.7\left(R_{B2} + R_{B1}\right)}{\eta\, V_{BB}}} \quad \text{... (2.6.4)}$$

Here R_{B_2} and R_{B_1} are interbase resistance of the UJT. R_2 can also be calculated approximately as,

$$\boxed{R_2 = \frac{10^4}{\eta V_{BB}}} \quad \text{... (2.6.5)}$$

Note that, this expression does not require R_{B_1} and R_{B_2}. Normally pulse transformer is connected at the base B_1 of UJT. Pulses are passed through pulse transformer. This provides isolation between SCR circuit and UJT triggering circuit. The resistance of pulse transformer primary can be denoted by R_1. This resistance controls width of the triggering pulse. From Fig. 2.6.7, this width is given as,

Width of triggering pulse, $\tau_2 = R_1 C$ ... (2.6.6)

More accurately this pulse width will be,

$$\tau_2 = (R_1 + R_{B_1})C \quad \text{... (2.6.7)}$$

Here we have considered the interbase resistance R_{B_1} also. If leakage current of UJT is given, then R_1 can be calculated using following equation,

$$V_{BB} = I_{leakage}(R_1 + R_2 + R_{B_1} + R_{B_2}) \quad \text{... (2.6.8)}$$

Here $I_{leakage}$ is the leakage current of UJT.

The maximum value of R_c is given as,

$$R_{c\,(\max)} = \frac{V_{BB} - V_p}{I_p} \quad \text{... (2.6.9)}$$

and the minimum value of R_c is given as,

$$R_{c(\min)} = \frac{V_{BB} - V_v}{I_v} \quad \text{... (2.6.10)}$$

Here V_p is peak voltage

I_p is peak current

V_v is valley voltage

I_v is valley current

2.6.7 Pedestal Circuit with Cosine Modified Ramp

Fig. 2.6.8 shows the pedestal circuit having cosine modified ramp control.

- In the circuit, the zener voltage is given to pedestal control and base of UJT.
- But the charging of capacitor C_1 takes place by rectified voltage.
- The pedestal voltage can be varied by resistance R_1.
- The charging of capacitor C_1 is cosine modified and its rate can be varied by resistance R_2.

- The firing angle can be controlled by controlling the pedestal voltage.

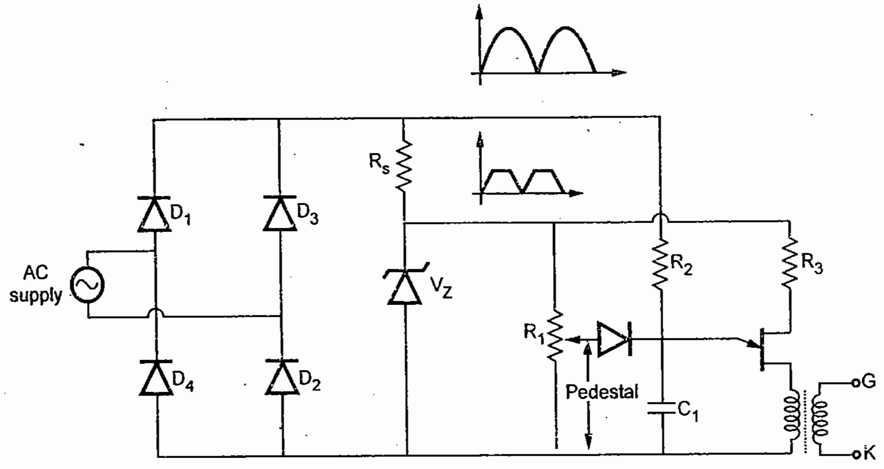


Fig. 2.6.8 Pedestal circuit with cosine modified ramp

Advantages of cosine modified ramp control

i) The control characteristics is linear.

ii) Control gain is high.

Example 2.6.1 *A UJT is used to trigger the thyristor whose minimum gate triggering voltage is 6.2 V. The UJT ratings are :*

$\eta = 0.66,\ I_p = 0.5\ mA;\ I_v = 3\ mA,$

$R_{B1} + R_{B2} = 5\ k\Omega$, *leakage current* $= 3.2\ mA$

$V_p = 14\ V$ *and* $V_v = 1\ V.$

Oscillator frequency is 2 kHz and capacitor $C = 0.04\ \mu F$. *Design the complete circuit.*

Solution : From equation (2.6.2),

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

Here $T = \frac{1}{f} = \frac{1}{2 \times 10^3}$, since $f = 2$ kHz and putting other values,

$$\frac{1}{2 \times 10^3} = R_c \times 0.04 \times 10^{-6}\ ln\left(\frac{1}{1-0.66}\right)$$

$$R_c = 11.6\ k\Omega$$

The peak voltage is given as,

$$V_p = \eta\ V_{BB} + V_D$$

Let $V_D = 0.8$, then putting other values,

$$14 = 0.66\ V_{BB} + 0.8$$

$$V_{BB} = 20\ V$$

The value of R_2 is given by equation (2.6.4) as,

$$R_2 = \frac{0.7\left(R_{B2} + R_{B1}\right)}{\eta\ V_{BB}}$$

$$= \frac{0.7\left(5 \times 10^3\right)}{0.66 \times 20}$$

$$\therefore \quad R_2 = 265\ \Omega$$

Value of R_1 can be calculated by equation (2.6.8) as,

$$V_{BB} = I_{leakage}\left(R_1 + R_2 + R_{B1} + R_{B2}\right)$$

$$20 = 3.2 \times 10^{-3}\ (R_1 + 265 + 5000)$$

$$R_1 = 985\ \Omega$$

The value of $R_{c\,(\max)}$ is given by equation (2.6.9),

$$R_{c\,(\max)} = \frac{V_{BB} - V_p}{I_p} = \frac{20-14}{0.5 \times 10^{-3}}$$

$$R_{c\,(\max)} = 12\ k\Omega$$

Similarly the value of $R_{c\,(\min)}$ is given by equation (2.6.10),

$$R_{c\,(\min)} = \frac{V_{BB} - V_v}{I_v}$$

$$= \frac{20-1}{3 \times 10^{-3}}$$

$$R_{c\,(\min)} = 6.33\ k\Omega$$

Fig. 2.6.9 shows the completely designed circuit.

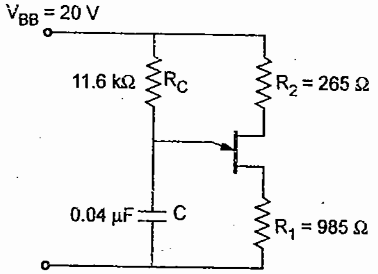


Fig. 2.6.9 UJT triggering circuit of example 2.6.1

Example 2.6.2 *Design the UJT triggering circuit for SCR. Given - $V_{BB} = 20$ V, $\eta = 0.6$, $I_p = 10\ \mu A$, $V_v = 2V$, $I_v = 10$ mA. The frequency of oscillation is 100 Hz. The triggering pulse width should be 50 μs.*

Solution : The frequency $f = 100$ Hz

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

From equation (2.6.2),

$$T = R_c C\, ln\left(\frac{1}{1-\eta}\right)$$

Putting values in above equation,

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

$$\therefore \quad R_c C = 0.0109135$$

Let us select $C = 1\mu F$. Then R_c will be,

$$R_c = \frac{0.0109135}{1\times10^{-6}}$$

$$= 10.91\ k\Omega$$

The peak voltage is given as,

$$V_p = \eta V_{BB} + V_D$$

Let $V_D = 0.8$ and putting other values,

$$V_p = 0.6\times20+0.8 = 12.8\ V$$

The minimum value of R_c can be calculated from equation (2.6.10) as,

$$R_{c\,(min)} = \frac{V_{BB}-V_v}{I_v}$$

$$= \frac{20-2}{10\times10^{-3}} = 1.8\ k\Omega$$

Value of R_2 can be calculated from equation (2.6.5) as,

$$R_2 = \frac{10^4}{\eta V_{BB}}$$

$$= \frac{10^4}{0.6\times20} = 833.33\ \Omega$$

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

Hence, value of R_1 will be,

$$\tau_2 = R_1 C \quad \text{from equation (2.6.6)}$$

The width $\tau_2 = 50\ \mu$sec and $C = 1\ \mu F$, hence above equation becomes,

$$50\times10^{-6} = R_1 \times 1\times10^{-6}$$

$$\therefore \quad R_1 = 50\ \Omega$$

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

$$R_1 = 50\ \Omega, \quad R_2 = 833.33\ \Omega$$

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

Example 2.6.3 *A UJT is connected across a 20 V volts DC supply. The valley and peak point voltages are 1 V and 15 V. The period of UJT relaxation oscillator is 20 ms. Find the value of charging capacitor, if a charging resistor of 100 kΩ is used.*

Solution : The given data is,

$$V_{BB} = 220\ V$$

$$V_v = 1, \quad V_p = 15\ V$$

$$T = 20\times10^{-3}$$

$$R_C = 100\ k\Omega$$

The peak voltage of the UJT is given as,

$$V_p = \eta V_{BB} + V_D$$

Let $V_D = 0.8$ and putting values in above equation,

$$15 = \eta\times20+0.8 \Rightarrow \eta = 0.71$$

From equation (2.6.2), $T = R_c C\ ln\left(\frac{1}{1-\eta}\right)$

Putting values in above equation,

$$20\times10^{-3} = 10\times10^{3}\times C\, ln\left(\frac{1}{1-0.71}\right)$$

$$\therefore \quad C = 0.162\ \mu F$$

Review Questions

1. *Explain the UJT pulse triggering circuit with waveforms.* **Dec.-12, 13, May-14, Marks 7, May-13, Marks 3, Dec.-16, Marks 5, Question Bank**
2. *Explain the construction and operation of UJT.* **Question Bank**
3. *Draw and explain the VI characteristics of UJT.* **Question Bank**
4. *List the applications of UJT.* **Question Bank**
5. *Draw the layer diagram of UJT and explain its operation.* **Question Bank**

2.7 Digital Firing Scheme

May-11, 13, Dec.-12

Fig. 2.7.1 shows the firing scheme that uses digital circuit. Here the AC input supply is given to zero crossing detector (ZCD). At every zero crossing of AC supply voltage, the ZCD circuit produces a pulse. This pulse resets the counter and oscillator. The presettable counter is loaded with a count set by preset input. Then the counter is decremented at every clock input. When the counter is exhausted, it triggers a flip-flop. The flip-flop drives the driver stage. The driver stage amplifies the flip-flop signal and gives it to gate-cathode of SCR.

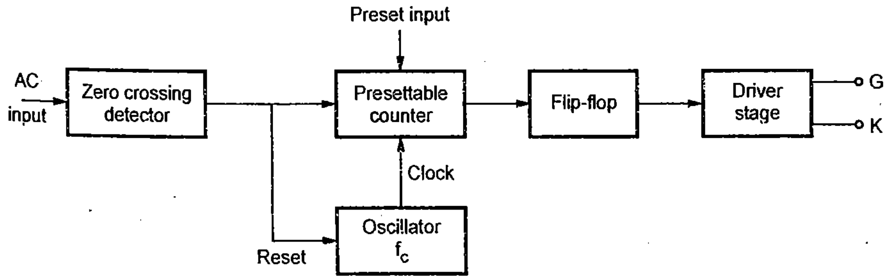


Fig. 2.7.1

The firing delay is set by the preset input. Thus the SCR can be triggered at any delay angle.

Advantages

1. The circuit is digital hence no component delays and variations in firing angle.
2. Firing angle can be set accurately.

Applications

1. Triggering of SCRs in controlled rectifiers.
2. Control circuits for AC voltage controllers.

Review Question

1. *Explain briefly the block diagram of digital firing circuit used in SCR circuits.* **May-11, Dec.-12, Marks 5, May-13, Marks 4, Question Bank, Model Q. P.**

2.8 Commutation of SCRs and its Types

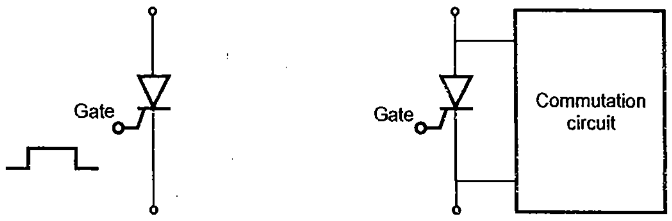
Nov.-11, May-11, 12, 13, 14, 15, 16, Dec.-12, 13, 14, 15, 16

2.8.1 Definition of Commutation

The SCR is used as a switch in many power electronic converters. It is turned on by applying a gate pulse. Once the SCR is latched, the gate has no control over the conduction of the SCR. By removing the gate pulse, SCR cannot be turned-off. An external circuitry is required to turn-off the SCR. Such process of turning-off the SCR is called *commutation.*

The commutation circuits use LC components. They store energy and it is then used to turn-off the SCR. The commutation can be of two types :

i) Natural commutation and ii) Forced commutation.



(a) Gate pulse is used to turn - on the SCR

(b) External commutation circuit is required to turn - off the SCR

Fig. 2.8.1 Commutation

2.8.2 Conditions for Successful Commutation

Following conditions must be satisfied for successful commutation of SCR.

i) The anode to cathode current of the SCR must be reduced below holding current value.

ii) As long as the SCR turns-off, the anode-cathode voltage must be reversed.

iii) The rate of change of anode-cathode voltage must be less than $\frac{dv}{dt}$ rating of SCR to avoid retriggering.

iv) Above conditions must be imposed till the SCR regains its forward blocking voltage capability.

2.8.3 Natural Commutation (Class F : Line Commutation)

The natural commutation does not need any external components. It uses supply (mains) voltage for turning-off the SCR. Hence it is also called as line commutation. Fig. 2.8.2 shows the circuit using natural commutation. It is basically half wave rectifier. The mains AC supply is applied to the input. The SCR is triggered in the positive half cycle at α. (Refer waveforms of Fig. 2.8.2 (b) Since the SCR is forward biased, it starts conducting and load current i_o starts flowing. At 'π' the supply voltage is zero. Hence current through SCR becomes zero. Therefore the SCR turns-off. The supply voltage is then negative. This voltage appears across the SCRs and it does not conduct. Thus natural commutation takes place without any external components.

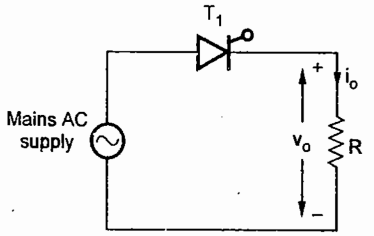


Fig. 2.8.2 (a) A half wave rectifier uses natural commutation to turn-off SCR

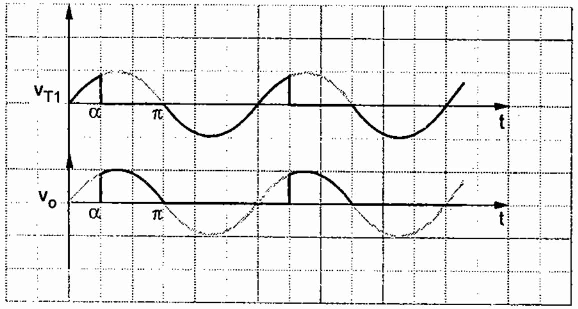


Fig. 2.8.2 (b) Waveforms of natural commutation

2.8.4 Forced Commutation

Forced commutation is used when the supply is D.C. A commutation circuit is connected across the SCR.

The commutation circuit is normally LC circuit. The LC circuit stores energy when the SCR is ON. This energy is used to turn-off the SCR. The LC circuit imposes reverse bias across the SCR due to stored energy. Hence forward current of SCR is dropped below holding current and the SCR turns-off.

2.8.5 Comparison of Natural Commutation and Forced Commutation

Table 2.8.1 shows the comparison between natural and forced commutation techniques.

Sr. No.	Natural commutation	Forced commutation
1.	No external commutation components are required.	External commutation components are required.
2.	Requires AC voltage at the input.	Works on DC voltages at the input.
3.	Used in controlled rectifiers, AC voltage controllers etc.	Used in choppers, inverters etc.
4.	No power loss takes place during commutation.	Power loss takes place in commutating components.
5.	SCR turns-off due to negative supply voltage.	SCR can be turned-off due to voltage and current both.
6.	Cost of the commutation circuit is nil.	Cost of the commutation circuit is significant.

Table 2.8.1 Natural and forced commutation

2.8.6 Self Commutation by Resonating Load (Class A)

Fig. 2.8.3 shows the circuit diagram of self commutation. It uses inductance and capacitance for commutation. The SCR is turned-off due to natural characteristics of LC circuit. Let us consider that the SCR T_1 is triggered at instant t_0. The current starts flowing through T_1, L and C. Because of inductance, the current through T_1 increases slowly. Fig. 2.8.4 shows the waveforms of the above circuit. The capacitor then starts charging. At $t = t_1$, the capacitor voltage becomes equal to supply voltage V_s. As shown in Fig. 2.8.3, the current $i(t)$ is maximum and $v_C(t) = V_s$. But the current $i(t)$ is maintained in the same direction by inductance. The inductance voltage acts as forward bias for T_1. The current $i(t)$ keeps on decreasing after t_1. Since $i(t)$ flows through capacitor, it charges above V_s after t_1. At $t = t_2$, the current $i(t)$ becomes zero. Since the current through SCR goes to zero, it turns-off at $t = t_2$. The capacitor voltage is greater than V_s. It acts as reverse bias on SCR_1. Hence it does not conduct. The voltage across the SCR is shown in Fig. 2.8.4.

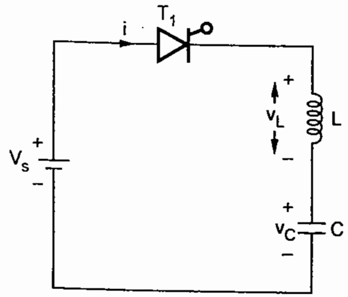


Fig. 2.8.3 Self commutation circuit

2.8.7 Impulse Commutation (Class D : Auxiliary Voltage Commutation)

Fig. 2.8.5 shows the circuit diagram of impulse commutation. T_1 is the main or load current carrying SCR. And T_2, T_3, C and L are the commutation components. T_2 is also called as auxiliary SCR. Let us assume that SCR T_1 is 'on' and carrying the load current I_o. Let the capacitor voltage be $v_c(t) = -V_s$. The SCRs T_2 and T_3 are off. To initiate turn-off

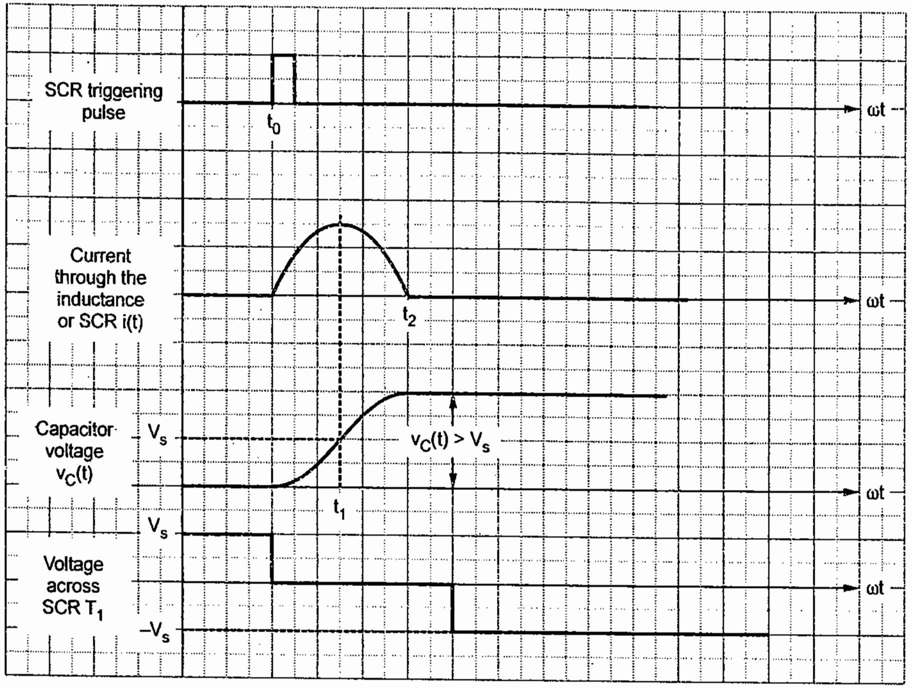


Fig. 2.8.4 Waveforms of self commutation

of T_1, the auxiliary SCR T_2 is triggered at $t=t_0$ as shown in Fig. 2.8.6. Because of this, the capacitor voltage is imposed as reverse bias on SCR T_1. Hence T_1 turns-off. The load current I_o starts flowing through capacitor and SCR T_2. In Fig. 2.8.6 observe that the capacitor voltage discharges from $-V_s$ towards zero.

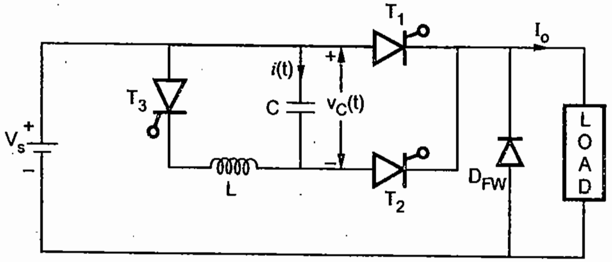


Fig. 2.8.5 Impulse commutation circuit

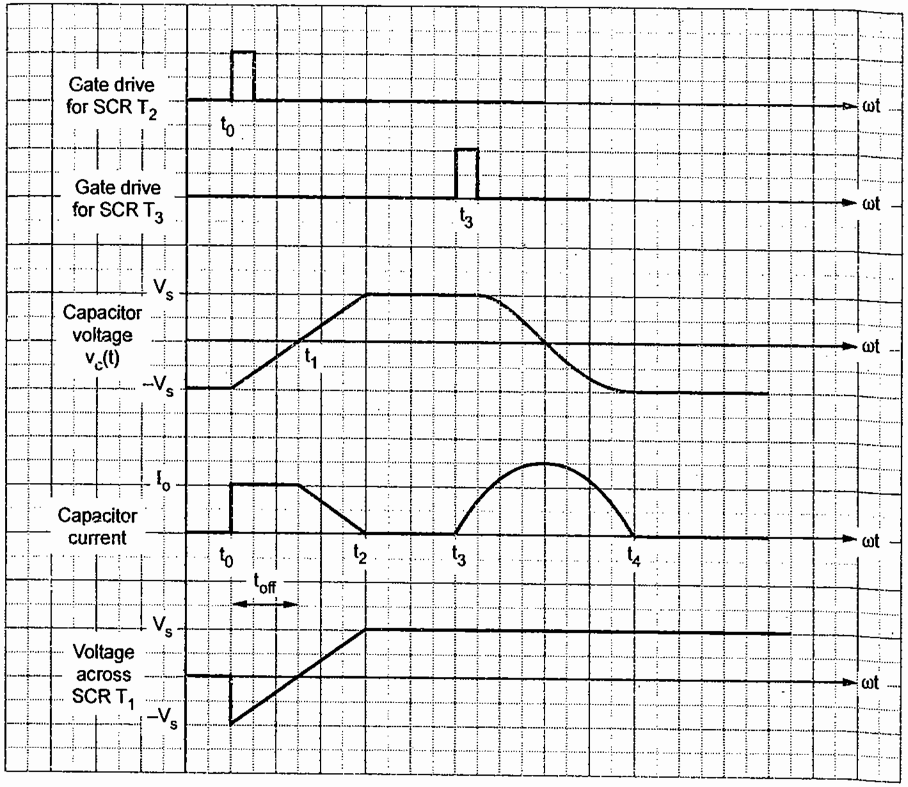


Fig. 2.8.6 Waveforms of impulse commutation circuit

At $t=t_1$ capacitor discharges fully. Thus the reverse bias is maintained across SCR T_1 from t_0 to t_1. The capacitor then starts charging in positive direction. At $t=t_2$, the capacitor voltage becomes $+V_s$ and its current becomes zero. Hence T_2 also turns-off due to self commutation. The polarity of the capacitor voltage is reversed by triggering T_3 at $t=t_3$. The capacitor discharges through inductance and T_3. This discharge current (capacitor current) is shown in Fig. 2.8.6. It becomes LC circuit. At $t=t_4$ capacitor voltage becomes $-V_s$ and its current is zero. Hence T_3 turns-off by self-commutation. In this commutation, the SCR T_1 turns off due to negative capacitor voltage. Hence it is also known as *voltage commutation*. Since auxiliary SCR $(T_2 \text{ and } T_3)$ is used to turn-off main SCR, it is also known as *auxiliary voltage commutation*. The negative capacitor voltage remains across T_1 from t_0 to t_1. This period is called circuit turn-off time $\left(t_{off}\right)$. This time must be greater than turn-off time 't_q' of the SCR T_1.

Comparison between Self Commutation and Impulse Commutation

Sr. No.	Self commutation	Impulse commutation
1.	Commutation takes place due to resonating load.	Commutation takes place due to auxiliary voltage.
2.	Only one SCR is used.	Additional auxiliary SCR is used to turn-off main SCR.
3.	Load current flows through commutating components.	Load current flows through commutating components at the time of commutation.
4.	Commutation time depends on load.	Commutation time is independent of load.
5.	Less number of commutation components are required.	More number of commutation components are required.

Table 2.8.2 Self and impulse commutation

2.8.8 Resonant Pulse Commutation (Class D : Auxiliary Current Commutation)

Fig. 2.8.7 shows the circuit diagram of resonant pulse commutation. Here T_1 is the main SCR carrying load current. T_2, T_3, L and C are the commutating components. T_2 is the auxiliary SCR. It is used to turn-off T_1. Let us assume that capacitor is charged initially to $v_C(t) = -V_C$. This is shown in first (extreme left) equivalent circuit of Fig. 2.8.8. And SCR T_1 is carrying the load current. At $t = t_0$, SCR T_2 is triggered to initiate the turn-off of T_1. The capacitor discharges from $-V_C$ to $-V_1$. The capacitor discharge current $i(t)$ increases from zero as shown in waveforms of Fig. 2.8.8. At $t = t_1$ the capacitor discharge current reaches to I_o. During period t_0-t_1, the SCRs T_1 and T_2 both carry the load current. This is shown in second equivalent circuit in Fig. 2.8.8. From t_1 to t_3, the load current is completely carried by SCR T_2 and T_1 carries no current. Hence T_1 is turned-off. The available turn-off time is from t_1 to t_2. In this period the capacitor voltage is negative. At t_4, the capacitor current becomes zero and T_2 turns off by self commutation. Because of flow of current, capacitor overcharges to V_C. From t_3 to t_4, the energy (charge) stored in the inductance is transferred to capacitor. Hence it overcharges.

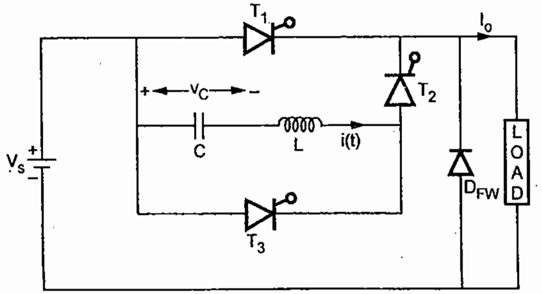


Fig. 2.8.7 Circuit diagram of resonant pulse commutation

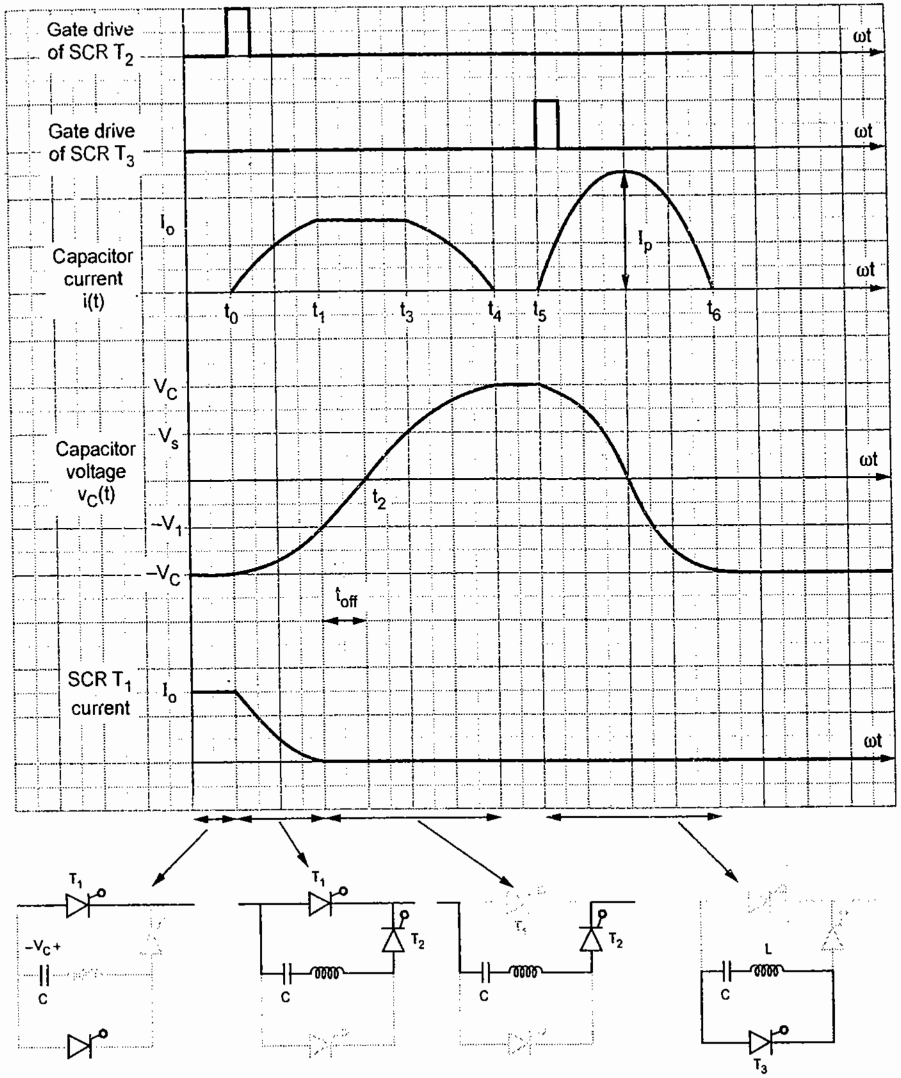


Fig. 2.8.8 Waveforms of resonant pulse commutation

At t_5, SCR T_3 is triggered to reverse the capacitor voltage polarity. The capacitor voltage becomes $v_C(t) = -V_C$ and its current falls to zero. T_3 turns-off by self commutation. In this circuit note that the resonant pulse of current (in LC circuit) is used to bypass forward current of T_1. Hence this commutation is called as current commutation. Since auxiliary SCR T_2 is used to carry the current of T_1, it is called as *auxiliary current commutation*. The circuit turn-off is $t_{off} = t_1$ to t_2.

2.8.9 Complementary Commutation (Class C)

Fig. 2.8.9 shows the circuit diagram of complementary commutation. There are two SCRs T_1 and T_2. These two SCRs are used to transfer the current between two loads R_1 and R_2. These SCRs turn-off each other. Hence it is called complementary commutation. Let us assume that the capacitor is charged to the voltage $v_C(t) = -V_s$ and SCR T_2 is conducting. The equivalent circuit for this operation is shown in Fig. 2.8.10 (circuit-I). Note that the current through capacitor is zero. SCR T_1 is triggered at $t = t_0$. Hence a negative voltage $-V_s$ is applied across T_1. The capacitor then discharges from $-V_s$ to zero. A reverse bias due to capacitor voltage is maintained from t_0 to t_1. This is the circuit turn-off time 't_{off}'. T_2 turns-off and capacitor charges to $+V_s$ through SCR T_1. The SCR T_1 also carries load current of R_1. This is shown by equivalent circuit-II in Fig. 2.8.10. At t_2, the capacitor charges to $+V_s$ and its current becomes zero (refer circuit-III in Fig. 2.8.10). (See Fig. 2.8.10 on next page)

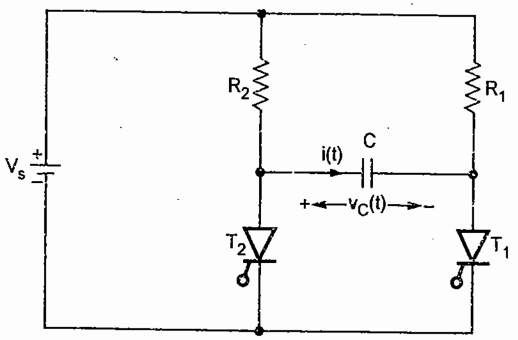


Fig. 2.8.9 Circuit diagram of complementary commutation

SCR T_2 is triggered at t_3. It applies a reverse voltage of $-V_s$ across SCR T_1. The capacitor then discharges from V_s to zero and charges towards $-V_s$. Thus the cycle repeats. Here note that the SCRs are switched off due to impulse commutation. Hence this is also called as complementary impulse commutation.

The circuit turn-off time and commutating capacitor are related as follows :

$$\therefore \quad t_{off} = 0.693 \; RC \qquad \dots (2.8.1)$$

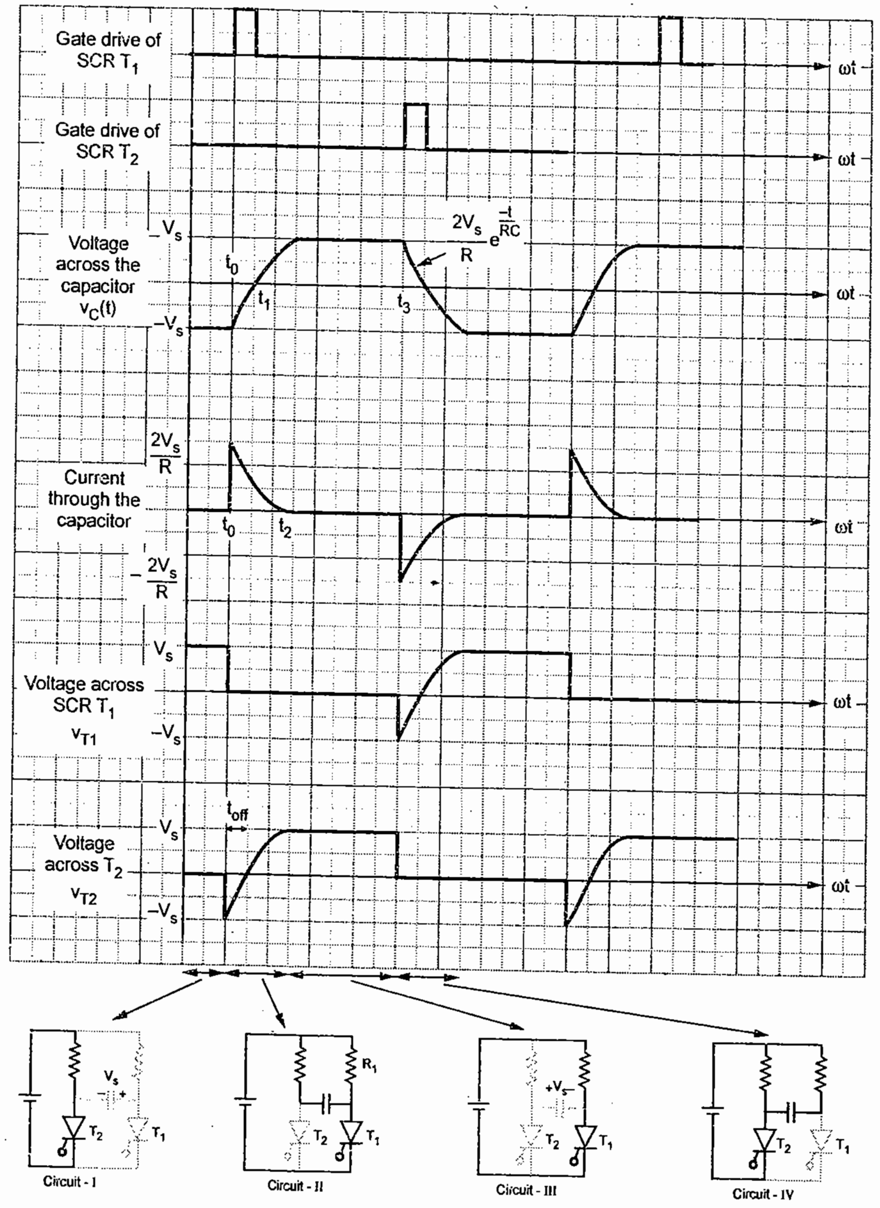


Fig. 2.8.10 Waveforms and operation of complementary commutation

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Example 2.8.1 *In Fig. 2.8.11, the source voltage $V_s = 100$ V and the current through R_1 and R_2 is 25 A. The turn-off time of both the SCRs is 40 μsec. Find the value of capacitor for successful commutation.*

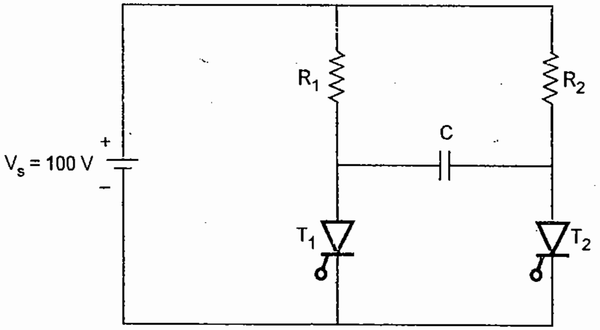

Fig. 2.8.11 Circuit diagram of example 2.8.1

Solution : This is complementary commutation. When T_1 is ON T_2 is OFF and vice versa. The values of R_1 and R_2 will be,

$$R_1 = R_2 = \frac{V_s}{I_o} = \frac{100\ V}{25\ A}$$

$$R = R_1 = R_2 = 4\ \Omega$$

For complementary commutation, the available turn-off time is given by equation (2.8.1) as,

$$t_{off} = 0.693\ RC$$

If t_q is the turn-off time of the SCRs, then $t_q \le t_{off}$ for successful commutation. Hence above equation can be written as,

$$t_q \le 0.693\ RC$$

$$\therefore \quad C \ge \frac{t_q}{0.693\ R}$$

The given data is $t_q = 40$ μsec and $R = 4\ \Omega$. Hence above equation becomes,

$$C \ge \frac{40 \times 10^{-6}}{0.693 \times 4}$$

$$\therefore \quad C \ge 14.43\ \mu F$$

Thus the capacitor must be more than 14.43 μF for successful commutation.

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2.8.10 External Pulse Commutation (Class E)

Fig. 2.8.12 shows the circuit diagram of external pulse commutation. Here T_1 is the main SCR carrying load current. SCRs T_2, T_3 and L, C are commutation components. The supply voltage V_s supplies power to the load. The supply 'V' is the auxiliary supply used to turn-off the SCR. When the SCR T_3 is triggered, the capacitor charges from the auxiliary source. It is LC resonant circuit. A resonant current pulse of peak amplitude $V\sqrt{\frac{C}{L}}$ flows through the LC circuit. Hence the capacitor charges approximately to voltage 2 V. The SCR T3 turns-off by self commutation. SCR T_2 is turned-on to initiate the commutation of T_1. The capacitor voltage is $v_C(t) = 2$ V. This voltage is greater than supply voltage V_s. When T_2 is triggered, a reverse voltage of $(V_s - 2\ V)$ is applied across the SCR T_1. Hence T_1 turns-off. Here the pulse of current from capacitor is used to bypass the current of T_1. Hence this is called external pulse commutation.

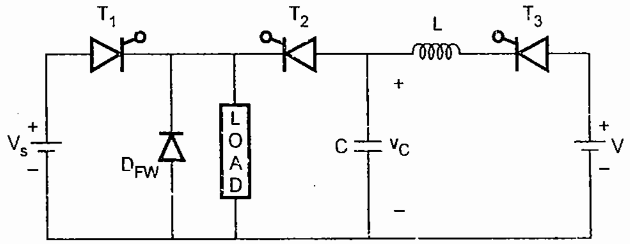

Fig. 2.8.12 External pulse commutation

Review Questions

1. *List different types of commutation.* **May-11, 12, 16, Marks 6, Nov.-[illegible], Marks [illegible], Dec.-12, Marks 6, Dec.-[illegible], Marks [illegible]**
2. *Define commutation.* **Nov.-11, May-12, 15, 16, Mark 1, Dec.-16, Marks 2, Question Bank**
3. *Explain natural commutation with neat sketch and waveforms.* **Nov.-11, May-13, 14, 15, Dec.-13, Marks 5, May-12, Dec.-14, 15, Marks 4, Dec.-16, Marks 3**
4. *Identify the types of commutation.* **Question Bank**
5. *Explain line commutation and forced commutation.* **Question Bank**
6. *Explain load commutation and complementary commutation.* **Question Bank**

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STUDENT'S NAME		TOTAL MARKS OBTAINED
CLASS	SUBJECT	
ROLL NO.	DATE	

Explain the types of power electronic converters

1- AC to DC Converter: This is controlled rectifier. its input is AC & output is controlled DC.

2- DC to AC converter (Inverters)
It's input is DC or fed from battery. output is variable AC voltage.

3- DC to DC converters (Choppers).
Input is fixed or variable DC & output is variable DC.

4- AC to AC converters (AC regulators)
Its input is fixed AC voltage & output is variable AC output voltage. the input & output frequencies of AC regulator are same.

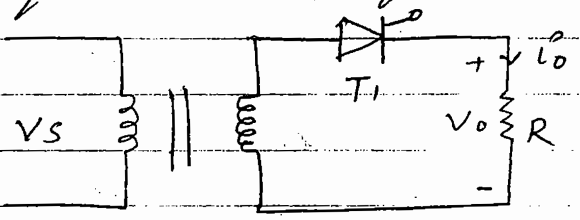
5- AC to AC converters (cyclo converters)
Its input is fixed voltage & fixed frequency. & output is variable voltage & variable frequency. the output frequency can be higher or lower than input frequency.

Teacher's Signature

STUDENT'S NAME		TOTAL MARKS OBTAINED
CLASS	SUBJECT	
ROLL NO.	DATE	

Explain single quadrant semi converter, two quadrant full converter & dual converter.

Single quadrant half wave converter



→ the secondary of the transformer is connected to resistive load through thyristor or SCR T_1.

→ The primary of the transformer is connected to the mains supply.

→ In positive cycle of the supply, T_1 is forward biased. T_1 is triggered at an angle α. now T_1 conducts & secondary voltage is applied to the load. current io starts flowing through the load.

→ current & voltage waveforms are shown in fig.

→ The shape of output current waveform is same as output voltage waveform.

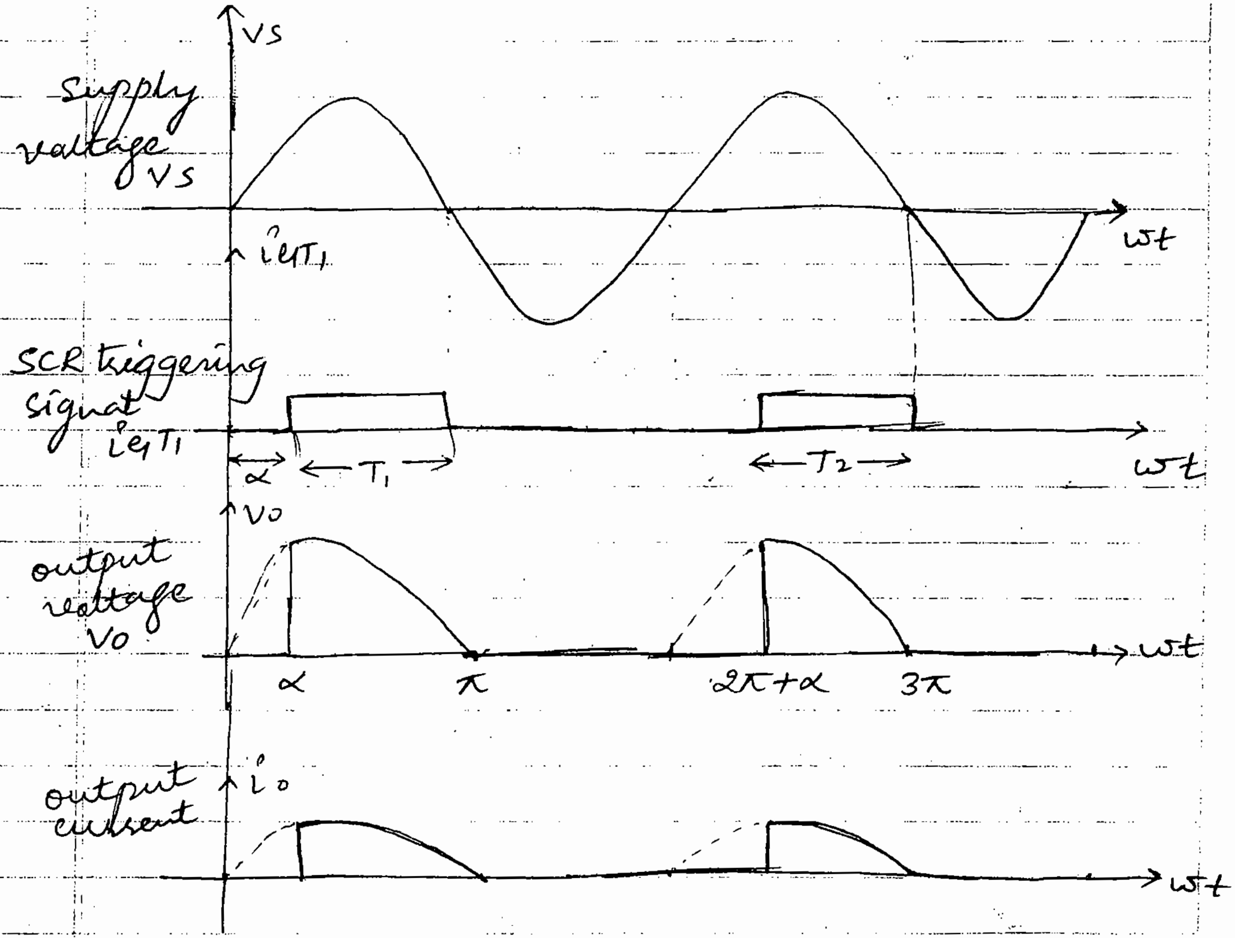
→ At π supply voltage drops to zero. hence current io flowing through T_1 becomes zero & it turns off.

→ In negative half cycle of the supply T_1 is reversed biased & it does not conduct.

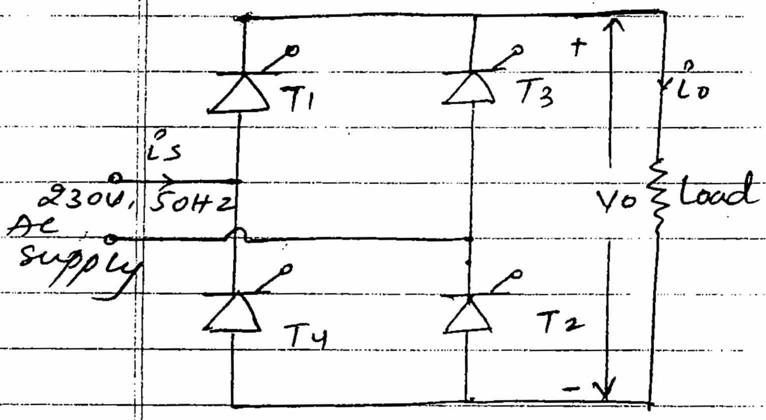
Teacher's Signature

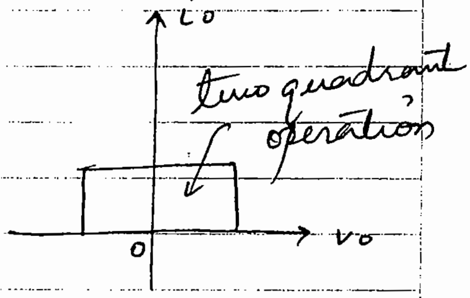
the average output voltage is

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



Two quadrant full converter (full bridge converter)





→ It contains four SCR's T_1, T_2, T_3, T_4. the conduction of all these SCR is controlled hence this is called full converter.

→ In the positive half cycle of the supply, SCRs T_1 & T_2 are triggered at firing angle α hence current starts flowing through the load.

→ waveforms are shown in figure.
from fig it is clear that, when T_1 & T_2 conducts,

$$V_o = V_s$$

$$i_o = \frac{V_o}{R} = \frac{V_s}{R}$$

Waveforms:-

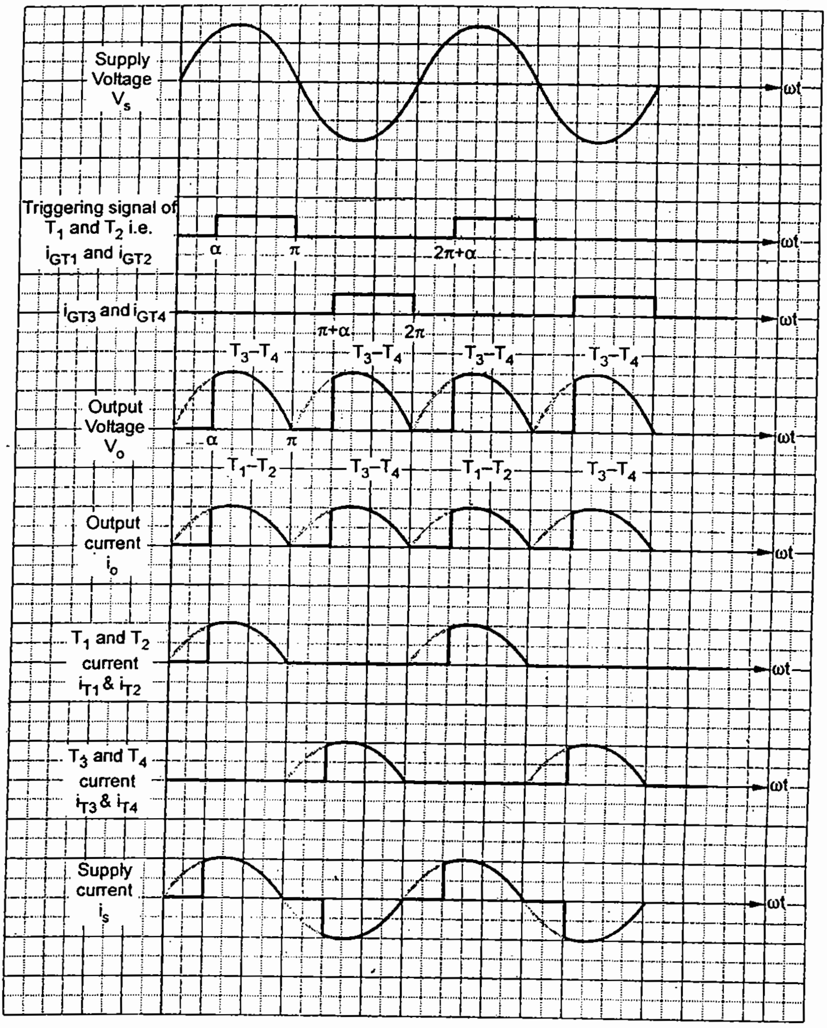
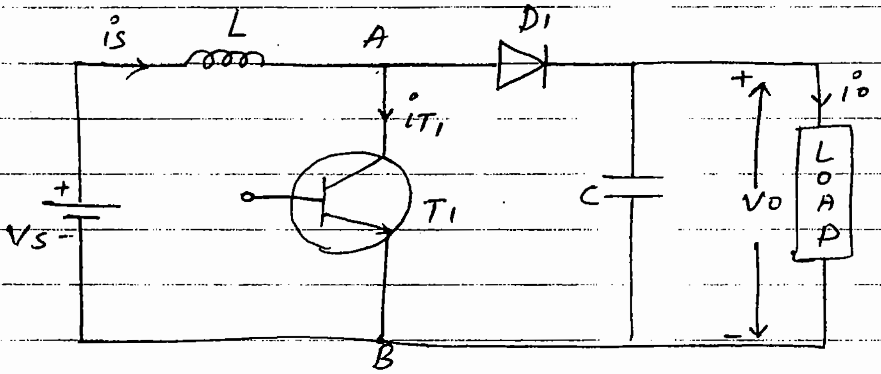


figure ⓐ shows the drive of the switch.
In case of power transistor, it will be base drive.
the drive is applied for period 0 to δT.
hence the switch turns ON for this period
& connects supply Vs to the load. hence
$v_o = V_s$ in this period. from δT to T
the drive of the switch is removed, hence
it turns off. hence the load voltage is zero.
since the load is resistive, output current
will be $i_o = \frac{v_o}{R}$

STUDENT'S NAME		TOTAL MARKS OBTAINED
CLASS	SUBJECT	
ROLL NO.	DATE	

Explain step up chopper with circuit diagram



→ A switch is connected across inductance & supply. A filter capacitor is used across the load to make vo smooth. the diode D1 blocks the reverse flow of output current when switched is turned 'on'.

→ waveforms are shown in figure. the transistor is turned on from 0 to δT. hence current flows through the inductance from the supply. the inductance current rises & inductance stores the energy from supply.

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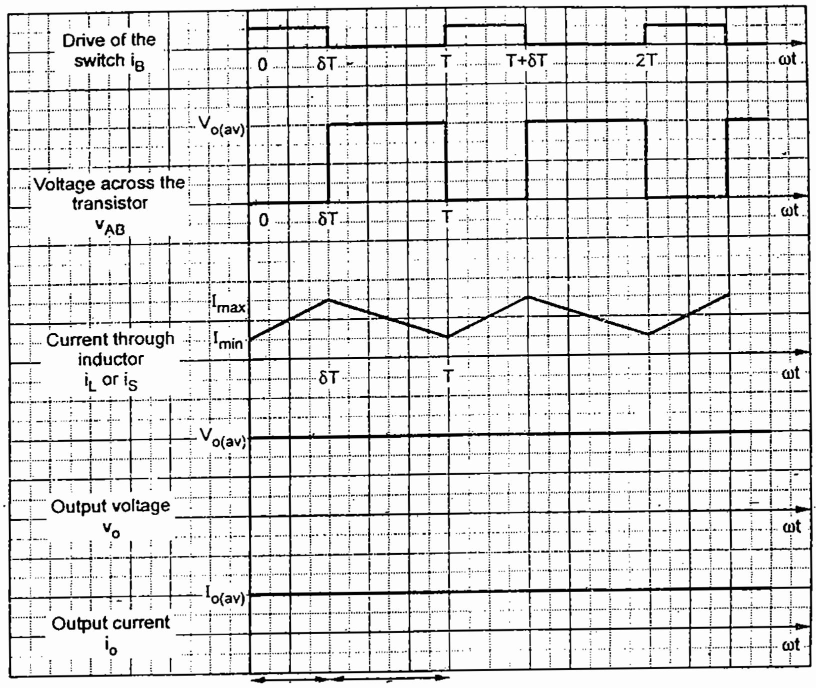
waveforms.



Waveforms of Step-up chopper.

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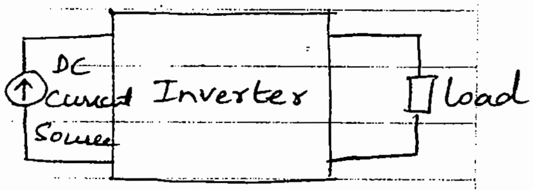
Explain VSI & CSI

Voltage Source Inverter

→ The input to the voltage source inverter is DC voltage supply or battery. for such inverters the amplitude of load voltage is equal to DC input voltage.

→ The current waveform depends upon load.

Current Source Inverter



→ The input to the current source is constant current source.

→ the constant current source can be obtained by connections large inductor in series with uncontrolled or controlled rectifier.

→ the load current is equal to input current.

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Explain Smart power modules.

→ The power electronic converter may require two, four or six devices. Sometimes additional feedback/freewheeling diodes are also required. rather than using descrete components & devices, a combined module of all the devices is used. it is called power module.

→ complete power converter is available in single power module. this makes the power converter very compact.

→ smart power modules include power devices as well as peripheral circuit

→ Smart power module consists of interfacing of power devices with triggering & control circuit with proper electrical isolation, drive circuit, protection & diagnostic circuit, micro computer control & power supply etc are included in smart power module.

→ It also include EMC unit to avoid electromagnetic radiation.

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List advantages & disadvantages of power electronic converters.

ADVANTAGES

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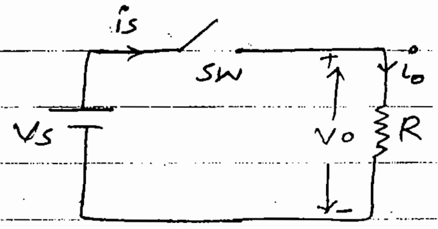
i) Extremely, compact circuit
ii) Common heat sink & power dissipation
iii) Reduced Cost
iv) Easy fault finding
v) Quick assembly

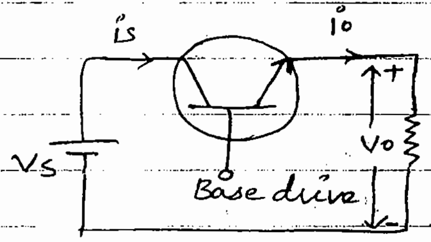
DISADVANTAGES

i) Not repairable
ii) costly for low power applications.
iii) Not much suitable for very high power applications.

Q] Draw the circuit of step down chopper & explain its operation.



(a) step down chopper



(b) step down chopper with transistor as a switch.

→ The switch (SW) can be power transistor, SCR, GTO, power MOSFET, IGBT

→ The drop in the switch is very small & its is neglected.

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waveforms

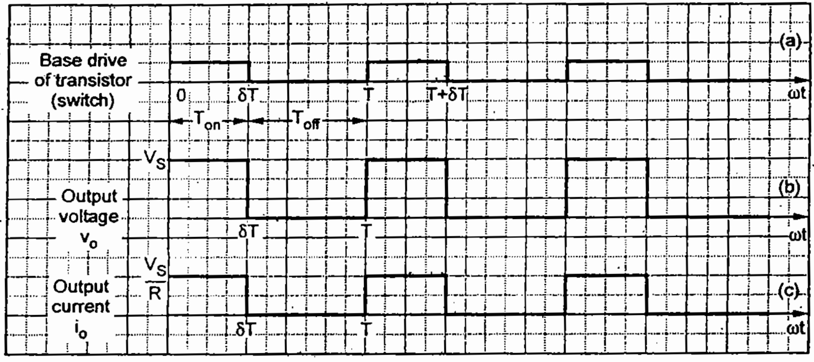

Fig. 4.10.2 Waveforms of the step-down chopper with resistive load

Waveforms of Stepdown chopper.

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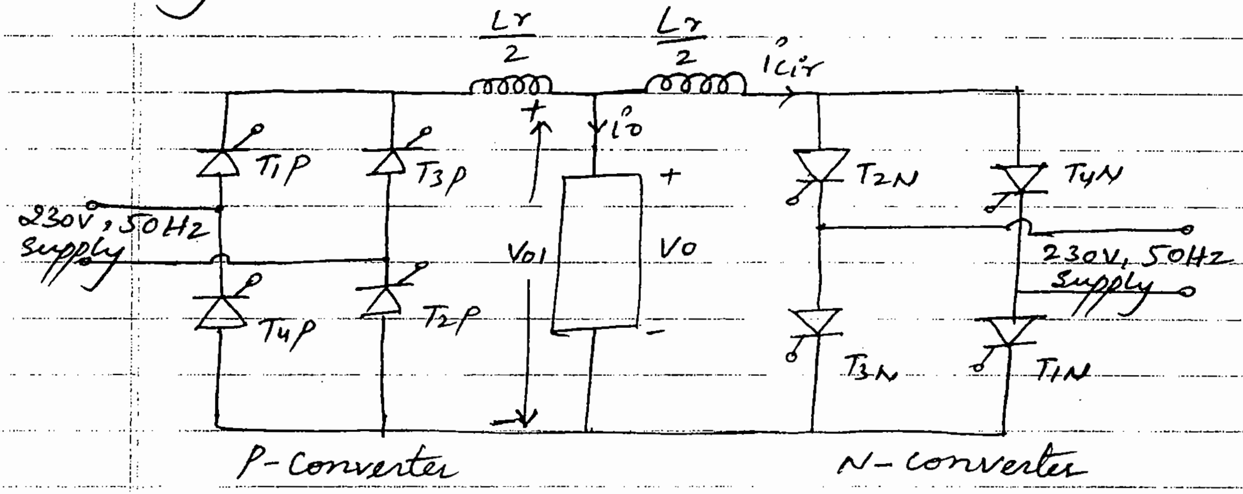
→ from waveform the load voltage is same as supply voltage from α to π. Since the load is resistive, waveforms of v_o & i_o are same. the supply current i_s & i_o are in the same direction hence $i_s = i_o$.

→ T_1 & T_2 turn off when supply voltage becomes zero at π. In negative half cycle T_3 & T_4 are triggered at $\pi+\alpha$.

Dual converters

the dual converter produces an output voltage that can be positive as well as negative.



→ for dual converter the load is normally inductive such as motor. the P-converter produces the output voltage which is positive. the N-converter produces negative output voltage.

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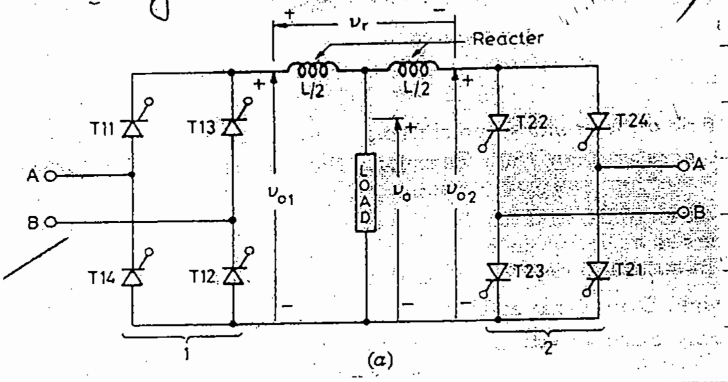
Q) Draw the circuit diagram of Single phase Dual converter and explain the principle of operation.

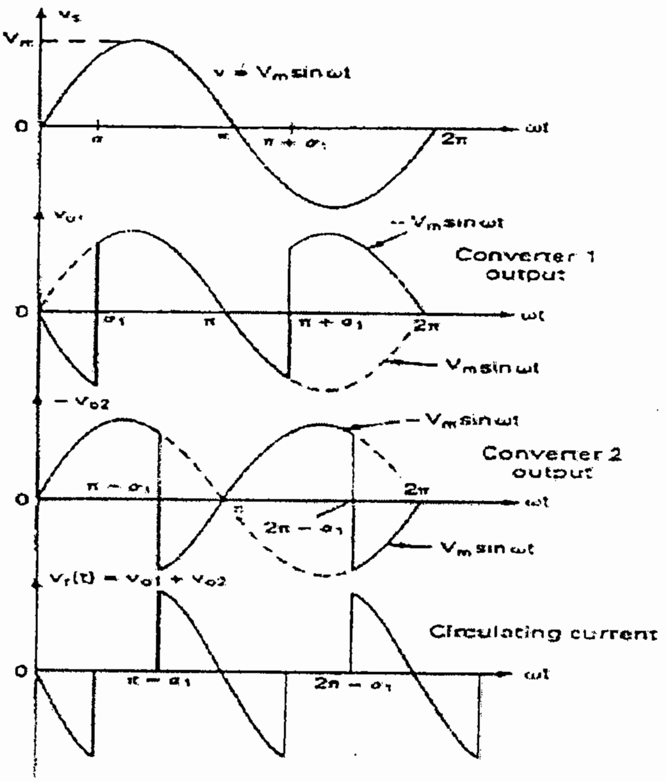
Ans:- Circuit diagram:-



- In the circulating current mode of dual converter, a reactor is inserted in between converters 1 & 2 as shown in the figure.
- This reactor limits the magnitude of circulating current to a resonable value.
- The firing pulses of two converters are so adjusted that $\alpha_1 + \alpha_2 = 180°$.
- As for example, if firing angle of converter-1 is 60°, then firing angle of converter 2 must be 120°.
- Therefore, through the output voltage at the terminals of both converters 1 & 2 has the same average value & also has the same polarity, their instantaineous output voltage waveforms, however, are not similar as shown by V_{o1} and V_{o2} in the figure.

- * As a consequence of it, circulating current flow between the two converters.
- * This circulating current is limited by the reactor.
- * If the load current is to be reversed, the role of two converters is interchanged.
- * This means that, converter-1 is now made to act as a inverter by making its firing angle greater than 90° and converter-2 is made to work as a rectifier by making its firing angle α_2 less than 90°, such that $\alpha_1 + \alpha_2 = 180°$.

<u>Waveforms:-</u>



(b) Waveforms

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Explain the gating pulse requirement of 3 phase full Converters.

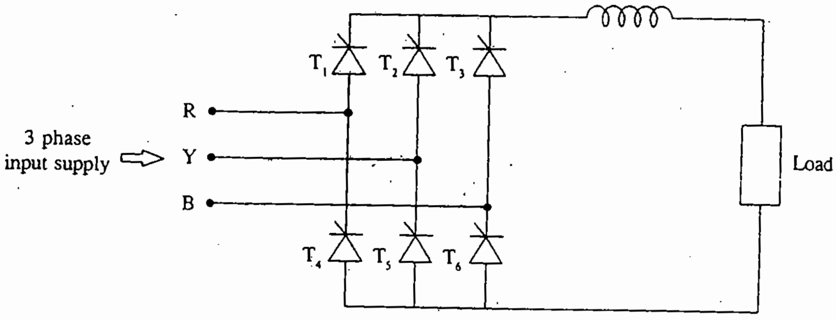

Fig. 4.7(d) : Typical 3-phase thyristor rectifier

- * A 3 phase bridge Converter requires 6 SCRs T_1 to T_6 which have to be triggered into Conduction in a Particular Sequence so as a to make the supply currents balanced.
- * In order to vary the average value of output voltage the gate Pulses to thyristors Pairs are to be controlled.
- * A three phase 50Hz power to be rectified is applied to SCR bridge, the three ph supply singnal as shown in Fig. below.

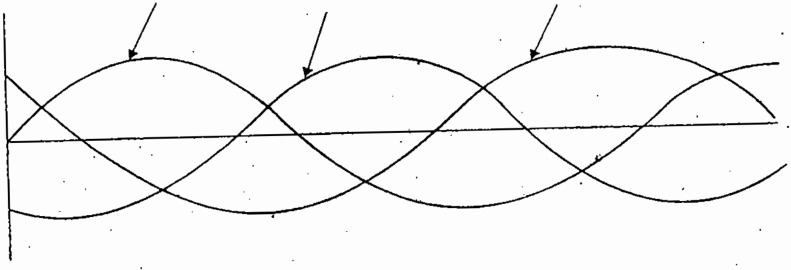

Fig. 4.7(c) : Three phase sine waves

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Waveforms

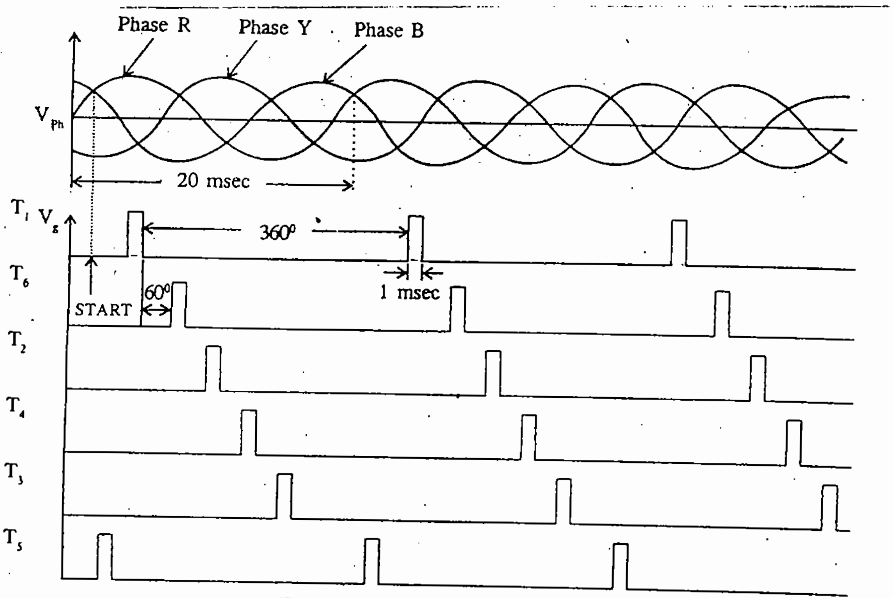

Fig. 4.7(e) : Desired gate pulses

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Draw the different chopper configurations (A, B, C, D & E) & explain them.

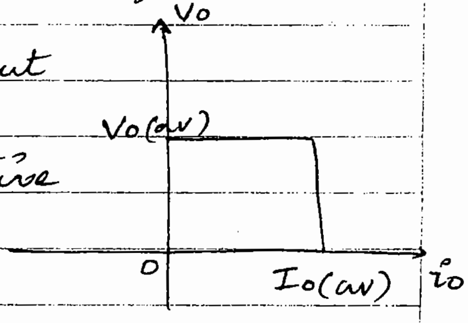
Class A chopper

→ The class A chopper operates in the first quadrant of Vo-io plane

→ The output current & output voltage both are positive. these values never go negative

→ This type of chopper operates as rectifier

→ The energy always flows from source to load. it is also called as forward ~~monitoring~~ motoring.

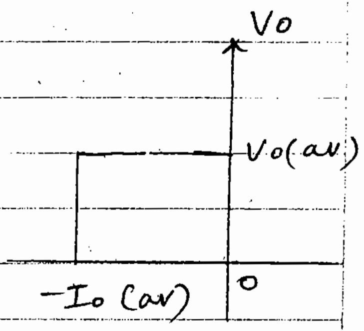


Class B chopper

→ The class B chopper operates in the second quadrant of the Vo-io plane.

→ the load voltage is positive & load current is negative.

→ The load current flows out of the load since the current flows from load to the source. the energy is transformed from load to the source. It is also called as inverting operation.



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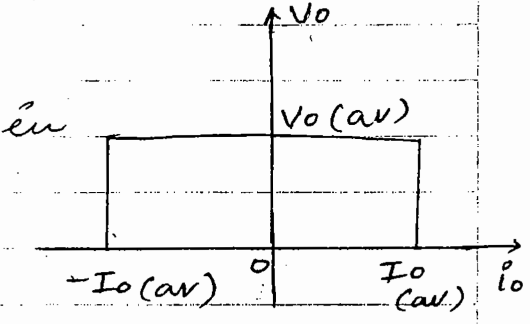
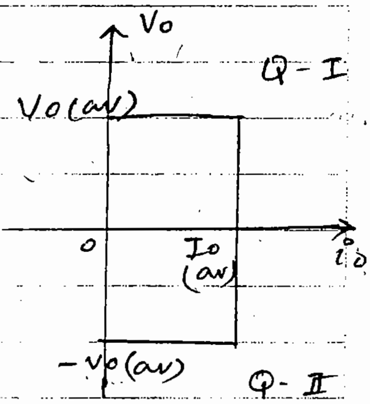
class C chopper



→ The class C chopper operates in two quadrants. it is combination of class A & B choppers.

→ It operates as a rectifier as well as inverter. in the first quadrant forward monitoring takes place. & in the second quadrent forward regenerative breaking takes place.

class D chopper



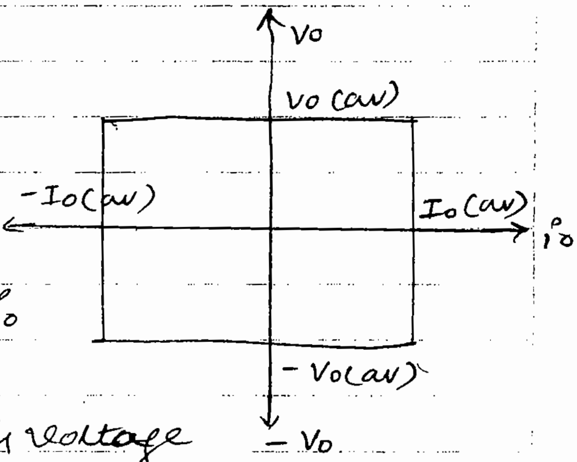
→ class D chopper also operates in two quadrants.

→ The output current is always positive. the output voltage can be positive or negative.

→ when v_o & i_o both are positive the rectifying operation takes place. it is also called forward motoring.

→ when the voltage is reversed, inverting operation takes place. the energy is fed from load to source. the IVth quadrant operation is also called reverse regeneration.

Class E chopper.



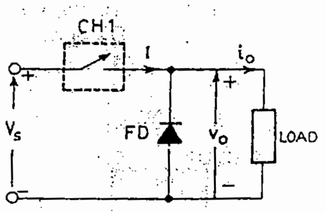
→ Class E is a four quadrant chopper. it operates in the four quadrants of $V_o - i_o$ as shown in fig.

→ the output current & voltage both can take positive or negative values.

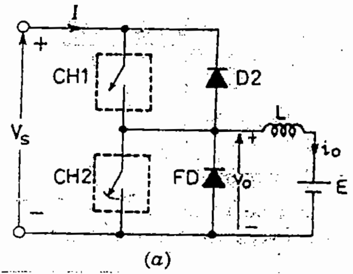
→ the 1st quadrant is forward motoring.

→ the output current & output voltage both are positive.

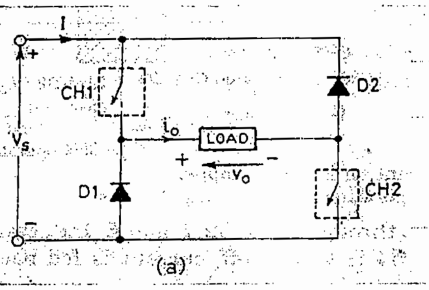
circuit diagrams:-



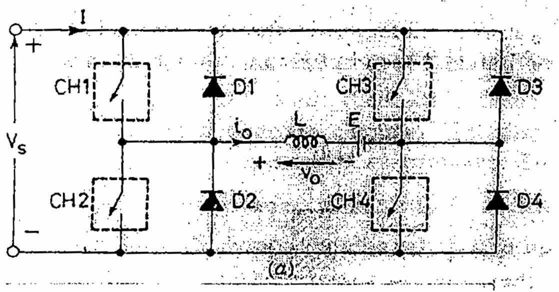
Ist Quadrant



IIIrd Quadrant

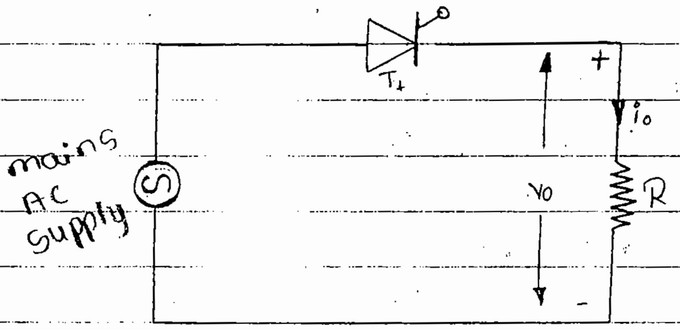


IInd Quadrant



IVth Quadrant

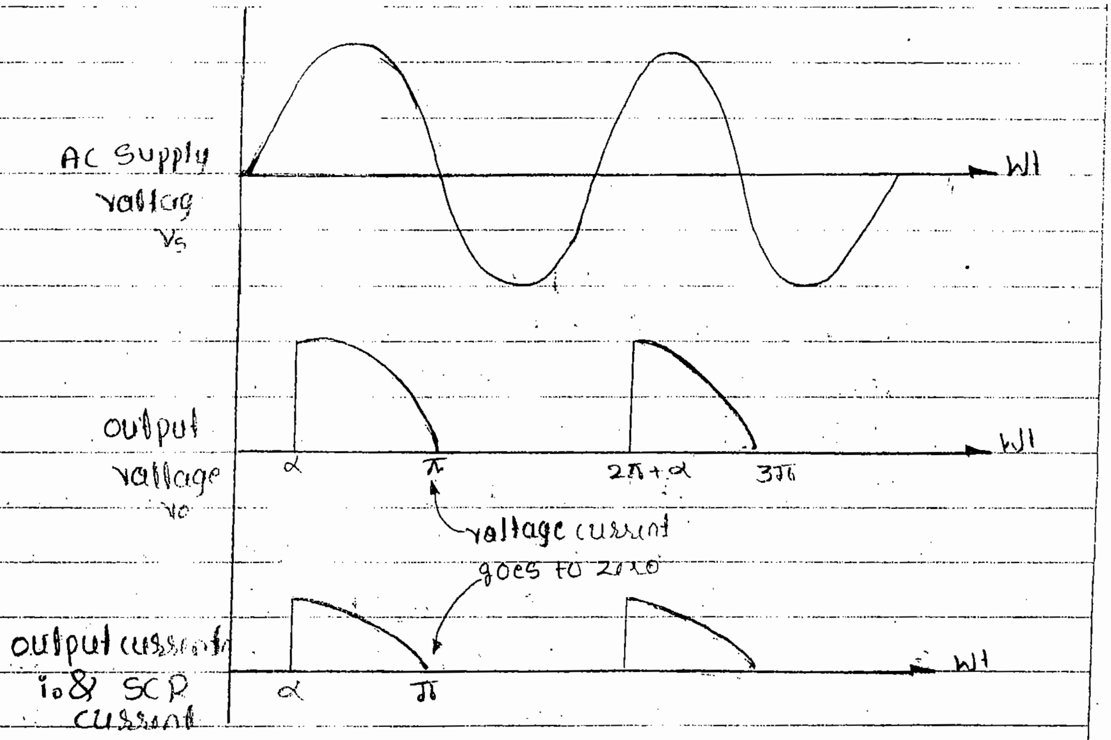
Q] 2 Explain principle of phase control with waveforms. For resistive load



Ans→ phase control means to control the portion of the Supply valtage applied across the load

Explanation

The mains AC Supply is applied to the input. The SCR is triggered in the positive half cycle at α. Since the SCR is forward biased it starts conducting and load current i_0 starts flowing. The waveforms of currents and valtages are shown in fig



Observe that the output current is basically SCR current. At 'π' the supply valtage is zero. Hence current through SCR becomes zero. therefore the SCR turns OFF. The supply valtage is then negative. this valtage appears across the SCR and it does not conduct

Hence note that the ~~averge~~ average rms value of output valtage can be controlled by controlling the firing angle α. It is nothing but controlling the phase of the supply valtage. Hence it is also called phase control

9) Draw the circuit diagram of half bride inverter & its operation with wave forms.

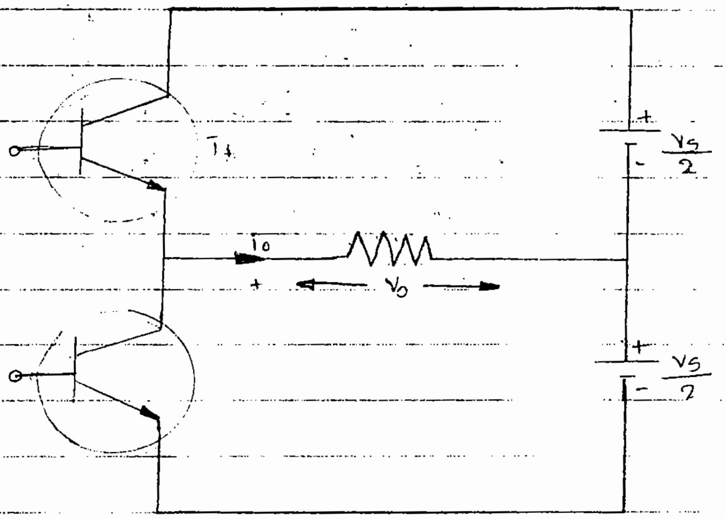


Fig (a)

Ans-> Fig shows the circuit diagram of single phase half bridge inverter. The two transistor T_1 and T_2 are used as switching devices. They can be MOSFET, GTO, SCR IGBT etc, fig(b) shows waveforms of the half bridge inverter having resistive load Transistor T_1 conducts from 0 to $\frac{T}{2}$ hence the output valtage is positive and it is $\frac{V_s}{2}$ In equivalent circuit -I in fig observe that current flows from point A to B in the load.

Transistor T_2 conducts from $\frac{T}{2}$ to T & T_1 is OFF. Equivalent circuit-II in fig (b) shows the situation When T_2 conducts current flows from point B to A in The load. The output voltage is $-\frac{V_s}{2}$. this is the negative half cycle of output. Since the load is resistive. output current waveform is same as voltage waveform also shows the currents through the transistors. the output of this inverter is a square wave since there are two transistors in the bridge. It is called half bridge inverter.

Waveforms

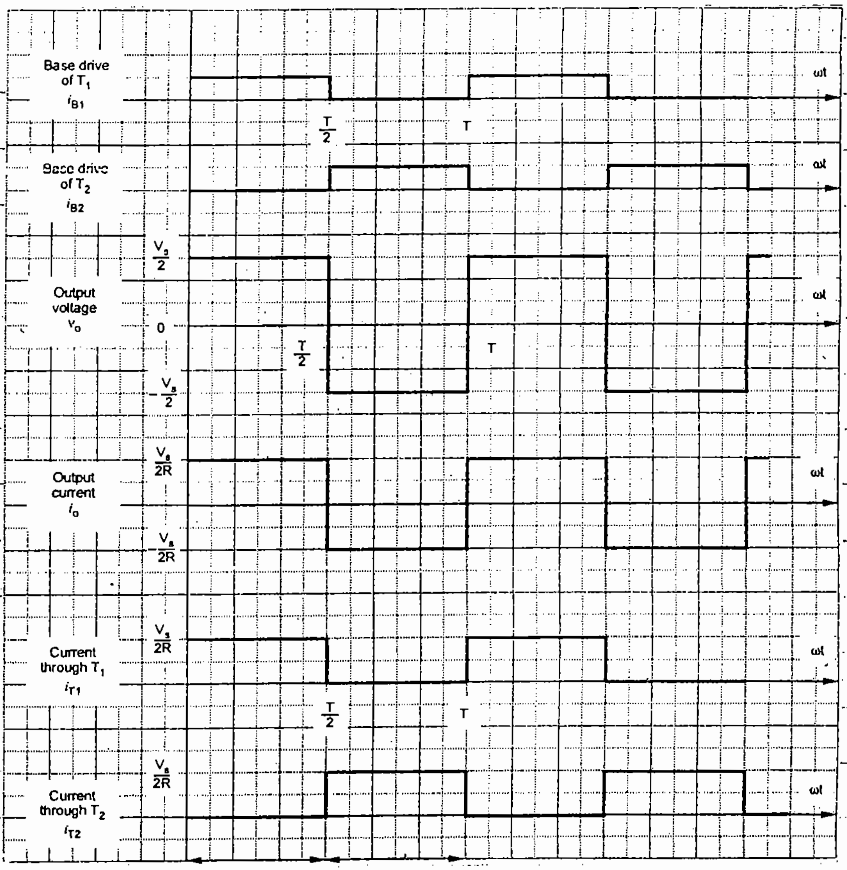


fig (b)

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Q) Draw the circuit diagram of full bride inverter and its operation with wave forms

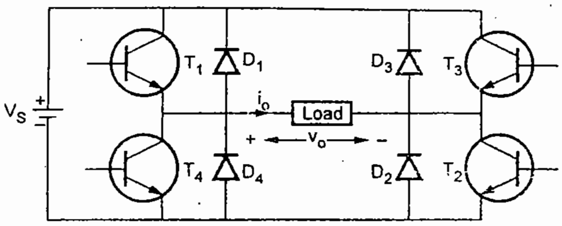
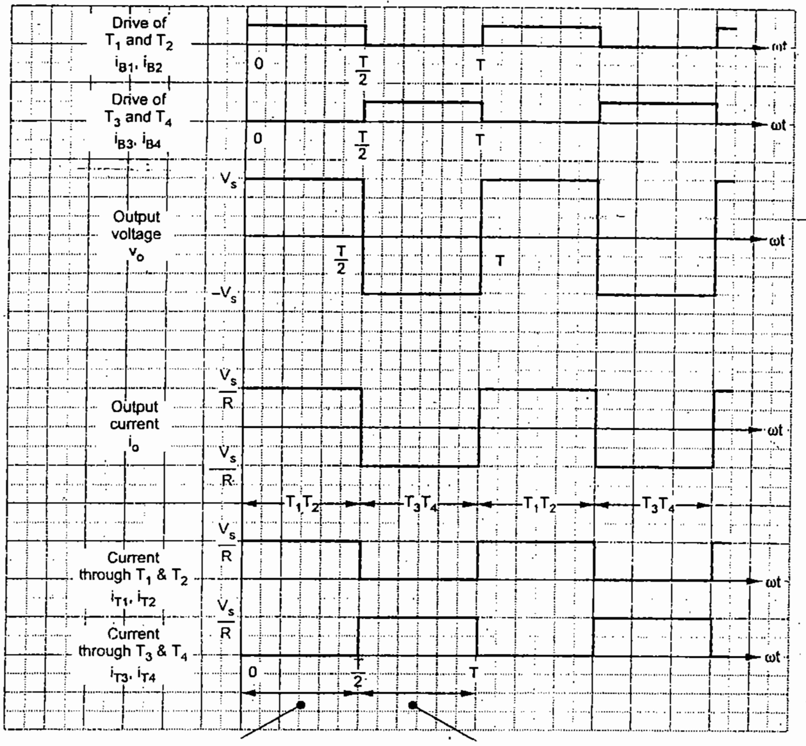


Fig. 4.19.1 Single phase bridge inverter

Ans → We studied half bridge inverter earlier. fig shows The circuit diagram of Full bridge inverter. Observe That there are four transistors and four diodes. the diodes are required for feedback when the load is inductive.

When the load is resistive the diodes does not carry any current. The transistor T_1 & T_2 conduct from 0 to $\frac{T}{2}$. equivalent circuit -I in fig shows the current path when T_1 & T_2 conduct. the output voltage & current are positive. Note that the amplitude of load voltage is V_s



Q- Draw the circuit of mid-point step-up ~~cyl~~ cycloconverter and explain its operation with Waveforms.

Circuit diagram.

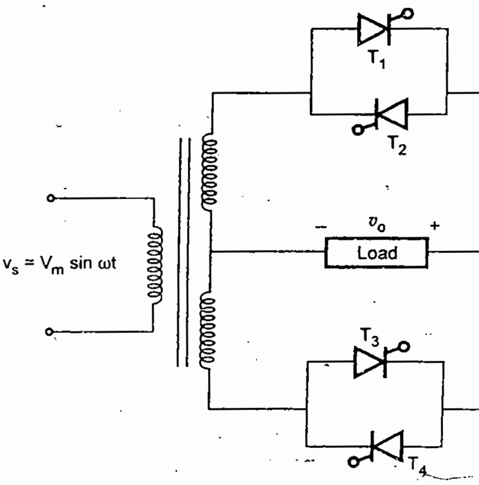


Fig. 4.24.1 Midpoint type cycloconverter

* When the frequency of the output is higher than the frequency of input, then it is called step-up cycloconverter.
* Fig. shows the midpoint type step-up cycloconverter.
* In the positive half cycle, T_1 conducts from 0 to t_1, hence, output voltage is positive.
* At t_1, T_1 is forced commutated and T_4 is triggered. Hence load voltage becomes negative as shown in fig.
* Then ~~the~~ at t_2, T_4 is forced commutated and T_1 is turned-on again.
* Therefore output voltage is again positive. At t_3, T_4 is turned-on and T_1 is forced commutated. Hence output vltg is negative.
* At π, T_3 is turned on. Therefore output voltage is positive. * At t_4, T_3 is forced commutated and T_2 is triggered. Hence the load voltage is negative.

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* This sequence continues. Observe that output voltage waveform has the frequency of,

$$f_0 = \frac{1}{t_2 - t_1}$$

This frequency is higher than supply frequency.

Waveforms:

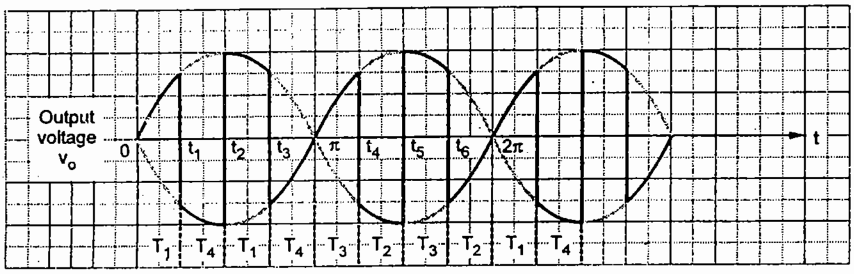

Fig. 4.24.2 Waveforms of step-up cycloconverter

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Q- Draw the circuit diagram of three phase bridge converter and explain 180 conduction mode with waveforms.

Ans:- Phasor diagram

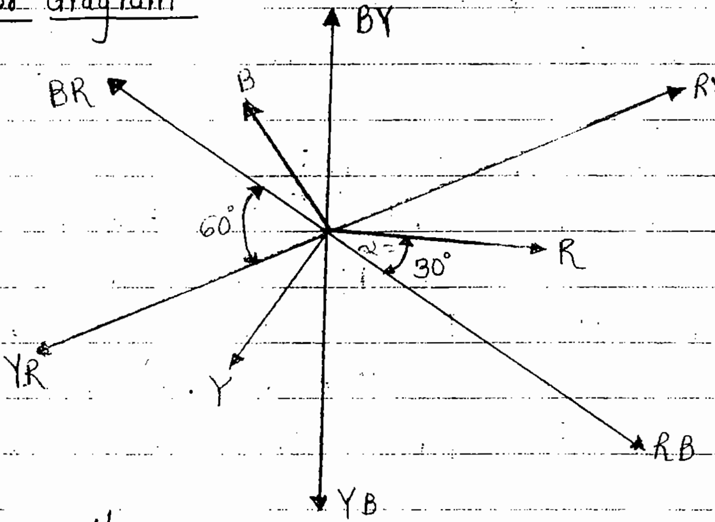
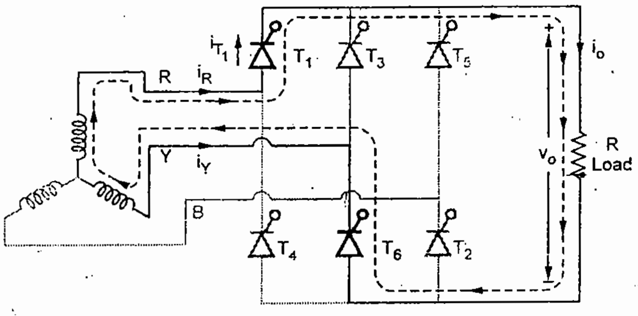


fig. shows the waveforms of 3ϕ full converter having resistive load. fig shows the supply phase voltages R, Y and B. fig shows the supply line voltages. These supply voltage waveforms are drawn according to the phasor diagram shown in Fig. above. shows the gate drives for α = 30°. For six SCRs, there are six gate drives.



Observe that output current i_o and R-phase current i_R flows in the same direction.

Hence, $i_R = i_o$.

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Similarly observe that Y-phase current i_Y and o/p current i_0 are in opposite directions. Hence,

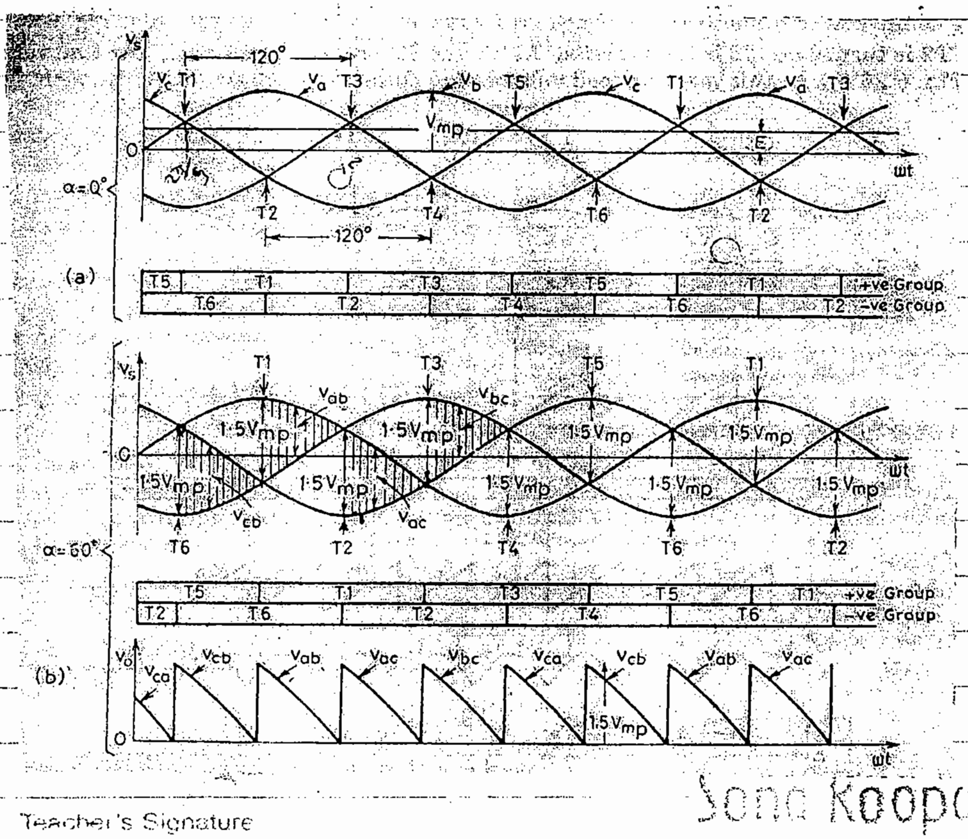
$$i_Y = -i_0.$$

The SCR pair $T_6 - T_1$ conduct from $\left[\frac{\pi}{6}+\alpha\right]$ to $\left[\frac{\pi}{2}+\alpha\right]$

Line voltage V_{RY} is applied.

During this period At $\left[\frac{\pi}{2}+\alpha\right]$ SCR T_2 is triggered. Here ~~do~~ note that T_6 turns-off, since T_2 is triggered. Hence $T_1 - T_2$ starts conducting and it is marked as interval-II. In this interval supply line voltage V_{RB} is applied across the load. At $\left[\frac{5\pi}{6}+\alpha\right]$ T_3 is triggered. Hence T_1 turns-off and $T_2 - T_3$ starts conducting. Therefore line voltage V_{YB} is applied across the load. It is marked as interval-III.

Waveforms :



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Q] List the differences between VSI and CSI

Ans:	Voltage Source inverters	Current Sources inverter
1]	Input is constant voltage Source.	1] Input is constant current Source.
2]	Current waveforms depends on load	2] Voltage waveforms depends on load
3]	Free wheeling diodes are required in case of inductive load.	3] Free wheeling diodes are not required.
4]	Large capacitor is connected across DC I/P Side of inverter.	4] Large inductor is connected in Series with DC I/P voltage.
5]	Parallel and Series are voltage Source inverters	5] Bridge type is current Source inverters
6]	A Series resonence or tank circuit is reqd.	6] No resonent circuit is required.

Q] Draw the circuit diagram of mid-point step down cycloconverter and explain its operation with waveforms.

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